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MANUAL OF PROTECTIVE ACTION GUIDES

AND

PROTECTIVE ACTIONS

FOR NUCLEAR INCIDENTS

Office of Radiation Programs
United States Environmental Protection Agency
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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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Washington, D.C.

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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	*Early*, *Intermediate*, *Late*	Evacuation Relocation Decontamination of land and property
6. Ingestion of contaminated food and water	*Early*, *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	1.5	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 (⅕ 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).

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Arthur Hull Hayes, Jr.,

Commissioner of Food and Drugs.

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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:

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

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

[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

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

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[e]	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 µCi · cm^{-3} · h	DRL[b,c] µCi · cm^{-3} · 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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CHAPTER 6

Implementing the PAGs for the Intermediate Phase (Food and Water)

See Chapter 3 and Appendix D for Current Implementation Recommendations for Food. Also refer to the following documents:

Federal Emergency Management Agency
Guidance Memorandum IN-1, The Ingestion Exposure Pathway. February 26, 1988 Federal Emergency Management Agency. Washington, DC 20472

Guidance on Offsite Emergency Radiation Measurement Systems Phase 2, The Milk Pathway, FEMA REP-12, September 1987.

Guidance on Offsite Emergency Radiation Measurement Systems. Phase 3, Water and Non-Dairy Food Pathway, September 1989.

HHS Publication FDA 82-8196

Background for Protective Action Recommendations: Accidental Radioactive Contamination of Food and Animal Feeds

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WHO Collaborating Centers for:
- Standardization of Protection Against Nonionizing Radiations
- Training and General Tasks in Radiation Medicine
- Nuclear Medicine

August 1982

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Food and Drug Administration
Bureau of Radiological Health
Rockville, Maryland 20857

FOREWORD

The Bureau of Radiological Health develops and carries out a national program to control unnecessary human exposure to potentially hazardous ionizing and nonionizing radiations and to ensure the safe, efficacious use of such radiations. The Bureau publishes the results of its work in scientific journals and in its own technical reports.

These reports provide a mechanism for disseminating results of Bureau and contractor projects. They are distributed to Federal, State, and local governments; industry; hospitals; the medical profession; educators; researchers; libraries; professional and trade organizations; the press; and others. The reports are sold by the Government Printing Office and/or the National Technical Information Service.

The Bureau also makes its technical reports available to the World Health Organization. Under a memorandum of agreement between WHO and the Department of Health and Human Services, three WHO Collaborating Centers have been established within the Bureau of Radiological Health, FDA:

WHO Collaborating Center for Standardization of Protection Against Nonionizing Radiations;

WHO Collaborating Center for Training and General Tasks in Radiation Medicine; and

WHO Collaborating Center for Nuclear Medicine.

Please report errors or omissions to the Bureau. Your comments and requests for further information are also encouraged.

John C. Villforth
Director
Bureau of Radiological Health

PREFACE

By FEDERAL REGISTER action of March 11, 1982 (47 FR 10758), the Federal Emergency Management Agency (FEMA) outlined the responsibilities of several Federal agencies concerning emergency response planning guidance that the agencies should provide to State and local authorities. This updated a prior notice published in the FEDERAL REGISTER by the General Services Administration (GSA) on December 24, 1975 (40 FR 59494), on the same subject. GSA responsibility for emergency management was transferred by Executive Order to FEMA. The Department of Health and Human Services (HHS) is responsible for assisting State and local authorities in developing plans for preventing adverse effects from exposure to radiation in the event that radioactivity is released into the environment. This includes developing and specifying protective actions and associated guidance to State and local governments for human food and animal feeds.

Proposed recommendations were published in the FEDERAL REGISTER on December 15, 1978 (43 FR 58790) and a background document accompanied their publication. Twenty-one comment letters were received in response to the proposal in addition to comments from various Federal agencies. Review of these comments led to changes in the recommendations and supporting rationale, dosimetric and agricultural models, and cost/benefit analysis. These changes have been incorporated into this background document, which is intended to accompany and support FDA's final recommendations on Accidental Radioactive Contamination of Human Foods and Animal Feeds: Recommendations for State and Local Agencies. The final recommendations will appear in the FEDERAL REGISTER.

This background report discusses the rationale for the Protective Action Guides; the dosimetric and agricultural models used in their calculation; some methods of analysis for radionuclide determination; appropriate protective actions; and cost considerations.

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Scientific Affairs
Bureau of Radiological Health

ABSTRACT

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This report provides background material for the development of FDA's Protective Action Recommendations: Accidental Radioactive Contamination of Food and Animal Feeds. The rationale, dosimetric and agricultural transport models for the Protective Action Guides are presented, along with information on dietary intake. In addition, the document contains a discussion of field methods of analysis of radionuclides deposited on the ground or contained in milk and herbage. Various protective actions are described and evaluated, and a cost-effectiveness analysis for the recommendations performed.

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CHAPTER 1. RATIONALE FOR DETERMINATION OF THE PROTECTIVE ACTION GUIDES

1.1 INTRODUCTION

The process of determining numerical limits for radiation standards is one of risk assessment. This process, in which risk considerations are an important factor in decision-making, consists of two elements: determination of the probability that an event will occur, and determination of "acceptable risk." A recent discussion of acceptable risk defines risk as a measure of the probability and severity of adverse effects. Safety is the degree to which risks are judged acceptable (1).

Since initiation of protective action assumes that an accident has occurred, no attention will be given to the estimation of probabilities for accident occurrence in the present analysis.

One process of determining "acceptable risk" is to compare estimates of risk associated with an action with already prevalent or "natural" risks that are accepted by society. This method of evaluation is employed in the present discussion by comparing the risk from natural disasters and from the variation in "natural radiation background" to the radiation risk associated with the numerical limits for the Protective Action Guides (PAG).

"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 prior to the assessment. "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. The projected dose commitment is expressed in the unit of dose equivalent or the rem.

The "natural radiation background" consists of contributions from external radiation and internal deposited radioactivity from ingestion and inhalation. For the most part, the variation in the internal natural radiation dose is due to the variability of whole-body potassium-40. Since these PAG's are limited to ingestion, a parameter that describes the variability of the internal natural radiation dose might appear more appropriate than using the variability of the external or total natural radiation dose in evaluating the acceptability of a given level of risk. However, the potassium level in the body (and hence internal dose) is controlled by metabolic processes and dietary intake has little effect. Hence the risk of natural disasters, which is dependent on geographical location of residence, is in this agency's opinion a better measure of acceptable risk.

1.2 MODELS FOR EVALUATION OF RISK

Models for the somatic and genetic effects of radiation are required for comparisons of radiation risks from the PAG's relative to other naturally occurring risks.

1.2.1 Somatic Risk Evaluation

A review of the current literature indicates that the risk estimates developed in the National Academy of Science Committee on the Biological Effects of Ionizing Radiation or the BEIR-I report (2) and the BEIR-III report (3) are appropriate for use in analysis of

somatic risk. Mortality rather than incidence estimates are employed in the comparisons. In the case of comparisons to natural background radiation, use of mortality data or incidence estimates would yield the same numerical PAG limits, because these limits are based on a comparison between risks rather than an evaluation of absolute risk.

The radiation doses in the event of a contaminating accident will most likely result from ingestion of the fission products cesium-134 and -137; strontium-89 and -90; and iodine-131. For the purpose of this analysis it is assumed that all projected extra cancers can be attributed to internal radiation via the food pathway (i.e., the risks from ingested radioactive material is the same as that from external radiation).

The BEIR-III (3) best estimate of lifetime cancer risk (linear quadratic model) for a single exposure to low-dose, low LET radiation is from 0.77 to 2.26 x 10^{-4} deaths per person-rem, depending on whether the absolute or relative-risk projection model is used (calculated from Table 1). The equivalent risk estimate from BEIR-I (2) is 1.17 to 6.21 x 10^{-4} deaths per person-rem.

Table 1. Risk estimates for single dose

Dose response model	Deaths per million persons per 10 rads single dose whole-body BEIR-III	
	Absolute risk	Relative risk
Linear quadratic	766	2255
Linear	1671	5014
Quadratic	95	276

These risk estimates are for a single dose of 10 rem, because limitations of the scientific information do not justify estimates at lower doses according to the BEIR Committee. Because of the uncertainty of risk estimates at low doses, BEIR-III provided risk estimates based on a linear model and a pure quadratic dose response model as well as estimates based on the preferred linear quadratic model. The risk estimates for the linear model are about a factor of 2 higher and those of the quadratic model and about a factor of 8 lower than those of the linear quadratic model. It should further be noted, that BEIR-III does not recommend that their risk estimates be extrapolated to lower doses because of the inadequacies of the scientific basis. BEIR-III does recognize however that Federal agencies have a need to estimate impacts at lower doses. While BEIR-III prefers the linear-quadratic dose response model as the best estimate, regulatory agencies have continued to favor the linear model as the basis for making risk estimates. While the BEIR-III estimates will be used here to estimate the impact (health effects) at lower doses, it is fully recognized that current scientific opinion leaves alternatives as to which dose response and risk model to use.

As previously stated, for the purpose of setting PAG's, comparison of radiation risks to those from natural disasters is considered the approach of choice in this document.

1.2.2 Genetic Risk Evaluation

The model for genetic risks from radiation exposure is described in the BEIR-III report (3). In the first generation, it is estimated that 1 rem of parental exposure throughout the general population will result in an increase of 5 to 75 additional serious genetic disorders per million liveborn offspring. The precision for estimating genetic risks is less precise than those for somatic risks. Given the broad range, genetic risks are evaluated, but are not precise enough to be a basis for setting the PAG's.

1.3 ASSESSMENT OF COMMON SOCIETAL AND NATURAL BACKGROUND RADIATION RISKS

1.3.1 Common Societal Risks

As previously stated, one method of determining the acceptability of a risk is by comparing prevalent or normal risks from hazards common to society. A list of the annual risks from common societal hazards is given in Table 2. Comparision of radiation risks to commonly accepted societal risks assumes that the age dependencies are similar and that all individuals are equally exposed to the hazard. This latter assumption is, of course, not entirely valid in that persons nearer a nuclear power plant or a dam, or in an earthquake or tornado area might be expected to be at greater risk than persons living at a distance from the particular hazard.

Table 2. Annual risk of death from hazards common to society

Category	Reference	Risk of death (per person per year)
All disease	(4)	8×10^{-3}
Leukemia and all other cancer	(5)	1.5×10^{-3}
Motor vehicle accidents	(6)	3×10^{-4}
Accidental poisoning	(6)	1×10^{-5}
Air travel	(7)	9×10^{-6}
Tornadoes (Midwest)	(8)	2×10^{-6}
Earthquakes (Calif.)	(8)	2×10^{-6}
Floods (46 million at risk)	(9)	2.2×10^{-6}
Catastrophic accidents (tornadoes, floods, hurricanes, etc.)	(10)	1.2×10^{-6}
Natural disasters	(11)	9×10^{-7}
	(6)	8×1^{-7}
Tornadoes	(7)	0.4×10^{-6}
	(9)	0.6×10^{-6}
Hurricanes	(7)	0.4×10^{-6}
	(9)	0.3×10^{-6}
Floods	(8)	2×10^{-6}
	(9)	0.5×10^{-6}
Lightning	(7)	0.5×10^{-6}
Winter storms	(9)	0.4×10^{-6}
Natural disasters (sum of above)		2.1 to 3.9×10^{-6}

Table 2 indicates that the annual individual risk from natural disasters is approximately 1 to 4×10^{-6}. This risk represents a common risk level, which is generally not considered in selecting place of residence. At this level of risk, some action to prevent further loss of life could be expected by society following the occurrence of a natural disaster. It thus appears prudent to evaluate the somatic risks from radiation in relation to the risk of death from a natural disaster. For comparison purposes, a value of 1 in a million (1×10^{-6}) annual risk of death, which is often quoted as an acceptable risk, will be used as the risk of natural disasters. Actual data indicate that the risk of natural disasters may be a 2 or 3 times greater risk than this value. For a risk of death of 1×10^{-6} per year, the lifetime accepted societal risk would be about 70×10^{-6}. This is equivalent to a single radiation dose of 140 to 420 mrem, using the linear model, or 310 to 910 mrem using the BEIR-III linear quadratic model (see Table 1). The upper and lower ranges are those obtained from employment of relative and absolute risk models and the dose response extrapolations mentioned above (from calculations based on data in Table 1). Genetic effects are not considered in evaluating common societal hazards because of the difficulty in assessing

deaths occurring from genetic consequences, either natural or radiation induced. If spontaneous abortions are deleted from this category, then fatal genetic effects are a small portion of the overall genetic impact on health. However, it is difficult to accurately evaluate genetic effects, and even more difficult to compare its impact to the impact of somatic effects in an effective manner.

1.3.2 Risks From Natural Radiation

Further perspective on acceptable risk can be obtained by examining the risks of natural background radiation. In risk assessments where a radiation risk is compared to that from the natural radiation background, the question is which variable associated with natural background should be used to determine "acceptable risk?" Since background radiation has always been a part of the natural environment, a plausible argument might be to assume that the risks associated with the average natural radiation dose represent an "acceptable risk."

It has also been argued that because of the ever present risk from natural radiation, a level of manmade radiation ought to be acceptable if it is "small" compared to natural background (12). It has been suggested that "small" be taken as the standard deviation of the population-weighted natural background (13). In previous evaluations that led to the FDA's proposed PAG recommendations (14) the geographic variable (two standard deviations) in the natural radiation dose was used as a point of comparison for judging acceptable radiation risk (15). This value, calculated on a State-by-State basis assuming a log-normal distribution and not weighted for population, is 8.5 mrem per year. The cumulative lifetime dose equivalent would thus be about 500 mrem, which was the basis for the proposed PAG recommendation for the whole body at the Preventive PAG level. The Environmental Protection Agency (EPA), in a further analysis of previously published data (16), has calculated the cumulative distribution of dose equivalent in the U.S. population. These data show that 95 percent of the population receives between 28 and 84 mrem/year from cosmic and terrestrial background radiation (17). The actual distribution is asymmetric and not log-normal. Thus, one-half of this 95-percent increment range, or 28 mrem/year, will be taken as the value for judging acceptable risk. Adler (13) notes that one standard deviation of the natural external and internal radiation background derived from earlier sources (18) is 20 mrem. Personal conversations with Adler revealed that this estimate is based on air exposures rather than dose equivalent (mean whole body) and involved a broad rounding off of values. At the 95-percent increment value (latest EPA data) of 28 mrem/year (19), the additional lifetime dose over 70 years is about 2000 mrem. About 6 million persons (2-1/2 percent of the population) receive lifetime doses that exceed the mean background radiation dose by this amount or more.

Another possibility, especially applicable to setting limits for internal emitters, is using the variation in internal natural radiation dose as a reference for establishing an acceptable standard for PAG's. For PAG limits for radionuclides via the ingestion pathway, doses to organs other than the lungs are most pertinent. Using this suggestion still requires a judgmental decision as to whether the variation in internal natural radiation dose is "small." A summary of internal natural radiation doses is given in Table 3. It is apparent that natural radiation doses to human tissues and organs is determined mainly by potassium-40 concentration. The average annual internal whole-body radiation dose per person from ingested natural radioactivity is 19.6 mrem, of which 17 mrem is due to potassium-40.

In potassium-40 whole-body measurements of 10,000 persons, a standard deviation of about 12 percent (95-percent confidence level of 23.52 percent) was observed (20). The study further concluded that the standard deviation is also the same for different groups of age and sex, and therefore, it may be concluded that the same biological variation exists for all the different age-sex groups. In another study based on the chemical determinations of total body potassium the average amount in a 70-kg man was estimated to be 136 g with a standard deviation of ± 28 g or ± 20 percent (95-percent confidence increment of ± 40 percent) (21).

Table 3. Annual internal radiation dose per person for non-inhaled natural radioactivity[a]

Annual dose (mrads/year) whole-body average (unless otherwise noted)	
H-3	0.001
Be-7	0.008
C-14	1.3
Na-22	0.02
K-40	17
Rb-87	0.4
U-238-U-234 series	0.043[b]
Ra-222	0.064[b]
Po-210	0.7
Ra-226	0.031[b]
Th-230	0.04[b]
Th-232	0.04[b]
Total	19.65

[a]UNSCEAR (1977).
[b]Based on soft tissue dose (lung, testes, and ovaries)

An indirect means of determining the variability of whole-body potassium values is based on the constant ratio of mean potassium values to total body water up to age 50 (20). The 95-percent confidence increment for the variability of total body water in males, ages 16 to 90 is 16 percent, while for females it is 13 percent for ages 16 to 30 and 21 percent for ages 31 to 90 (22).

From the above data, it appears that the increment for the 95-percent confidence level for whole-body potassium, and hence potassium-40, is between ± 15 percent and ± 40 percent. Note that this variability may be due to differences in body water or body weight. Only in the case of one study (21) is it clear the total body weight is considered a constant. It is apparent that a range of values between approximately 3 to 7 mrad per year may be used to describe the variability in natural potassium-40 dose to the population on a whole-body dosimetric basis. The mid-point of this range is 5 mrad per year or a lifetime dose commitment (70 years) of 350 mrem.

Thus, the lifetime radiation dose associated with the variability in natural radiation is about 350 mrem (internal) and 2000 mrem (external).

1.4 PREVENTIVE AND EMERGENCY PAG'S

PAG's have been proposed for two levels of response:

1. Preventive PAG - applicable to situations where protective actions causing minimal impact on the food supply are appropriate. A preventive PAG establishes a level at which responsible officials should take protective action to prevent or reduce the concentration of radioactivity in food or animal feed.

2. Emergency PAG - applicable to incidents where protective actions of great impact on the food supply are justified because of the projected health hazards. An Emergency PAG establishes a level at which responsible officials should isolate food containing radioactivity to prevent its introduction into commerce, and at which the responsible officials must determine whether condemnation or another disposition is appropriate.

1.4.1 Preventive PAG

During recent years numerous reports on risks and risk/benefit assessments for the evaluation of technological insults have been published. A number of these have concluded that an annual risk of death of 1 in a million is acceptable to the public (8). The total average annual risk to the U.S. population from natural disasters appears to be about 2 or 3 times greater than the 1 in a million annual risk. Those individuals living in certain flood plains, tornado, or earthquake areas accept risks that may be greater than the average by a factor of 2 or more (See data for tornadoes and earthquakes in Table 2).

As previously mentioned, based on BEIR-III (3) upper risk estimates, a 1 in a million annual risk of death corresponds to a single radiation dose of 140 to 910 mrem.

It is our conclusion that an annual risk of 1 in a million provides a proper perspective for setting food protective actions guides (PAG's) for radiation contamination accidents of low probability. It appears that most individuals in the United States will never be exposed to such a radiation contamination accident and that any one individual is not likely to be potentially exposed more than once in his lifetime.

Based on the above considerations, the uncertainty in radiation risk estimates and the uncertainty in the average natural disaster risks, a value of 0.5 rem whole body is selected for the Preventive PAG. Thus, at projected doses of 0.5 rem from contaminated food, it is recommended that protective actions having low impacts be taken for protection of the public. The specific value of 0.5 rem represents a judgment decision rather than a specifically derived value from specific models and assumptions.

Further perspective on acceptable risks for setting the PAG's is the risks associated with natural background radiation. The discussion above indicates that lifetime dose associated with the 95-percent increment of the variability in natural radiation is about 350 mrem internal and 2000 mrem external (that is, 2-1/2 percent of the population receives doses greater than the average by this amount or more).

This Preventive PAG is applicable to whole-body radiation exposure and to major portions of the body including active marrow (ingestion of strontium) in conformity with current U.S. radiation protection practice. Coincidently, 0.5 rem is the Federal Radiation Council's (FRC) annual limit for individuals of the general population (23).

Present convention, recommended by the Federal Radiation Council (23) based on prior estimates of relative radiation risks for various organs indicates that radiation limits for the thyroid gland be set at 3 times those for the whole body. More recent scientific information indicates that the risks from organ doses relative to whole body differ from those assumed when the current U.S. regulations and FRC guidance were established. The International Commission on Radiological Protection (ICRP) in revising its recommendations on internal exposure derived weighting factors that represent the ratio of risk from irradiation to a given tissue (organ) to the total cancer risk due to uniform irradiation to the whole body. The ICRP weighting factors are 0.12 for red bone marrow and 0.03 for thyroid, indicating that the cancer risk is 8 times less for red bone marrow and 33 times less for thyroid than for whole body exposure (24). Further considerations of effects other than cancer resulted in the limitation of organ doses to 50 rems per year for occupational workers. Thus the ICRP recommendations in effect provide for or allow single organ doses that are 8 times greater for red bone marrow and 10 times greater for thyroid than for whole body. The EPA has recently proposed Federal guidance for occupational radiation protection that incorporates the basic ICRP recommendations (46 FR 7836, Jan. 23, 1980). Setting the Preventive PAG at 0.5 rem for whole body and red bone marrow and 1.5 rem for thyroid provides significantly more protection from the actual risks of organ doses than from whole-body risks. To the extent that the whole-body risk is considered acceptable, the red bone marrow and thyroid limits are conservative by factors of 8 and 3.3, respectively.

1.4.2 Emergency PAG

The philosophy of the protective action guidance of FDA is that low impact protective actions should be initiated when contamination of food exceeds the Preventive PAG. The intent is that such protective actions be implemented to prevent the appearance of radioactivity in food at levels that would require the condemnation of food. If such actions are ineffective, or high levels appear in food, then the Emergency PAG is that level at which higher impact (cost) protective actions are warranted. At the Emergency PAG radiation level, action should be taken to isolate and prevent the introduction of such food into commerce and to determine whether condemnation or other disposition is appropriate.

With regard to the numerical relationship between the Preventive PAG level and the Emergency PAG level, prior conventions may be considered. For example, the Federal Radiation Council (23) assumed that the dose to the most highly exposed individual does not vary from the average dose to the whole population by a factor greater than three; Hence, a factor of 3 was used to define the difference between maximum and average population limits. Traditionally, it has been more common to use a factor of 10 as a safety factor, such as between occupational and general public limits. A factor of 10 difference between the Emergency and Preventive PAG levels, based on these traditional radiation protection approaches has in the past been thought to introduce a sufficient level of conservatism. The proposed PAG's (14) adopted this rationale in setting the Emergency PAG's. The analyses of costs, to follow, also indicate that a factor of 10 between the Preventive PAG and Emergency PAG is appropriate. As calculated in the last chapter of this report the cost of condemnation of milk (high impact protective action) is about a factor of 10 greater than the cost of using uncontaminated stored feed (low impact protective action). Since contamination of the milk pathway is considered to be the most probable and significant food problem, this is the only pathway that is cost analyzed.

The use of a factor of 10 adopted here results in an Emergency PAG of 5 rem for the whole body which numerically is equivalent to the current occupational annual limit. This limit permitted each year over a working lifetime is associated with the expectation of minimal increased radiation risks.

1.5 EVALUATION OF PAG RISKS

The risks associated with a radiation dose equal to the PAG's can be readily calculated from the BEIR-III risk estimates in Table 1. For the Preventive PAG of 0.5 rem, the deaths per million persons exposed are one-twentieth of those given for the 10-rad single dose (or about 38 to 250 deaths for the linear quadratic and linear models respectively). On an individual basis, this is a risk of death of 0.38 to 2.50 x 10^{-4} (0.0038 to 0.025 percent) over a lifetime. BEIR-III gives the expectation of cancer deaths in the U.S. population as 167,000 per million or an individual expectation of cancer death of 16.7 percent.

As noted above, the BEIR-III estimate of serious first generation genetic disorders is 5 to 75 per million live offspring per rem of parental exposure. Thus, for a dose of 0.5 rem, the expectation is 2.5 to 38 disorders per million live offspring. BEIR-III notes the current estimate of the incidence of serious human disorders of genetic origin as roughly 10 percent of liveborn offspring.

CHAPTER 2. DOSIMETRIC MODELS, AGRICULTURAL TRANSPORT MODELS, DIETARY INTAKE, AND CALCULATIONS

2.1 DOSIMETRIC MODELS

2.1.1 Introduction

The dosimetric models and metabolic parameters for estimating the dose from internally deposited radionuclides are in a state of flux. The recent reports and current activity represent the first major revision since the adoption of ICRP Publication 2 (25) and NCRP Report 22 (26) in 1959. ICRP Publication 30 (27) superseded ICRP Publication 2 and revised the basic approach in setting limits for intake of radionuclides by workers. The ICRP recommendations are intended to avoid nonstochastic effects and to limit the occurrence of stochastic effects to an acceptable level. This approach includes the use of weighting factors to sum the risk from organ doses in setting the limits for intakes. This system contrasts with the earlier approach where limits were based on the dose to the "critical organ."

The ICRP Publication 30 approach has considerable merit, but is not yet widely accepted in the United States. Its use in calculating the derived response levels would represent a major change. Accordingly, the approach is to use the organ to whole-body dose relationship of current U.S. regulations and to select critical organ dose conversion factors that are based on current dosimetric models and metabolic parameters. Where apropriate, the recent ICRP and NCRP organ dose models will be accepted as representing current scientific opinion. It should be noted that future reports and revisions by NCRP, MIRD (Medical Internal Radiation Dose Committee of The Society of Nuclear Medicine) and other Federal agencies may necessitate a revision of the dose conversion values selected here.

The PAG's are applicable to the most critical or sensitive segment of the population. In most cases this means that the infant or child is the critical segment. In the case of the Emergency PAG, derived response levels are also presented for the adults. This permits greater flexibility in the choice of protective actions in cases where infants are not present or can be excluded from use of the specific food item being considered.

2.1.2 Iodine-131: Dose To Thyroid

Fetal uptake of iodine begins at about the 9th week of gestation and reaches a maximum in the newborn infant (28,29) before returning to adult levels. Kereiakes et al. (30) report that thyroid uptake during the first 2 weeks of life is very high and report a value of 70 percent of that administered for the newborn. The radioiodine uptake expressed per unit thyroid weight remains high for the newborn and infant and only gradually decreases throughout childhood and adolescence to adult levels. The newborn infant will be taken as the most critical segment of the population because factors concerning intake, uptake, and radiosensitivity indicate that the thyroid gland of an infant receives a higher radiation dose per unit I-131 ingested than any other age group (30). However, it is interesting to note that data indicate that only about 3 percent of infants are given whole cow's milk at 1 month of age and about 1 percent at 10 days (31). Hence, assuming that all infants are given whole milk provides a conservative estimate of infant thyroid doses.

Data on the dose to the fetal thyroid from I-131 ingested by the mother is rather limited. The study of Dyer and Brill (29) reports an increase in the fetal thyroid dose from 0.7 to 5.9 rads per μCi administered to the mother for fetal ages of 13 to 22 weeks. It thus

appears that the fetal thyroid dose is less than that of the newborn infant ingesting I-131 contaminated milk.

The current literature on normal thyroid uptake in U.S. adults shows 24-hour uptake has decreased from about 30 percent reported in the 1960's to about 20 percent or less in current comparable studies. Kereiakes et al. (32) use a 20-percent uptake for all ages. This reduced uptake apparently results from changes in the U.S. diet, whereas ICRP 30 (27) has continued to use an uptake of 30 percent to reflect world averages.

The Medical Internal Radiation Dose (MIRD) Committee schema (33) has been used by Wellman and Anger (34) to calculate dose factors per μCi ingested for the newborn for the 1-, 5-, 10-, and 15-year-old child, and for the adult. These factors were then modified by Kereiakes et al. (32) to reflect a 20-percent uptake for all ages. A biological half-life of 68 days is used for all ages, which results in an effective half-life of 7.2 days. Although there is some evidence that the biological half-life for the infant is less, the radiation dose is largely controlled by the radiological half-life and use of a single value appears appropriate here. Because of some uncertainty regarding the fetal thyroid dose and lack of acceptance by national and international groups, the older data (27-percent uptake) of Wellman and Anger (34) will be used. This provides some additional conservatism in the derived response levels for I-131. The cumulative activity is 2.08 μCi-days per μCi ingested (administered).

Table 4. Summary of I-131 dose conversion factors

Age	Thyroid weight (g)	Dose rad/ μCi
Newborn	1.5	16.0
1 yr.	2.2	10.9
5 yrs.	4.7	5.1
10 yrs.	8.0	3.0
15 yrs.	11.2	2.1
Adult	16.0	1.5.

For the infant and adult, the dose conversion factors to be used are 16.0 and 1.5 rad/ μCi ingested.

2.1.3 Cesium-137 and -134: Dose To Whole Body

The NCRP (35) has reviewed the behavior of Cs-137 in the environment and its metabolism and dose to man. From studies of Cs-137 in food chains, the biological half-life is found to vary from 15 ±5 days in infants to 100 ±5 days in adults. The biological half-life in pregnant women is reported to be 1/2 to 2/3 that in nonpregnant women and consequently the dose to the fetus is also reduced.

Retention of Cs-137 in the adult is stated to be well represented by a 2-exponential equation with biological half-times of 1.4 days and 135 days applicable to retention in body fluid and soft tissues, respectively. Integration of this equation yields an accumulated activity of 170 μCi-days per μCi of intake. This accumulated activity may be expressed in terms of a single retention function yielding a value of 118 days.

The dosimetry of internally deposited Cs-137 in infants and adults is treated separately for the beta particle and photon components. The difference between infants and adults is a smaller photon contribution to the infant because of the smaller body size. For a uniform concentration of 1 μCi/kg of body weight, the total beta and photon dose rate is 19 mrad/day to the infant and 25 mrad/day to the adult. Use of the above accumulated activity factor of 170 μCi-days per μCi intake yields a dose of 0.061 rad/ μCi intake for the adult. Assuming an effective retention time of 20 days for the infant, the corresponding factor for the infant is 0.071 rad/ μCi intake. The use of a smaller effective retention

time (15 days as noted in NCRP (26)) or 10 days as used in NUREG-0172 (36) would reduce the infant dose conversion factor. The use of 20 days thus tends to overestimate the infant dose.

It is also important to consider the dose from Cs-134 which, depending on operating history, occurs in nuclear reactor fuel at levels equal to or greater than that of Cs-137. Unfortunately, published dosimetry data for Cs-134 for the infant are rather limited. Conversion factors for the adult that use current models and metabolic data are found in ORNL/NUREG/TM-190 (37). Johnson et al. (38) have used this same data base to compute committed effective dose equivalent conversion factors for both infants and adults. The mean absorbed dose per cumulated activity factor for the infant were modified by the ratio of adult and infant organ mass (with a further correction to photon component based on absorbed fraction) to produce the infant factors. It was stated that this procedure may underestimate the infant dose.

The approach adopted here will be to modify the adult dose conversion factor in ORNL/NUREG/TM-190 (37) based only on relative body weight and cumulated activity (effective retention half-times). The dose conversion factor for cesium-134 from ORNL/NUREG/TM-190 adult whole body is 0.068 rem/μCi ingested and the estimated factor for the infant is then 0.118 rem/μCi ingested. This value should overestimate the infant dose and is conservative.

Summary of Cs-134 and Cs-137 Dose Conversion Factors

Table 5. Summary of dose factors for Cs-134 and Cs-137

	Infant	Adult
Body Mass	7,700g	70,000g
Uptake to whole body[a]	1.0	1.0
T biological (days)	20	118
T effective Cs-134 (days)	19.5	102
Cs-137 (days)	20	118
Dose conversion (rem/μCi ingestion)		
Cs-134	0.118	0.068
Cs-137	0.071	0.061

[a]For cesium-134, ORNL/NUREG/TM-190 uses uptake of 0.95.

2.1.4 Strontium: Dose To Bone Marrow

The tissues at greatest risk in the skeleton have been identified as the active red marrow in trabecular bone and endosteal cells near bone surfaces (generally referred to as bone surface). Spiers and his coworkers (39,40) have developed methods to calculate the absorbed doses, D_m and D_s, received by red marrow and bone surfaces, respectively from beta-emitting radionuclides uniformly distributed throughout the volume of bone. They consider the dose, D_o, in a small, tissue-filled cavity in an infinite extent of mineral bone uniformly contaminated with the radionuclide and give dose factors D_s/D_o and D_m/D_o for obtaining the absorbed doses. For both Sr-89 and Sr-90, the ratio of D_s/D_m is about 1.5. Therefore, since the dose limit recommendations are 15 rem to bone and 5 rem to red marrow (occupational limits), the dose to red marrow is the limiting criterion and will be used in this report (26).

The work of Spiers and his coworkers has been used by the ICRP (27) in calculating dose commitment factors for adults and by Papworth and Vennart (41) for doses as a function of age at times of ingestion. The dose commitment values from Papworth and Vennart in red marrow per μCi of Sr-89 and Sr-90 ingested are as follows (Table 6).

Table 6. Dose commitment values for Sr-89 and Sr-90

Age at Ingestion (years)	rem per μCi ingested[a] Sr-89	Sr-90
0	0.414	4.03
0.5	0.194	2.49
1	0.130	1.83
2	0.080	1.20
3	0.060	0.91
4	0.050	0.77
5	0.044	0.70
6	0.039	0.69
7	0.035	0.71
8	0.032	0.76
9	0.029	0.83
10	0.026	0.89
11	0.023	0.94
Adults[a]	0.012	0.70

[a]Ages 0-11 from Papworth and Vennart (41), Adults from ICRP-30 Supplement to Part 1 (27).

Thus the dose conversion factors adopted in rem/μCi ingested are for Sr-89, 0.194 and 0.012, and for Sr-90, 2.49 and 0.70, for the infant and adult, respectively. As before, the 0.5-year infant is taken as the critical population. The values for the adult are those given in ICRP 30 (27) which also used the work of Spiers and coworkers.

2.1.5 Other Radionuclides

Adult - The most authoritative reference using current data and models for dose conversion factors per μCi ingested is that of the ICRP 30 (27) Part 1, 1979; Part 2, 1980; Part 3, 1981; and the Supplements, Pergamon Press (42). ICRP 30 Parts 1, 2, and 3 (and Supplements) provide data only for adults (occupational workers) for the radionuclides of 94 elements.

As a further resource, ORNL/NUREG/TM-190 is suggested (37). This document represents initial efforts by ORNL under contract to NRC to provide review and update on internal dosimetry.

Infant, Child - Unfortunately the initial efforts to update internal dosimetry have all been directed at the adult or occupational worker and comprehensive dosimetry using current data for the younger age groups do not exist. Further efforts are in process or contemplated by the U.S. Nuclear Regulatory Commission (NRC), Medical Internal Radiation Dose Committee, (MIRD), Society of Nuclear Medicine, and NCRP, and generally will involve or use the models developed by Oak Ridge National Laboratory (ORNL). Until such time that new dosimetric calculations appear for the younger age group, it is suggested that Nuclear Regulatory Commission Regulatory Guide 1.109 be used: "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," Regulatory Guide 1.109, Revision 1, Oct. 1977, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

2.2 AGRICULTURE TRANSPORT MODELS

A review of the agricultural transport mechanism for radionuclides, which employs parameters appropriate for the U.S. experience, is contained in the Reactor Safety Study, WASH-1400, Appendix VI (7). An analysis specific for calculating derived response levels (concentration values) in agricultural media for emergency action that reflects the British experience is found in a report of the Medical Research Council (43).

A more recent and comprehensive assessment of the transport mechanisms for the forage-cow-milk pathway is found in UCRL-51939 and will be used here (44)

2.2.1 Transport Models

According to Ng et al., the time dependency of the concentration of a radionuclide in the milk of a cow continuously grazing pasture contaminated by a single event can be described by (44):

$$C_M(t) = I_C(0) \sum_{i=1}^{n} A_i \frac{e^{-\lambda_{MEi} t} - e^{-\lambda_p t}}{\lambda_P - \lambda_{MEi}}$$

where $C_M(t)$ = concentration of radionuclide in milk at time t (μCi/l)

$I_C(0)$ = initial rate of ingestion of radionuclide by the cow (μCi/d)

A_i = coefficient of ith exponential term, which describes the secretion in milk (liter^{-1})

λ_{MEi} = effective elimination rate of the ith milk component (d^{-1})

$\lambda_{MEi} = \lambda_R + \lambda_{MBi}$

λ_R = radiological decay constant (d^{-1})

λ_{MBi} = biological elimination rate of ith milk component (d^{-1})

λ_P = effective rate of removal of the nuclide from pasture (d^{-1}), and

$\lambda_P = \lambda_R + \lambda_W$, where λ_W is removal rate for a stable element from pasture (d^{-1}), and

t = time of milk secretion (d).

The total activity ingested by a person who drinks this milk can now be determined by integration:

$$\int_0^\infty I\,dt = \int_0^\infty J C_M(t)dt = \int_0^\infty J I_C(0)$$

where I = rate of ingestion of the radionuclide by a person (μCi/d) and

J = rate of consumption of milk (liter/d).

The solution for the total activity ingested by man is:

$$\int_0^\infty I\,dt = \frac{J I_C(0) f_M}{\lambda_P}$$

where f_M = transfer coefficient; i.e., the fraction of daily intake by cow that is secreted per liter of milk at equilibrium (d/liter)

$$f_M = \sum_{i=1}^{n} \frac{A_i}{\lambda_{MBi}}$$

Ng et al. have conducted a comprehensive review of the literature relevant to the determination of transfer coefficients for both stable elements and radionuclides (44). These data are summarized in UCRL-51939, which also include values of the normalized coefficients, A_i, the biological half-life T_{MBi} (related to λ_{MBi}) for selected elements and values of f_M for all stable elements. This information is then used with the radioactive half-life to calculate values of f_M for specific radionuclides of interest (Table B-1 of Ng et al. (44)).

An examination of the logistics of the forage-cow-milk-man pathway shows that there is generally a delay time between the production of milk by the cow and its consumption by the general public. Therefore, it is appropriate to introduce a factor, S, to account for radioactive decay between production and consumption, where

$S = e^{-\lambda t}$ where λ = the decay constant for a given radionuclide (d^{-1})
and t = the delay between production and consumption (d).

Since the delay time for fresh whole milk is assumed to be 3 days only I-131 of the radionuclides of interest here has a sufficiently short half-life to result in a value of S significantly smaller than one. Thus, for I-131:

$S(I\text{-}131) = e^{-0.086 \times 3}$
$S(I\text{-}131) = 0.772$

Therefore, the total activity ingested as calculated by the above formula ($\int dt$) must be multiplied by 0.772 in the case of iodine-131.

2.2.2 Total Intake

The calculated values of integrated activity ingested per $\mu Ci/m^2$ deposition from Appendix B of UCRL-51939 will be accepted as the basis for deriving the response levels equivalent to the PAG (44). The values in Appendix B are based on these values of parameters:

(1) $I_C(0)$, initial rate of intake by cow

UAF = "utilized area factor" (93)

UAF = 45 m^2/d

Initial Retention on Forage = 0.5 fraction

Initial Deposition = 1 $\mu Ci/m^2$

thus $I_C(0)$ = 22.5 $\mu Ci/d$,

(2) J = 1 liter/day consumption of milk, and

(3) Half-residence time on forage is 14 days.

The UAF of 45 m^2/d assumes a forage consumption by the cow of 11.25 kg/d dry weight or 56 kg/d wet weight based on a forage yield of 0.25 kg/m^2 (dry weight) (45).

The values of the total intake per unit deposition (µCi µCi m^2) for a 1-liter per day milk intake from Ng et al., are given in Table 7, line 1 (44).

Table 7. Derivation of response levels equivalent to 1 rem dose commitment to critical organ

	I - 131		Cs - 134		Cs - 137		Sr - 90		Sr - 89	
1. Pathway intake factory (42) (uCi/uCi/m^2 per ℓ/d)	1.34		3.12		3.22		.636		.46	
	Infant	Adult	Infant	Adult	Infant	Adult	Infant	Adult	Infant	Adult
2. Dose conversion factor (rem/uCi ingested)	16	1.5	.118	.068	.071	.061	2.49	.70	.194	.012
3. Intake per rem ($\frac{1}{\text{line 2}}$) (uCi intake per rem)	.063	.67	8.5	14.7	14.1	16.4	.40	1.43	5.2	83
4. Specific intake factor (line 1 x 0.7 or 0.55) - (uCi per u Ci/m^2	.72[a]	.57[a]	2.18	1.72	2.25	1.77	.45	.35	.322	.253
5. Initial surface deposition ($\frac{\text{line 3}}{\text{line 4}}$) (uCi/$m^2$ per rem)	.086	1.17	3.9	8.6	6.3	9.3	.90	4.1	16	329
6. Peak concentration factor (see text) (uCi/ℓ per u Ci/m^2)	0.116		0.078		0.078		0.0196		0.018	
7. Peak milk concentration (line 5 x line 6) (uCi/ℓ per rem)	.0100	.136	.303	.67	.49	.72	.0177	.080	.288	5.9
8. Initial grass concentration (line 5 x 0.4) (uCi/kg per rem)	.0345	.47	1.55	3.43	2.50	3.70	.361	1.63	6.40	132

[a]Corrected for decay during distribution (3 days factor - .772)

2.3 DIETARY INTAKE

Infant less than 1 year old - For the purposes of these recommendations, the dietary intake of milk is estimated to be 0.7 liters per day for a newborn infant.

Based on the average intake up to and including 1 year of age, the daily intake of milk for an infant less than 1 year of age is 0.7 liters (46). An additional 300 g of food may also be assumed to be ingested by an infant less than 1 year of age (based on intake of 6 month-old infants - Kahn, B. (47)).

Adult - Based on U.S. Department of Agriculture Household Food Consumption Survey 1965-1966, the average consumption for the general population is given in Table 8. The dietary intake of milk is taken to be 0.55 liters per day for the adult.

In addition to water ingested in food and drink, an estimated 150 ml of tap water is also ingested each day (46) for a total daily food intake of 2.2 kg.

Table 8. Average consumption for the general population

Food	Average consumption for the general population g/day	% of total diet
Milk, cream, cheese, ice cream[a]	567.5	27.2
Fats, oils	54.5	2.6
Flour, cereal	90.8	4.3
Bakery products	149.8	7.2
Meat	217.9	10.4
Poultry	54.5	2.6
Fish and shellfish	22.7	1.1
Eggs	54.5	2.6
Sugar, syrups, honey, molasses, etc.	72.6	3.5
Potatoes, sweet potatoes	104.4	5.0
Vegetables (excluding potatoes) fresh	145.3	7.0
Vegetables canned, frozen, dried	77.2	3.7
Vegetables juice (single strength)	9.1	0.4
Fruit, fresh	163.4	7.8
Fruit canned, frozen, dried	36.3	1.7
Fruit juice (single strength)	45.4	2.2
Other beverages (soft drinks, coffee, alcoholic bvgs.)	177.1	8.5
Soup and gravies (mostly condensed)	36.3	1.7
Nuts and peanut butter	9.1	0.4
Total	2088.1	99.9

[a]Expressed as calcium equivalent; that is, the quantity of whole fluid milk to which dairy products are equivalent in calcium content.
(From the U.S. Department of Agriculture Household Food Consumption Survey, 1965-1966)

2.4 CALCULATIONS

The calculation of the derived response levels equivalent to 1 rem dose commitment to critical organ for the grass-cow-milk-man pathway is summarized in Table 7. An explanation of Table 7 and the calculations follow:

Line 1 Pathway Intake Factor is the total intake (μCi) for a 1 liter per day milk ingestion per 1 $\mu Ci/m^2$ of initial area deposition (44).

Line 2 Dose Conversion Factor is the dose commitment in rem/μCi ingested. See section 1 for summary.

Line 3 Intake per rem is intake in μCi to yield a 1 rem organ dose.

COMPUTATION - The reciprocal of line 2.

Line 4 Specific Intake Factor is the product of the Pathway Intake Factors (line 1) and the milk ingestion rate of 0.7 1/day infant or 0.55 1/day adult. In the case of I-131, a factor of 0.772 is included to adjust for 3 day's decay between production and consumption.

COMPUTATION - Line 1 x (1 or .772) x (0.7 or 0.55)

Line 5 Initial Surface Deposition is initial area deposition of a specific radionuclide in $\mu Ci/m^2$ which gives a 1-rem dose commitment.

COMPUTATION - Line 3 divided by Line 4

Line 6 Peak Concentration Factor is the peak maximum concentration in milk (μCi/l) from an initial area deposition of 1 μCi/m^2. Summary in Section 2.2.3 per model of Ng et al. (44).

Line 7 Peak Milk Concentration is the maximum milk concentration (μCi/l) that yields a dose commitment of 1 rem from continuous ingestion of the contaminated milk supply.

COMPUTATION - Line 5 x Line 6

Line 8 Initial Grass Concentration is the activity concentration (μCi/kg) on grass (edible forage) that results from the Initial Surface Deposition giving a 1-rem dose commitment.

Retention fraction on forage - 0.5

Forage yield - 1.25 kg/m^2 (wet weight)

COMPUTATION - Line 5 x $\frac{0.5}{1.25 \text{ kgm}^2}$

The derived response levels that correspond to the Preventive PAG (1.5 rem thyroid: 0.5 rem whole body and bone marrow) and the Emergency PAG (15 rem thyroid; 5 rem whole body and bone marrow) are given in Tables 9 and 10.

Table 9. Derived response levels for grass-cow-milk pathway equivalent to Preventive PAG dose commitment of 1.5 rem thyroid, 0.5 whole body or red bone marrow to infant[1]

Response levels for Preventive PAG	I-131[2]	Cs-134[3]	Cs-137[3]	Sr-90	Sr-89
Initial activity area deposition (μCi/m^2)	0.13	2	3	0.5	8
Forage concentration[4] (μCi/kg)	0.05	0.8	1.3	0.18	3
Peak milk acitivity (μCi/l)	0.015	0.15	0.24	0.009	0.14
Total intake (μCi)	0.09	4	7	0.2	2.6

[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.

[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]Intake of cesium via the meat-man pathway for adult may exceed that of the milk pathway; therefore, such levels in milk should cause surveillance and protective actions for meat, as appropriate. If both Cs-134 and Cs-137 are equally present, as might be expected in reactor accidents, the response levels should be reduced by a factor of 2.

[4]Fresh weight.

Table 10. Derived response levels for grass-cow-milk pathway equivalent to emergency PAG dose commitment of 15 rem thyroid, 5 rem whole body or red bone marrow

Response levels for emergency PAG	I - 131[3]		Cs - 134[5]		Cs - 137[5]		Sr - 90		Sr - 89	
	Infant[1]	Adult	Infant[2]	Adult	Infant[2]	Adult	Infant[2]	Adult	Infant[2]	Adult
Initial activity area deposition ($\mu Ci/m^2$)	1.3	18	20	40	30	50	5	20	80	1600
Forage concentration ($\mu Ci/kg$)[4]	0.5	7	8	17	13	19	1.8	8	30	700
Peak milk activity ($\mu Ci/\ell$)	0.15	2	1.5	3	2.4	4	0.09	0.4	1.4	30
Total intake (μCi)	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 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-man pathway for adult may exceed that of the milk pathway: therefore, such levels in milk should cause surveillance and protective actions for meat, as appropriate. If both Cs-134 and Cs-137 are equally present as might be expected for reactor accidents, the response levels should be reduced by a factor of 2.

CHAPTER 3. METHODS OF ANALYSES FOR RADIONUCLIDE DETERMINATION

3.1 INTRODUCTION

The measurement of radionuclides in food can be accomplished by either laboratory methods or field methods using portable survey instrumentation. Unfortunately, neither method of analysis was developed expressly for the purpose of implementing protective actions. In order to provide instrumentation guidance to the States, the Federal Radiological Preparedness Coordinating Committee formed a Task Force on offsite instrumentation. A draft report on instrumentation analysis methods for the milk pathway is now undergoing review by the Task Force and a second report on other food is under development. This effort is being fostered by past and current contracts of Nuclear Regulatory Commission (NRC) and Federal Emergency Management Agency (FEMA) with Brookhaven National Laboratory and Idaho National Engineering Laboratory.

The material and methods are given as interim guidance until these more definitive reports are available. It should be noted that laboratory methods of Chapter 3.2, below, were developed for environmental monitoring purposes and are more sensitive than required for protective actions implementation. And, conversely, the field methods of Chapter 3.3 are generally inadequate for the purpose of implementing action at the Preventive PAG level. Analysis methods should be able to measure radionuclide concentrations in food lower by a factor of 10 than the derived levels for Preventive PAG. Thus, it may be necessary to use a combination of laboratory and field methods in implementing and ceasing protective actions.

3.2 DETERMINATIONS OF RADIONUCLIDE CONCENTRATIONS BY SENSITIVE LABORATORY METHODS

Many compendia of methods of analysis of environmental samples are available. The EML Procedure Manual recommended is noted for its up-to-date methodologies, which continuously undergo revision and improvement (48). Analysis need not be limited to reference 48 but laboratory analysis of food should provide limits of detection as listed below, which are lower than required for protective action:

Radionuclide	Limit of detection* pCi/liter or kg
I-131	10
Cs-137	10
Sr-90	1
Sr-89	5

*Concentration detectable at the 95-percent confidence level.

A source of more rapid methods of analysis of radionuclides in milk, applicable to these recommendations is described by B. Kahn et al. (49). The methods for gamma radionuclide analysis (applicable to I-131 and Cs-137 presented in this reference are also applicable to pasture. The gamma scan determinations of I-131 and Cs-137 in milk (or water) can generally be accomplished within 2 or 3 hours. For samples measuring in the 0-100 pCi/liter range, the error at the 95-percent confidence level (2 sigma) is 5 to 10 pCi/liter. For samples measuring greater than 100 pCi/liter the error is 5 to 10 percent.

Radiostrontium procedures permit analyses of several samples simultaneously in 5 hours of laboratory bench time, plus 1-2 weeks for ingrowth of yttrium daughters. If the laboratory is set up for routine analysis of these radionuclides recovery in tracer studies is 80 ± 5 percent.

An ion exchange field method for determination of I-131 in milk, which uses gamma spectroscopy after sample collection, has also been described (50). The main advantage of this method is that it permits a large number of samples to be processed in the field or shipped and analyzed in a central laboratory.

For analysis of samples other than milk the HASL reference (48) is recommended.

3.3 DETERMINATIONS OF RADIONUCLIDE CONCENTRATIONS BY FIELD METHODS

3.3.1 Ground Contamination (Beta Radiation)

The conversion of ground survey readings to contamination levels can be accomplished by using the following equations and factors (assuming a metal tube wall thickness (steel) of 30 mg/cm^2):

1. Use a G-M survey meter calibrated to yield 3,000 counts/min per 1 mR/h of Ra γ.

2. Hold the probe not more than 5 cm above the ground with the beta shield open.

3. Assure that 100 counts/min can be detected above a normal 50 to 100 counts/min background.

4. Take readings in open terrain; that is, not in close proximity to heavy vegetation, cover, or buildings.

For determinations of ground deposition:

$D = R \times F$

where, D = ground deposition (in μCi/m^2),

R = G-M reading (in units of 10^2 counts/min) (background corrected), and

F = factor given in Table 11.

For determination of concentrations in vegetation:

$C = (D \times f)\, d$

where, C = concentration (in μCi/kg),

D = ground deposition (in μCi/m^2),

f = fraction of deposited nuclide in the vegetation, and

d = density of vegetation cover (in kg/m^2).

Generally, f ranges from 0.1 to 1 and is usually taken to be 0.25 for I-131 in the United Kingdom, and 0.5 in the United States.

Data of a similar nature may also be found in "Emergency Radiological Plans and Procedures," in the Chapter (Item 04.3.4) on "Conversion of Survey Meters to Concentration," (51).

Table 11. Ground surface contamination levels[a] of various nuclides required to yield 100 counts/min (net) on a G-M meter (open window)

Nuclide	F (μ Ci/m^2 per 100 counts/min)
Zr-95 + Nb-95	6
Ce-141	2
I-131, Ru-103m, mixed Ru-Rh (100-d old)[b]	1
Co-60, Sr-89, Y-90, Y-91, Cs-137, Ba-140, La-140 Ce-144 + Pr-144, Ru-105 + Rh-106, mixed radioiodines (1-h to 1-week old), mixed fission-products (100-d old)	0.3

[a]Level varies with background readings, ground roughness, and vegetation cover.
[b]Age refers to time since irradiation of the fuel from which the Fission Products were released.

3.3.2 Herbage

A field method for estimation of radionuclide contamination at the response levels equivalent to the Emergency PAG for pasture (forage) which has been suggested by International Atomic Energy Agency (52) is as follows:

1. Obtain enough vegetation to fill a 30 cm x 40 cm plastic bag approximately half full. This is about one-third of a kilogram (Note: the vegetation cover should be obtained from at least 1 m^2 of ground. The vegetation should be cut at approximately 1 to 2 cm from the ground and should not be contaminated in the process by soil).

2. Note the area represented by this quantity of material.

3. Compress the air from the bag and seal.

4. Transfer the sample to a low background area.

5. Flatten bag and lay probe of a portable G-M survey meter on the center of the bag.

6. Wrap bag around probe and note reading (window open and background corrected).

7. Calculate the contamination from the following equation:

   $C = R/k$

   where, C = vegetation concentration (in μ Ci/kg),

   R = G-M reading (in units of 10^2 counts/min) (background corrected), and

   k = 10^2 counts/min per μ Ci/kg as given in Table 12.

8. Convert μ Ci/kg to μ Ci/m^2 on the basis of the area represented by the sample.

9. The limiting radionuclide (i.e., having the lowest recommended PAG relative to its deposition on pasture) is iodine-131. According to Table 12, this radionuclide is detected with the lowest efficiency. Thus, if the operator assumes this radionuclide to be exclusively present in the pasture the most conservative estimates relative to the Emergency PAG would be reached.

Table 12. Typical G-M survey-meter readings probe inserted in the center of a large sample of vegetation

Nuclide	(10^k x counts/min per μCi/kg)
Sr-89, Sr-90 + Y-90	20
Ru-106 + Rh-106	50
Ba-140 + La-140	10
I-131, Cs-137	4

3.3.3 Milk

The experimental data for field determination of radionuclides in milk are limited to determination of iodine-131, and the details are rather sketchy. What material is available is abstracted below.

1. Although no data are available for field determination of radionuclides other than iodine-131 in milk, Table 13 presents experimental information obtained in water (52,53). To the extent milk is more self-shielding than water, the following data is presented as a guide rather than a means of analysis.

Table 13. G-M survey-meter open window readings (counts/min per μCi/liter) (probe immersed in contaminated water)

Nuclide	Size of sample container		
	1 liter	5 liters	>10 liters
	Counts/min per μCi/l		
Sr-89	2000	2000	2000
Sr-90 + Y-90	2000	2000	2000
Ru-106 + Rh-105	6000	8000	10000
I-131	500	800	1000
Cs-137	400	600	800
Ba-140 + La-140	1000	1500	2000

2. Method of Kearney (54):

   a. Instrument: CDV-700 Model No. 6B with beta window closed at all times.

   b. Geometry: See Figure 1.

   c. The count rate is determined by ear. If the counts per minute recorded by ear are more than 60 to 70 cpm, then the milk should be diluted with "pure" water so as to produce a sample having a 50%-50%, 25%-75% or other concentration low enough to produce counts per minute somewhat less than 60 to 70 cpm.

   d. Background: The experimental conditions duplicated "sky shine" from a trans-Pacific transfer of fallout. If the exposure around the test hole was 0.75 mR/hr a couple of feet above the hole, the sky shine increased cpm recorded

by the probe shielded within the test hole by 3 cpm. Background, on the average, was measured (in "pure" water) to be 12 to 15 cpm (in an uncontaminated environment). Thus, total background counts (with sky shine) is on the average around 19 cpm.

e. From Figure 2, the net counts per minute equivalent to the response level for the Emergency PAG applicable for milk (infant as critical segment of population) is approximately 20.

3. Method of C. Distenfeld and J. Klemish (55).

   a. Instruments:

      i. CDV 700 instrument turned to 10 X scale and calibration adjustment turned to require the meter to indicate 2 mR/hr. (NB: Discrepencies were noted between data from scale and pulse counting with an oscilloscope).

      ii. Modified CDV 700 M with factory calibration. Good agreement between scale reading and electronic check.

   b. Geometry: The basic container was a 5-gallon heavy-wall polyethylene "Jerri" type measuring 12x9x10 inches. A 2-inch O.D. blind tube was installed to allow the G-M probe to sample the center of the container.

   c. Counts were taken inside and at the top (external) to the container.

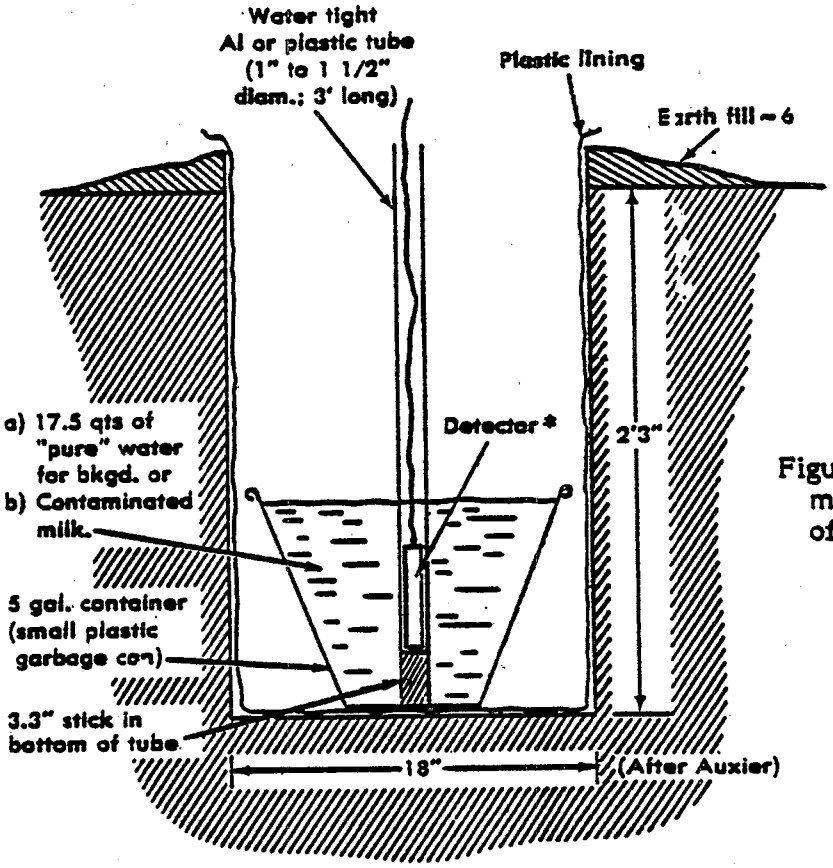
   d. Background was determined in a water filled plastic container (15x25x20 cm) about 7 meters from the sample vessel.

   e. Net counts per minute equivalent to the response levels for the Emergency PAG for milk are summarized in Table 14.

4. The International Atomic Energy Agency reports on a series of experiments (53). The data are duplicated in Table 15.

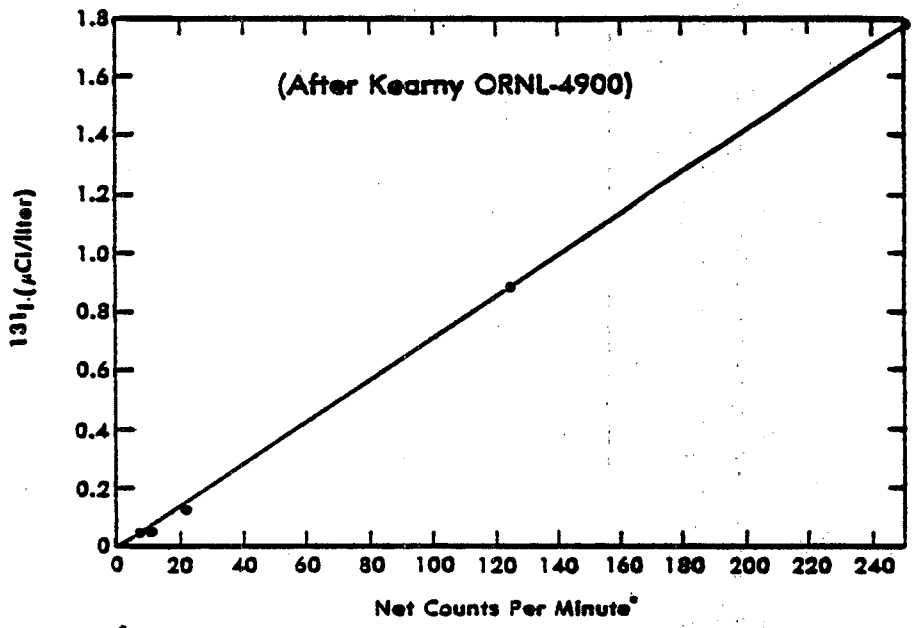
5. A forthcoming report of the Federal Interagency Task Force on Offsite Emergency Instrumentation for Nuclear Incidents to be published by FEMA is "Monitoring and Measurements of Radionuclides to Determine Dose Commitment in the Milk Pathway." A subsequent report by the Task Force will address field methods and monitoring strategies for other food pathways.

6. The relative sensitivity of the various techniques is summarized in Table 16.



*CDV-700, Model No. 68 covered with small plastic bag taped to cable of probe to further protect against dampness.

Figure 1. Geometry for making measurements within a volume of liquid.



*Net counts per minute determined by ear. Net counts per minute = grosscounts per minute — background in pure water.

Figure 2. Net counts per minute*

Table 14. Net counts per minute equivalent to the response levels for the Emergency PAG for milk

Instrument	Approximate net counts per minute			
	CDV-700		CDV-700M	
Probe Position	Inside	Outside	Inside	Outside
Response level for Emergency PAG				
(Milk-Infant)	20[a]	8[a]	220	100
(Milk-Adult)	260	110	2,900	1,300

[a]At or below background cpm - precision not adequate.

Table 15. Survey-meter readings versus concentration of I-131 in a 40-liter milk can

Meter used	μCi I-131/liter milk	Net counts per minute Inside can	Outside can
Al-walled GM probe	0.9	1,500	300
	0.5	500	200
	0.1	100	50
	0.05	50	50
	Background	50	50
Mica-window GM probe	0.9	600	250
	0.5	400	100
	0.1	100	50
	0.05	50	50
	Background	50	50
α,β,γ scintillation survey-meter[a]	0.9	5,500	3,000
	0.5	3,000	1,500
	0.1	600	300
	0.05	250	150
	Background	100	100
Transportable single-channel analyzer system	0.10	1,200	-
	0.05	650	-
	0.01	140	-
	0.005	80	-
	Background	30	-

[a]Crystal is 3-mm thick disc of "Bioplastic" scintillator sprayed with 10 mg/cm^2 of ZnS. Effective area is 6.4 cm^2.

Table 16. Comparison of methodologies

	cpm per μCi liter^{-1} Inside	Outside
IAEA - 1974 (52)	1,000	-
Kearney - ORNL (54)	140	-
Distenfeld and Klemish - Brookhaven (55)		
CDV-700	134	56
CDV-700M	1,450	660
IAEA - 1966 (53)		
Al Walled GM Probe	1,100	350
Mica-Window GM Probe	700	250
α,β,γ Scintillation Survey Meter	6,000	3,300
Transportable Single Channel Analyser	12,000	-

CHAPTER 4. PROTECTIVE ACTIONS

The National Advisory Committee on Radiation (56) (NACOR) made the following recommendation that applies to action taken to reduce potential exposure following the accidental release of radioactivity:

"A countermeasure, useful to public health, must fulfill a number of requirements. First, it must be effective; that is, it must substantially reduce population exposures below those which would prevail if the counter measure were not used. Second, it must be safe; i.e., the health risks associated with its use must be considerably less than those of the contaminant at the level at which the countermeasure is applied. Third, it must be practical. The logistics of its application must be well worked out; its costs must be reasonable; and all legal problems associated with its use must be resolved. Next, responsibility and authority for its application must be well identified. There must be no indecision due to jurisdictional and misunderstandings between health and other agencies concerned with radiation control. Finally, careful attention must be given to such additional considerations as its impact on the public, industry, agriculture, and government."

An action, in order to be useful must be effective, safe, and practical. An action may be applied at the source in an attempt to control the release of radioactivity from the source; or, the action may be applied at the beginning of the food chain (soil, vegetation, or cattle), to the immediate vector prior to ingestion by man (milk or food), or to the population itself. For the most part these recommendations suggest protective actions to milk, human and animal foods, or soil and this chapter is limited to actions concerning these media. Further recommendations by NACOR (56) extend the discussion of protective measures to public health actions directly affecting the exposed population. For details of agriculture actions, several Department of Agriculture reports are available that deal with specific actions for crops and soil (57,58,59).

Potential actions relative to the pasture-milk-man pathway are summarized in Table 17. For this pathway, only four countermeasures are rated as effective, safe, and practical (a somewhat arbitrary scale of judgment was used). Of the four, one has distinctive disadvantages. Although removal of radionuclides from milk has been shown to be practical no facilities for doing this exist. Another, diverting fresh milk to processed milk products, freezing and/or storage, is effective only for short-lived radionuclides. Thus, changing dairy cattle to an alternate source of uncontaminated feed and condemnation of milk are the only two protective actions rated good for effectiveness, safety, and practicality.

Of course the other countermeasures should also be considered, but they appear less promising.

Actions for fruits and vegetables are presented in Table 18 (60,61,62). Note that studies in which these products were contaminated under actual conditions with fallout (Studies 2 and 3) yielded a lower reduction in the radioactivity removed during preparation than was the case in an investigation (Study 1) in which radionuclides were sprayed on the food. Depending on the food, reductions between 20 and 60 percent in strontium-90 contaminations are possible by ordinary home preparation or by food canning processes (60).

Milled grains contain only a small portion of the total radioactive contamination of the whole grain; removal of bran from wheat and polishing of rice are effective methods of reducing contaminating fallout (58). Todd indicated average concentration of Sr-90 (pCi/kg)

in wheat of wheat berry (22%), wheat bran (68%), and only 4.4% in flour. In rice the corresponding values are: whole grain (4.9%), and milled rice (0.7%) (58).

Although these recommendations are intended for implementation within hours or days after an emergency, long-term actions applicable to soil are shown for information purposes only in Table 19. Alternatives to decontamination and soil management should be considered, especially if the radioactive material is widespread, because great effort is required for effective treatment of contaminated land.

The concept of Protective Action assumes that the actions implemented will continue for a sufficient period of time to avoid most of the projected dose. The concentration of radioactivity in a given food will decrease because of radioactive decay and weathering as a function of time after the incident. Thus, as discussed in Chapter 5 of this report, actions that have a positive cost-benefit ratio at the time of initial contamination or maximum concentration may not have a positive cost-benefit ratio at later times. Therefore, dependent on the particular food and food pathway, it may be appropriate to implement a series of protective actions until the concentrations in the food have essentially reached background levels.

As an example of the implementation of protective actions, consider the case where an incident contaminates the pasture-cow-milk-man pathway with a projected dose of 2-3 times the Emergency PAG due to iodine-131. In such a situation these protective actions may be considered appropriate:

1. Immediately remove cows from pasture and place them on stored feed in order to prevent as much iodine-131 as is possible from entering the milk;

2. Condemn any milk that exceeds the Emergency PAG response at the farm or milk plant receiving station;

3. Divert milk contaminated at levels below the Emergency PAG to milk products; and

4. Since the supply of stored feed may be limited and the costs of this protective action greater than diversion to milk products, the use of stored feed may be the first action to cease; this should not be done, however, until the concentration of I-131 has dropped below the Emergency PAG and preferably is approaching the Preventive PAG.

5. The diversion of fresh milk to milk products must continue until most of the projected dose has been avoided; this action might be ceased when the cost-effectiveness point is reached or the concentration of iodine-131 approaches the background levels.

This discussion assumes that there is an adequate supply of whole milk from noncontaminated sources, that there is an available manufacturing capacity to handle the diverted milk, and that the iodine-131 is the only radionuclide involved. In an actual situation these conditions may not be present and other factors may affect the practicality of proposed protective actions. The agency responsible for emergency action must identify and evaluate those factors that affect the practicality of protective action, and thus develop a response plan (with tentative protective action) that is responsive to local conditions and capabilities.

Table 17. Actions applicable to the pasture-milk-man pathway (compiled from references 57 and 59)

Action	Radionuclide(s) for which protective action is applicable	Effectiveness	Safety	Practicality (effort required)	
Applicable to cattle					
Provide alternate source of uncontaminated animal feed	^{131}I, ^{90}Sr, ^{89}Sr, ^{137}Cs	(+)[a]	(+)	(+)	Good
Add stable iodine to cattle ration	^{131}I	Marginal[b]	Some hazard	(+)	
Add stable calcium to cattle ration	^{89}Sr, ^{90}Sr	Marginal	Some hazard	(+)	
Add binders to cattle ration	^{137}Cs, ^{89}Sr, ^{90}Sr	Marginal	Questionable	(+)	
Substitute sources of uncontaminated water	^{137}Cs, ^{89}Sr, ^{90}Sr	(+)	(+)	(+)[c]	
Applicable to milk					
Condemnation of milk	^{131}I, ^{89}Sr, ^{90}Sr, ^{137}Cs	(+)	(+)	(+)[d]	Good
Divert fresh milk to processed milk products	^{131}I, ^{89}Sr	(+)	(+)	(+)	Good
Process fresh - store	^{90}Sr, ^{137}Sr	Marginal	Questionable	(+)	
Process fresh - store	^{131}I	(+)	(+)	(+)	Good
Remove radionuclides from milk	^{131}I, ^{89}Sr, ^{90}Sr, ^{37}Cs	(+)	(+)	(+)[e]	Good

[a](+): 90% effective
[b]Marginal: less than 90% effective
[c]Depends on availability
[d]Somewhat dependent on volume
[e]No processing plant presently available

Table 18. Percent reduction in radioactive contamination of fruits and vegetables by processing

	Study 1 (60) Normal food preparation for freezing, canning or dehydration				Study 2 (61)	Study 3 (62)
	External	Contamination[a]	Internal	Contamination[a]	Canning	Home preparation
	^{90}Sr	^{137}Cs	^{90}Sr	^{137}Cs	^{90}Sr	^{90}Sr
Spinach	92	95	64	88	22	-
Snap beans	-	-	-	-	62	-
Carrots	-	-	-	-	19	19
Tomatoes	-	-	65	-	21	28
Broccoli	94	92	72	89	-	-
Peaches	≈ 100	≈ 100	≈ 100	≈ 100	50	-
Onions	-	-	-	-	-	37
Potatoes	-	-	-	-	-	24
Cabbage	-	-	-	-	-	53
Green beans	-	-	-	-	-	36

[a]Contamination on surface is referred to as external contamination. Internal contamination is contamination of fleshy portion of product from surface deposition of radionuclide.

Table 19. Actions applicable to soil (compiled from references 57 and 59)

Action	Radionuclide(s) for which protective action is applicable	Effectiveness[a]	Safety	Practicality (effort required)[b]
Applicable to soil				
Soil management—minimum tillage:	^{90}Sr	Poor to fair	Not applicable	Good
deep plowing with root inhibition	^{90}Sr	Good to fair	"	Poor
irrigation & leaching	^{90}Sr	Poor	"	Good
liming & fertilizing	^{90}Sr	Poor to fair	"	Good
Removing contaminated surface crops	^{90}Sr	Most poor	"	Poor to fair
Removal of soil surface contamination:				
warm weather with vegetation cover	^{90}Sr	Good to fair	"	Poor
cold weather no cover	^{90}Sr	Good to poor	"	Good to poor

[a]Rating for reducing strontium-90
Good - 95% reduction
Fair - 75-95% reduction
Poor - 75% reduction

[b]Rating for effort required
Good - not significantly more than normal field practice
Fair - extra equipment or labor required
Poor - very great requirement of equipment, materials, and labor

CHAPTER 5. COST CONSIDERATIONS

5.1 COST/BENEFIT ANALYSIS

5.1.1 Introduction

The general expectation is that protective action taken in the event of a nuclear incident will result in a net societal benefit considering the cost of the action and the corresponding avoided dose. These cost assessments, including cost/benefit analysis, have not been used to set the numerical value of the PAG's but rather to evaluate the feasibility of specific protective actions.

At least two basically different approaches can be used to assess the cost/benefit ratio of protective actions for the milk pathway. One approach would be to assume a protective action scenario (maximum milk concentration and length of time of protective action) and to calculate the total cost of the action and the benefit because of the avoided dose. The ratio of the cost/benefit can then be used to scale the maximum milk concentration to that concentration that yields equal costs and benefits. The problem with this approach is that positive net benefits when milk concentration of radioactivity is high are used to offset the negative net benefits during the later times of action.

This deficiency leads to the second approach of calculating the milk concentration on a per liter basis where the cost of the protective action equals the benefit because of the dose avoided. This approach will be used here since it gives a clearer picture of the identified costs and benefits. The specific concentration at which costs equals benefits should not however be viewed as the appropriate level for taking protective action. The philosophy of protective action is to take action to avoid most of the projected doses. Further, the simple analysis considered here treats only the direct cost of protective actions and ignores the administrative costs of starting, monitoring, and ceasing action, and other related social and economic impacts.

Although the PAG recommendations provide that protective actions be taken on the basis of projected dose to the infant, cost/benefit analysis must consider the cost impact on the milk supply and the benefit on a whole population basis. Accordingly the benefit realized from avoiding the dose associated with a given level of milk contamination C (μCi/l) must be summed over the age groups having different Intakes (I) and Dose Factors (DF) and is:

$$\text{Benefit} = C\ (\mu\text{Ci/l}) \times \text{Value}\ (\$/\text{rem})\ \Sigma Ii(\text{l/d}).DFi(\text{rem}/\mu\text{Ci}).$$

The total cost of the protective actions, which must also be summed over all the age intake groups is:

$$\text{Cost} = \text{PA COST} \times \Sigma Ii$$

Costs are in 1980 - 1981 dollars. These equations can then be solved for the concentration (C) at which cost = benefit giving:

$$C\ (C{=}B) = \frac{\text{PA COST}\ \Sigma Ii}{\text{Value}\ (\$/\text{rem})\ \Sigma(Ii \cdot DF_i)}$$

5.1.2 Benefit of Avoided Dose

In situations in which there has been an uncontrolled release of radioactivity to the environment, both the health savings and cost of a protective action can be expressed in terms of dollar values. This does not exclude the probability that undesirable features will result from an action that is difficult to evaluate in economic terms.

A previous cost-benefit analysis described the radioactive concentration of iodine-131 in milk at which it would be justifiable to initiate condemnation of milk (63). Following is a summary of the monetary benefit of radiation dose avoided using the approach suggested, with changes because of increased costs over time and new data on the relative incidence of various tumors.

The International Commission on Radiological Protection, (64) has endorsed the principle of expressing the detriment from radiation in monetary terms in order to facilitate simplified analysis of costs and benefits. This permits a direct comparison between the societal advantage gained in a reduction of the radiation dose and the cost of achieving this reduction. Cost-benefit analysis is the evaluation process by which one can determine the level at which, or above which, it would be justifiable to initiate the protective action because the health savings equaled or exceeded, the economic costs of the protective action. Certain factors, such as loss of public confidence in a food supply, are not considered; nor are economic factors because of hoarding and a shortage of supply considered. A similar treatment of the problem with almost the same result has been published (65). This type of exercise is useful prior to taking an action as one, and only one, of a series of inputs into decisionmaking.

The costs, and hence health savings to society, of 1 person-rem of whole-body dose (the product of a dose of 1 rem to the whole body and 1 person) has been estimated by various authors to be between $10 and $250 (66). The Nuclear Regulatory Commission (NRC) value for a cost-benefit analysis for augmented equipment for light-water reactors to reduce population dose, sets radiation costs at $1000 per person-rem (67).

Based on medical expenses in 1970, the total future cost of the consequences of all genetic damage of 1 person-rem (whole-body) was estimated by the BEIR Committee (2) to be between $12 and $120. These costs are in good agreement with estimates made by Arthur D. Little, Inc., for the Environmental Protection Agency, which calculated that in terms of 1973 dollars, 1 person-rem of radiation yielded a tangible cost of between $5 and $181 due to excess genetic disorders. A tangible cost of between $7 and $24 per person-rem was estimated to be the result of excess cancer in the same report. Therefore, the total health cost of a person-rem from these studies is between $12 and $205 (68).

Assuming that $200 is a reasonable estimate for the overall somatic health cost to society per person-rem whole body, the proportionate cost for individual organ doses must then be derived. For the purposes of assessing health cost, it is appropriate to use the relative incidence of cancer estimated to result from organ doses vs. whole body doses. From BEIR-III (3) (Table V-14 and V-17, and using an average of the male and female incidence) the thyroid contributes 20 percent of cancer and leukemia (red bone marrow doses) 11 percent of the total cancer incidence. Hence, the monetary costs per rem of radiation dose avoided are: to thyroid $40; and to red bone marrow $22.

5.1.3 Protective Action Costs

The direct cost of protective action will be assessed for (1) cost of stored feed, (2) condemnation at the farm (farm value), and (3) condemnation at the processing plant (retail value).

1. Cost of stored feed. For the participating herds (May 1, 1978 - April 30, 1979) the Dairy Herd Improvement Letter (69) reports a consumption of 12,600 lbs. of succulent

forage and 3,000 lbs. of dry forage, with a corresponding annual milk production of 14,129 lbs. (6200 liters). (The cows also consumed 5,800 lbs. of concentrates, which are not of concern here.) Taking 3 lbs. of succulent forage (silage) as equivalent to 1 lb. of hay, the annual hay equivalent consumption is 7,200 lbs (70). Thus, 1.16 lbs. of hay equivalent is consumed per liter of milk production. The 1980 average price received by farmers for all baled hay was $67.10 per ton or $0.0335 per lb. (71). The Protective Action (PA) cost of buying baled hay to replace pasture as the sole forage source is then $0.039 per liter.

2. Milk-farm value. The average price received by farmers for fluid-eligible milk, sold to plants and dealers in 1980, was $13.21 per hundred weight (monthly range $12.70 to $14.20) (71). The lower prices are received during the pasture season of April through August. For 44 liters per hundred weight, the farmer value of milk is $0.30 per liter.

3. Milk-retail value. Since it may be necessary to take protective action at some stage in the milk processing and distribution system it is appropriate to consider the retail value of milk. If condemnation of milk is taken at the receiving station or processing plant there will be additional costs above farm value associated with disposal. It is felt that retail price should represent an appropriate value. The average city retail price of fortified fresh whole milk sold in stores, January through October 1980 was $1.037 per 1/2 gallon (72). The monthly price increased from $1.015 in January to $1.067 in October, apparently because of inflation. Based on the average price the value of $0.56 per liter will be used.

5.1.4 Population Milk Intake and Dose

Table 20 summarizes the milk intake by population age groups and gives values of the age group intake factor Ii(l/d). The total intake by a population of 1000 is 281 l/d or an average individual daily intake of 0.28 l. The intake factor (Ii) is used with the dose factor DFi listed in Table 21 to calculate the dose factor summed over the whole population weighted by age per μCi/l of milk contamination.

5.1.5 Milk Concentration For Cost = Benefit

The above results are then used to calcultate the milk concentration at which the Protective Action (PA) costs equals the benefit from the dose avoided. The results are presented in Table 22. The cost = benefit concentration for use of stored feed in place of contaminated pasture is about 0.2 to 0.3 of the Preventive PAG for strontium and 0.01 to 0.02 for iodine and cesium. For condemnation, the cost = benefit concentrations based on farm value of milk have ratios of the Emergency PAG similar to those above. The cost = benefit concentrations based on retail value of milk are about a factor of 2 greater than those based on the milk's farm value. The fact that the cost = benefit concentrations are a significant percent of the PAG for strontium results largely because the value of the person-rem dose to red bone marrow is one-ninth that of whole-body doses while the PAG's are set at equal doses consistent with current regulations. Further the controlling PAG's are for the infant, while the cost/benefit reflects population averaged benefits.

Table 20. Population milk intake (Σ Ii)

Age group	Persons per 1000 population	Milk intake[a] (l/d)	Intake (Ii) by age group (l/d)
In utero	11	.4	4.4
0 < 1	14	.775	10.9
1 - 10	146	.470	68.6
11 - 20	196	.360	70.6
>20	633	.200	126.7
		ΣIi	281.2

[a]ICRP, 1974

Table 21. Population dose factors

Age group	Sr-89 DFi rem/μCi	Sr-89 Ii x DFi rem/μCi · 1/d	Sr-90 DFi rem/μCi	Sr-90 Ii x DFi rem/μCi · 1/d	Reference for DFi values[a]
In utero	.414	1.82	4.03	17.7	0 yr old
0 < 1	.194	2.12	2.49	27.2	0.5 yr-old
1 - 10	.0565	3.88	.929	63.8	Average
11 - 20	.0175	1.24	.82	57.9	Av 11 yr & adult
> 20	.012	1.52	.70	88.7	Adult
	ΣIiDFi	10.58		255.3	

[a]See Chapter 2.

Age group	Cs-134 DFi rem/μCi	Cs-134 Ii x DFi rem/μCi · 1/d	Cs-137 DFi rem/μCi	Cs-137 Ii x DFi rem/μCi · 1/d	Reference for DFi values[a]
In utero	.068	.3	.061	.27	Adult[b]
0 < 1	.118	1.29	.071	.77	Infant
1 - 10	.093	6.39	.066	4.53	Av. infant & adult
11 - 20	.093	6.57	.066	4.66	"
> 20	.068	8.51	.061	7.73	Adult
	ΣIiDFi	23.06		17.966	

[a]See Chapter 2.
[b]No credit taken for reduced biological half-life in pregnant women.

Age group	I-131 DFi rem/μCi	I-131 Ii x DFi rem/μCi · 1/d	Reference for DFi values[a]
In utero	.8	35	Max. estimate
0 < 1	16	174	Newborn
1 - 10	5.7	391	Average from smooth curve
11 - 20	2.1	148	15 yr old
> 20	1.5	190	Adult
	ΣIi DFi	938	

[a]See Chapter 2.

Table 22. Milk concentration at which cost = benefit
(Population basis - value of ΣIixDFi for 1000 persons)

		Sr-89	Sr-90	I-131	Cs-134	Cs-137
$\Sigma Ii \times DFi$ $\frac{rem}{\mu Ci} \cdot \frac{1}{d}$		10.58	255	938	23.1	17.96
Value ($/rem)		22	22	40	200	200
	PA cost	CONC. (Cost = Benefit) (μCi/l)				
Stored Feed	$0.039	.047	.002	.0003	.0025	.003
Farm Milk	0.30	.36	.015	.0023	.018	.025
Retail Milk	0.56	.68	.028	.0042	.034	.044
		Peak CONC. (μCi/l)				
Preventive PAG		.14	.009	.015	.15	.24
Emergency PAG infant		1.4	.09	.15	1.5	2.4
Emergency PAG adult		30	.4	2.0	3.0	4.0

5.2 ECONOMIC IMPACT

The Emergency Planning Zone (EPZ) for the ingestion pathway has been set at 50 miles (73). The area impacted that requires protective action is the major factor influencing cost. Assessment of the economic impact will be considered for the case of contamination of the milk pathway in one 22.5° Sector out to a distance of 50 miles. Table 23 gives data on the annual sales of whole milk and total area of leading dairy States and selected States. The annual milk sales in Wisconsin of 3.52×10^5 lbs. per sq. mile exceeds that of any other State and will be used to assess the economic impact. There may, of course, be individual counties and areas surrounding nuclear power plants where milk production exceeds the Wisconsin State average. The Wisconsin average should, however, represent a maximum for most areas of the United States.

Table 23. Milk production of selected States
(Statistical Abstract of the U.S., 1978)

State	Whole milk sold (10^9 lbs/year)	Total area (mi^2)	Milk per unit area 10^5 lbs/mi^2
WI	20.5	56,154	3.52
VT	2.06	9,609	2.14
NY	9.92	49,576	2.00
PA	7.37	45,333	1.64
IA	4.07	56,290	1.38
CT	.595	5,009	1.19
MN	9.27	84,068	1.10
OH	4.43	41,222	1.08
MI	4.63	58,216	0.80
CA	11.53	158,693	0.73
MA	0.55	8,257	0.67
NJ	0.52	7,836	0.66

Another important factor in assessing the economic impact of protective actions in the milk pathway is the length of time that such actions will be necessary. During most of the year in northern parts of the U.S., cattle will already be on stored feed and there will be no

additional costs for the stored feed protective action. For other situations and the Emergency PAG, the time over which protective actions will be necessary is a function of a number of parameters unique to each site and the causative accident. Thus, what are intended as conservative assumptions will be selected. The time behavior of I-131 on pasture grass is controlled by the 8-day radioactive half-life and the 14-day weathering half-life (yielding an effective half-life of about 5 days). Milk which contains I-131 at the Emergency PAG of 0.15 μCi/l will be reduced to the cost = benefit concentration (farm value) of 0.0023 μCi/l about 30 days later. Obviously in most cases of an atmospheric release, those areas closer to the release point will have higher levels of contamination and longer times of protective action. The NRC and EPA in the Planning Basis Report NUREG-0396 (NRC, 1978) assume that radiation doses from the airborne plume decrease according to the $r^{1.5}$ factor. Use of this factor for contamination of pasture results in milk concentrations at 2 miles that are about 100 times that at 50 miles. For an effective half-life of 5 days this would require an additional 30-35 days of protective action at 2 miles over that at 50 miles to yield the same milk levels upon ceasing action. Although these models cannot be assumed to be rigorously accurate in a specific accident situation, they do indicate that action might be required for 1 or 2 months.

NUREG-0396 notes that the dose from milk pathway is of the order of 300 times the thyroid dose from inhalation (74). Under this assumption (and above models), the food PAG's would be exceeded at hundreds of miles if protective action because of inhalation were required at 10 miles. It should be noted that the meteorological models that are empirically derived are not likely to be valid for such long distances. Further changes in wind direction and meteorological dispersion conditions may reduce the levels of pasture contamination and the downwind distance. For assessing ecomomic impact, contamination of a 22.5° Sector out to a distance of 50 miles will be arbitrarily assumed, even though actual contamination patterns are not likely to be similar.

Under these assumptions we then have:

Area (Circle - 50 mile radius) - 7850 mi^2

Area (22.5° Sector - 50 mile) - 491 mi^2

Milk Production - 3.52×10^5 lbs/mi^2 per year - 2.93×10^4 lbs/mi^2 per month

Production (22.5°/50 mi Sector) - 1.44×10^7 lbs./month

Cost of Stored Feed - $0.017 per lb. milk

Cost Impact (22.5°/50 mile Sector) - $2.46 x 10^5 per month

Thus, the direct cost of placing cows on stored feed within a 22.5° Sector out to 50 miles based on farm value, would be about $0.25 million per month. The cost would be zero during that portion of the year and in geographical areas where cattle are already on stored feed. While such protective actions might be required for periods up to 2 months at areas near the accident site, such would not be the case at the greater distances which involve the major portion of the area. Condemnation of milk is the protective action of last resort for areas of very high contamination. As noted above, the farm value of milk is $0.30 per liter. Thus, the condemnation of milk at the Emergency PAG for a 22.5°/50 mile sector would have a cost of about $2 million for a month of protective action. Where I-131 is the only significant contaminant, whole milk can be diverted to manufactured products, such as powdered milk, which can be stored to allow disappearance of the radioactivity. We do not have cost figures for this action.

It is of interest to compare the arbitrary assumptions on land area used above to the contamination resulting from the Windscale accident. (NB: This was not a power reactor of the type presently used in the United States). According to Booker, the Windscale accident resulted in milk values exceeding 0.015 μCi/l at about 200 kilometers or 125 miles

downwind (75). Milk contamination was estimated as exceeding *0.01 μCi/l over 16,700* km^2 or 6400 mi^2. Thus, the Windscale accident resulted in contamination exceeding the Preventive PAG over an area about 10 times greater than that assumed above. Protective actions were taken at Windscale at milk concentrations of 0.1 μCi/l (approximately the Emergency PAG) and involved an area of about 520 km^2 or 200 mi^2 for periods of 3-6 weeks.

5.3 COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis is defined as the economy with which a particular task may be carried out.

The data available for this analysis was obtained with the cooperation of the Nuclear Regulatory Commission. Briefly, the NRC employed the models cited in the Reactor Safety Study (7) to evaluate the agricultural costs and cumulative dose commitment that could occur under two accident conditions - a design basis for siting purposes and a PWR 7 accident (7). A typical reactor site in the northeastern United States was envisioned. Unfortunately, the parameters employed are not directly comparable with the pathways and dosimetric parameters associated with the PAG's. Nevertheless, a good indication of the effects of taking a protective action (in this case the condemnation of milk) at specific interdiction levels can be ascertained.

Figure 5 presents the agricultural costs at specific interdiction criteria. The costs are, for the most part, associated with the market value of milk. The interdiction criteria are in terms of rem to an infant thyroid. From Figure 3, it can be seen that costs drop rapidly between 0.5 and 10 rem and more gradually after 20 rem. The ratio of costs for a design basis accident (siting) to a PWR 7 remains constant.

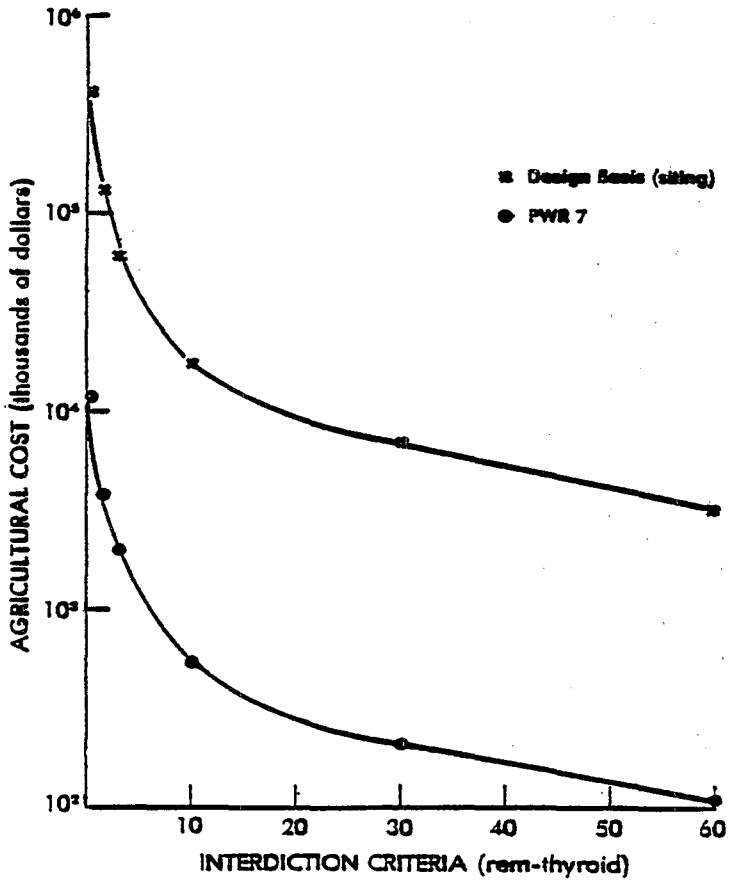


Figure 3. Agricultural cost model accident.

Figure 4 is a graph of the dose commitment for a design basis accident and a PWR 7 assuming protective action is initiated at specific interdiction levels. The dose commitments are accrued via external as well as internal exposure (inhalation and ingestion). Therefore, they do not exactly fit the situation described in the PAG's under consideration. The dose commitment rises rapidly when the interdiction criteria are between 0.5 and 20 rem. The increase in dose commitment for a design basis accident is less rapid than for a PWR 7. Hence, at or above an interdiction criteria of 20 rem, savings in radiation dose are minimal compared to the savings accrued below 10 rem.

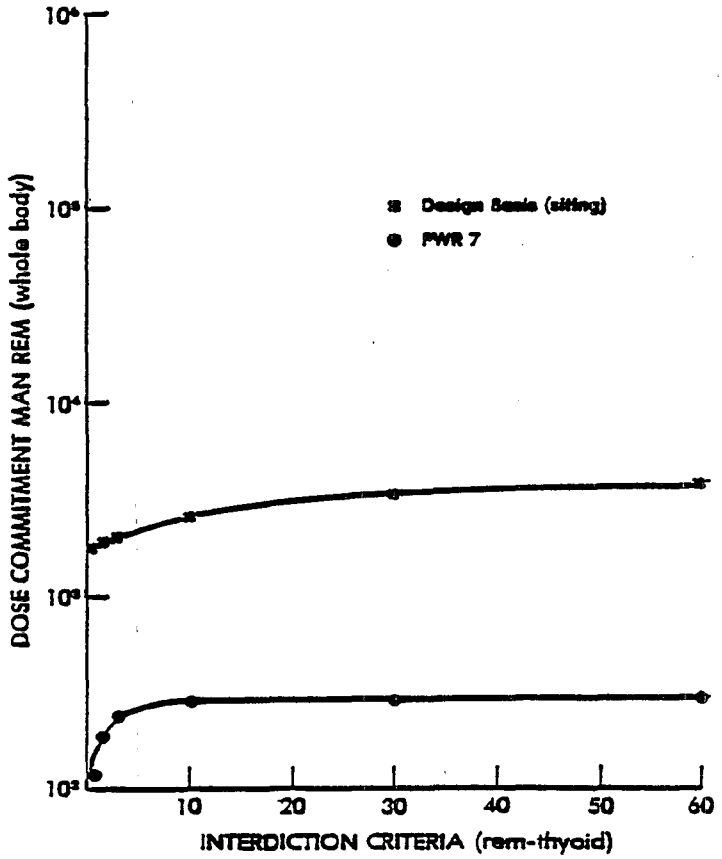


Figure 4. Dose commitment model accident.

5.4 SUMMARY AND CONCLUSION

The milk concentration at which the population benefits (from dose avoided) equals the direct costs of stored feed is equivalent to about one-third of the Preventive PAG for strontium and to one-fiftieth or less for iodine-131 and cesium. If condemnation is based on retail milk value, then the respective concentrations are about one-half and one-fiftieth of the Emergency PAG. Unless the indirect costs of implementing protective actions are significantly greater than the direct costs, it appears feasible to take protective actions at the respective PAG level and to continue such action to avoid about 90 percent of the projected dose for iodine and cesium. In the case of strontium contamination of milk, such action is only cost beneficial until the concentration is about 30 percent of the PAG response level.

Estimated costs of taking protective action within the Emergency Planning Zone (EPZ) for a 22.5° Sector to 50 miles (about 500 mi^2) is $2 million per month for condemnation (farm milk value) and $0.26 million per month for use of stored feed. In the case of

atmospheric dispersed contamination, protective action may have to continue for 2 months near the site.

The recommended approach is to place all cows on stored feed to prevent the contamination of milk at significant levels, to divert iodine contaminated milk to manufactured products that have a long shelf life to allow radioactive decay, and only consider condemnation of milk exceeding the Emergency PAG. It appears that doses to the public can be limited to less than 10 percent of the Preventive PAG (or less then 0.15 rem thyroid) by actions having direct costs of a few milion dollars for a significant accident.

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CHAPTER 7

Implementing the Protective Action Guides for the Intermediate Phase: Exposure to Deposited Materials

7.1 Introduction

This chapter provides guidance for implementing the PAGs set forth in Chapter 4. It is for use by State and local officials in developing their radiological emergency response plans to protect the public from exposure to radiation from deposited radioactive materials. Due to the wide variety in types of nuclear incidents and radionuclide releases that could occur, it is not practical to provide implementing guidance for all situations. The guidance in this chapter applies primarily to radionuclides that would be involved in incidents at nuclear power plants. It may be useful for radionuclides from incidents at other types of nuclear facilities or from incidents not involving fixed facilities (e.g., transportation accidents).However, specific implementation procedures for incidents other than those at nuclear power plants should be developed by planners on a case-by-case basis.

Contrary to the situation during the early phase of a nuclear incident, when decisions usually must be made and implemented quickly by State and local officials before Federal assistance is available, many decisions and actions during the intermediate phase can be delayed until Federal resources are present, as described in the Federal Radiological Monitoring and Assessment Plan (FE-85). Because of the reduced level of urgency for immediate implementation of these protective actions, somewhat less detail may be needed in State radiological emergency response plans than is required for the early phase.

At the time of decisions on relocation and early decontamination, sheltering and evacuation should have already been completed to protect the public from exposure to the airborne plume and from high exposure rates from deposited materials. These protective actions may have been implemented prior to verification of the path of the plume and therefore some persons may have been unnecessarily evacuated from areas where actual doses are much lower than were projected. Others who were in the path of the plume may have been sheltered or not protected at all. During the intermediate phase of the response, persons must be relocated from areas where the projected dose exceeds the PAG for relocation, and other actions taken to reduce doses to persons who are not relocated from contaminated areas. Persons

evacuated from areas outside the relocation zone may return.

7.1.1 Protective Actions

The main protective actions for reducing exposure of the public to deposited radioactivity are relocation, decontami- nation, shielding, time limits on exposure, and control of the spread of surface contamination. Relocation is the most effective, and, usually, the most costly and disruptive. It is therefore only applied when the dose is sufficiently high to warrant it. The others are generally applied to reduce exposure of persons who are not relocated, or who return from evacuation status to areas that received lower levels of deposited radioactivity. This chapter provides guidance for translating radiological conditions in the environment to projected dose, to provide the basis for decisions on the appropriate protective actions.

7.1.2 Areas Involved

Figure 7-1 provides a generalized example of the different areas and population groups to be dealt with. The path of the plume is assumed to be represented by area 1. In reality, variations in meteorological conditions would almost certainly produce a more complicated shape, but the same principles would apply.

Because of plant conditions and other considerations prior to or after the release, persons will already have been evacuated from area 2 and sheltered in area 3. Persons who have been evacuated from or sheltered in areas 2 and 3, respectively, as precautionary actions for protection from the plume, but whose homes are outside the plume deposition area (area 1), may return to their homes as soon as environmental monitoring verifies the boundary of the area that received deposition (area 1).

Area 4 is designated a restricted zone and is defined as the area where projected doses are equal to or greater than the relocation PAG. Persons residing just outside the boundary of the restricted zone may receive a dose near the PAG for relocation if decontamination or other dose reduction efforts are not implemented.

Area 1, with the exception of the restricted zone, represents the area of contamination that may continue to be occupied by the general public. Nevertheless, there will be contamination levels in this area that will require continued monitoring and dose reduction efforts other than relocation.

The relative positions of the boundaries shown in Figure 7-1 depend on areas evacuated and sheltered, and the radiological characteristics of the release. For example, area 4 (the restricted zone) could fall entirely inside area 2 (area evacuated), so that the only persons to be relocated would be those residing in area 4 who were either missed in the evacuation process or who, because of the high risk for their evacuation, had remained sheltered during plume passage.

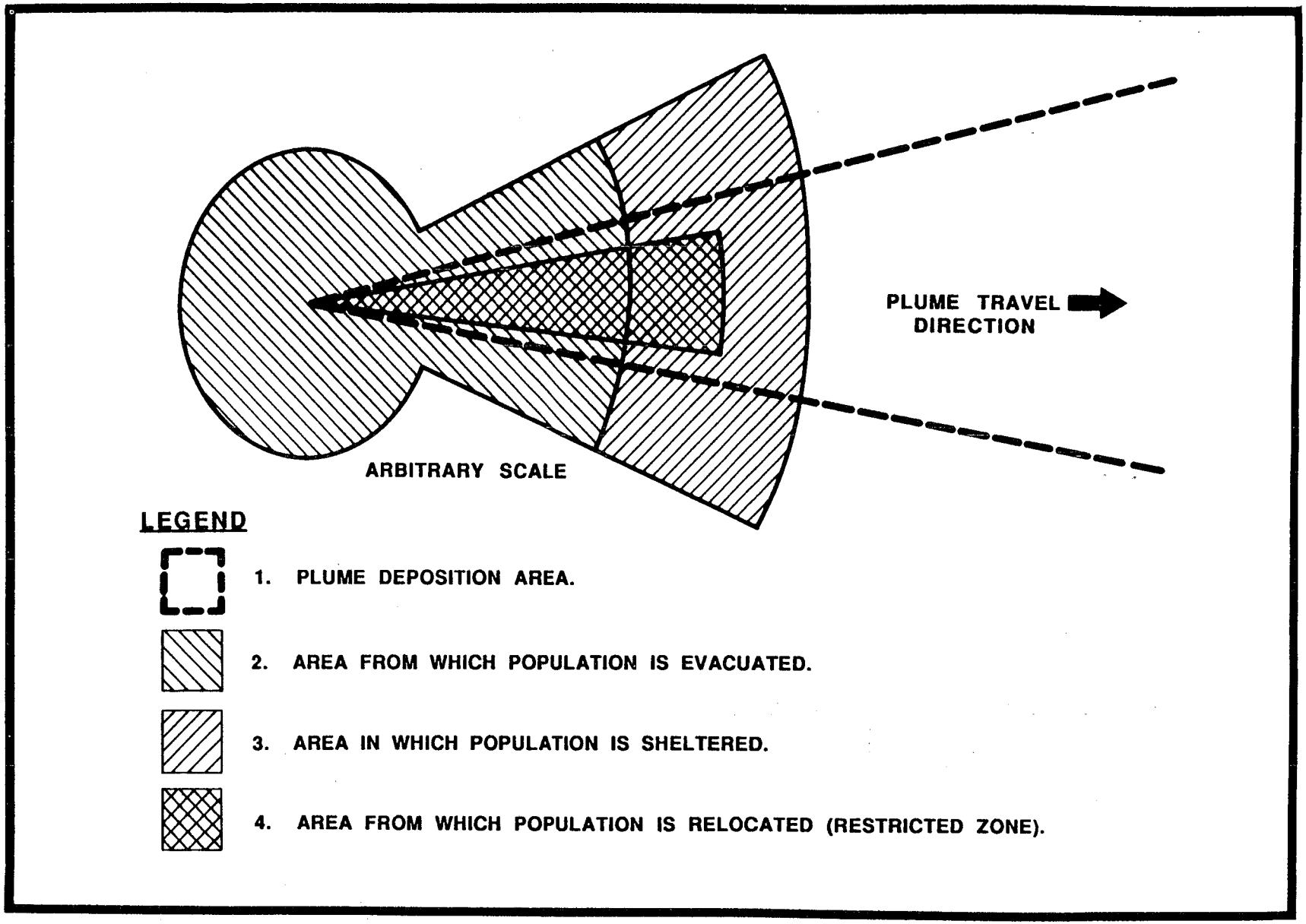

FIGURE 7-1. RESPONSE AREAS.

At the time the restricted zone is established, a temporary buffer zone (not shown in Figure 7-1) may be needed outside portions of the restricted zone in which occupants will not be allowed to return until monitoring confirms the stability of deposited contamination. Such zones would be near highly contaminated areas in the restricted zone where deposited radionuclides might be resuspended and then redeposited outside the restricted zone. This could be especially important at locations close to the incident site where the radioactivity levels are high and the restricted zone may be narrow. The extent of the buffer zone will depend on local conditions. Similarly, a buffer zone encompassing the most highly contaminated areas in which persons are allowed to reside may be needed. This area should be monitored routinely to assure acceptability for continued occupancy.

7.1.3 Sequence of Events

Following passage of the airborne plume, several tasks, as shown in Figure 7-2, must be accomplished simultaneously to provide for timely protection of the public. The decisions on the early task of relocating persons from high exposure rate areas must be based on exposure rate measurements and dose analyses. It is expected that monitoring and dose assessment will be an on-going process, with priority given to the areas with the highest exposure rate. The general sequence of events is itemized below, but the time frames will overlap, as demonstrated in Figure 7-2.

1. Based on environmental data, determine the areas where the projected one-year dose will exceed 2 rem and relocate persons from those areas, with priority given persons in the highest exposure rate areas.

2. Allow persons who were evacuated to return immediately to their residences if they are in areas where field gamma measurements indicate that exposure rates are near normal background levels (not in excess of twice the normal background in the area before the incident). If, however, areas of high deposition are found to be near areas with low deposition such that resuspended activity could drift into the occupied areas, a buffer zone should be established to restrict occupancy until the situation is analyzed and dose projections are confirmed.

3. Determine the location of the isodose line corresponding to the relocation PAG, establish the boundary of the restricted zone, and relocate any persons who still reside within the zone. Also, convert any evacuees who reside within the restricted zone to relocation status. Evacuated persons whose residence is in the area between the boundary of the plume deposition and the boundary to the restricted zone may return gradually as confidence is gained regarding the projected dose in the area.

4. Evaluate the dose reduction effectiveness of simple decontamination

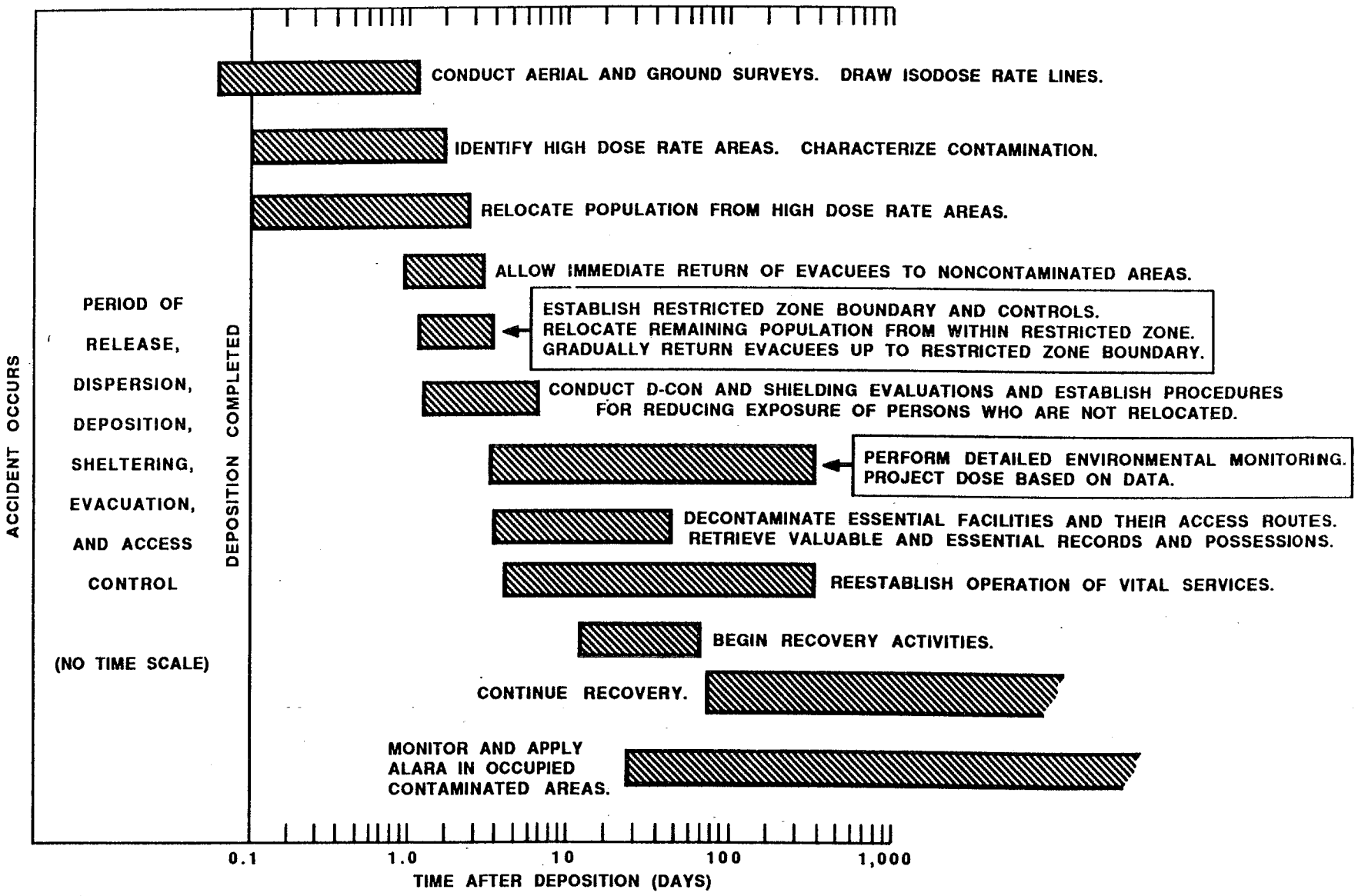

FIGURE 7-2. POTENTIAL TIME FRAME OF RESPONSE TO A NUCLEAR INCIDENT.

techniques and of sheltering due to partial occupancy of residences and workplaces. Results of these evaluations may influence recommendations for reducing exposure rates for persons who are not relocated from areas near, but outside, the restricted zone.

5. Establish a mechanism for controlling access to and egress from the restricted zone. Typically this would be accomplished through control points at roadway accesses to the restricted zone.

6. Establish monitoring and decontamination stations to support control of the restricted zone.

7. Implement simple decontamination techniques in contaminated areas outside the restricted zone, with priorities for areas with higher exposure rates and for residences of pregnant women.

8. Collect data needed to establish long-term radiation protection criteria for recovery and data to determine the effectiveness of various decontamination or other recovery techniques.

9. Begin operations to recover contaminated property in the restricted zone.

7.2 Establishment of Isodose-rate Lines

As soon as Federal or other assistance is available for aerial and ground monitoring, a concentrated effort should begin to establish isodose-rate lines on maps and the identification of boundaries to the restricted zone. Planning for this effort should include the development of standard maps that can be used by all of the involved monitoring and dose assessment organizations to record monitoring data.

Aerial monitoring (e.g., the Department of Energy Aerial Monitoring Service) can be used to collect data for establishing general patterns of radiation exposure rates from deposited radioactive material. These data, after translation to readings at 1 meter above ground, may form the primary basis for the development of isodose lines out to a distance where aerial monitoring shows no radiation above twice natural background levels. Air sample measurements will also be needed to verify the contribution to dose from inhalation of resuspended materials.

Gamma exposure rates measured at 1 meter will no doubt vary as a function of the location of the measurement within a very small area. This could be caused by different deposition rates for different types of surfaces (e.g., smooth surfaces versus heavy vegetation). Rinsing or precipitation could also reduce levels in some areas and raise levels in others where runoff settles. In general, where exposure rates vary within designated areas, the higher values should be used for dose projection for persons within these areas unless judgment can be

used to estimate an appropriate average exposure rate.

Measurements made at 1 meter to project whole body dose from gamma radiation should be made with instruments of the "closed window" type so as to avoid the detection of beta radiation. Although beta exposure will contribute to skin dose, its contribution to the overall risk of health effects from the radionuclides expected to be associated with reactor incidents should not be controlling in comparison to the whole body gamma dose (AR-89). Special beta dose analyses may be appropriate when time permits to determine its contribution to skin dose. Since beta dose rate measurements require sophisticated equipment that is generally not available for field use, beta dose to the skin should be limited based on measured concentrations of radionuclides per unit area.

7.3 Dose Projection

The primary dose of interest for reactor incidents is the sum of the effective gamma dose equivalent from external exposure and the committed effective dose equivalent from inhalation. The exposure periods of interest are first year, second year, and up to 50 years after the incident.

Calculation of the projected gamma dose from measurements will require knowledge of the principal radionuclides contributing to exposure and their relative abundances. Information on these radiological characteristics can be compiled either through the use of portable gamma spectrometers or by radionuclide analysis of environmental samples. Several measurement locations may be required to determine whether any selective radionuclide deposition occurred as a function of weather, surface type, distance from the point of release, or other factors. As part of the Federal Radio- logical Monitoring and Assessment Plan (FE-85), the U. S. Department of Energy and the U. S. Environmental Protection Agency have equipment and procedures to assist State officials in performing environmental measurements, including determination of the radiological characteristics of deposited materials.

The gamma exposure rate may decrease rapidly if deposited material includes a significant fraction of short-lived radionuclides. Therefore, the relationship between instantaneous exposure rate and projected first- and second-year annual or the 50-year doses will change as a function of time, and these relationships must be established for the particular mix of deposited radioactive materials present at the time of the gamma exposure rate measurement.

For incidents involving releases from nuclear power plants, gamma radiation from deposited radioactive materials is expected to be the principal exposure pathway, as noted above. Other pathways should also be evaluated, and their contributions considered, if significant. These may include inhalation of resuspended material and beta dose to the skin.

Exposure from ingestion of food and water is normally limited independently of decisions for relocation and decontamination (see Chapters 3 and 6). In rare instances, however, where withdrawal of food and/or water from use would, in itself, create a health risk, relocation may be an appropriate protective action for protection from exposure via ingestion. In this case, the committed effective dose equivalent from ingestion should be added to the projected dose from other exposure pathways for decisions on relocation.

The following sections provide methods for evaluating the projected dose from whole body external exposure and from inhalation of resuspended particulate material, based on environmental information.

7.3.1 Projected External Gamma Dose

Projected whole body external gamma doses at 1 meter height at particular locations during the first year, second year, and over the 50-year period after the incident are the parameters of interest. The environmental information available for calculating these doses is expected to be the current gamma exposure rate at 1 meter height and the relative abundance of each radionuclide contributing significantly to that exposure rate. Calculational models are available for predicting future exposure rates as a function of time due to radioactive decay and weathering. Weathering is discussed in WASH-1400, Appendix VI (NR-75), and information on the relationship between surface concentrations and gamma exposure rate at 1 meter is addressed in reference (DO-88).

Following the incident, experiments should be conducted to determine the dose reduction factors associated with part-time occupancy of dwellings and workplaces, and with simple, rapid, decontamination techniques, so that these factors can also be applied to the calculation of dose to persons who are not relocated. However, these factors should not be included in the calculation of projected dose for decisions on relocation.

Relocation decisions can generally be made on the basis of the first year projected dose. However, projected doses during the second year and over 50 years are needed for decisions on the need for other protective actions for persons who are not relocated. Dose conversion factors are therefore needed for converting environmental measurements to projected dose during the first year, second year, and over 50 years following the incident. Of the two types of environmental measurements that can be made to project whole body external gamma dose, gamma exposure rate in air is the easiest to make and is the most directly linked to gamma dose rate. However, a few measurements of the second type (radionuclide concentrations on surfaces) will also be needed to properly project decreasing dose rates.

Tables 7-1 and 7-2 provide information to simplify development

Table 7-1 Gamma Exposure Rate and Effective Dose Equivalent (Corrected for Radioactive Decay and Weathering) due to an Initial Uniform Concentration of 1 pCi/m^2 on Ground Surface

Radionuclide	Half-life (hours)	Initial exposure[a] rate at 1 m (mR/h per pCi/m^2)	Integrated dose (weathering factor included)[b]		
			year one (mrem per pCi/m^2)	year two (mrem per pCi/m^2)	0-50 years (mrem per pCi/m^2)
Zr-95	1.54E+03	1.2E-08	3.3E-05	4.0E-07	3.4E-05
Nb-95	8.41E+02	1.3E-08	(b)	(b)	(b)
Ru-103	9.44E+02	8.2E-09	7.1E-06	0	7.1E-06
Ru-106	8.84E+03	3.4E-09	1.2E-05	3.7E-06	1.8E-05
Te-132	7.82E+01	4.0E-09	3.2E-06	0	3.2E-06
I-131	1.93E+02	6.6E-09	1.3E-06	0	1.3E-06
I-132	2.30E+00	3.7E-08	(b)	(b)	(b)
I-133	2.08E+01	1.0E-08	2.1E-07	0	2.1E-07
I-135	6.61E+00	2.4E-08	1.6E-07	0	1.6E-07
Cs-134	1.81E+04	2.6E-08	1.0E-04	4.7E-05	2.4E-04
Cs-137	2.65E+05	1.0E-08	4.5E-05	2.9E-05	6.1E-04
Ba-140	3.07E+02	3.2E-09	1.1E-05	0	1.1E-05
La-140	4.02E+01	3.5E-08	(b)	(b)	(b)

[a]Estimated exposure rate at 1 meter above contaminated ground surface. Based on data from reference (DO-88).

[b]Radionuclides that have short-lived daughters (Zr/Nb-95, Te/I-132, Ru/Rh-106, Cs-137/Ba-137m, Ba/La-140) are assumed to quickly reach equilibrium. The integrated dose factors listed are the effective gamma dose due to the parent and the daughter. Based on data from reference (DO-88).

Table 7-2 Exposure Rate and Effective Dose Equivalent (Corrected for Radioactive Decay) due to an Initial Concentration of 1 pCi/m^2 on Ground Surface

Radionuclide	Half-life (hours)	Initial exposure[a] rate at 1 m (mR/h per pCi/m^2)	Integrated dose (weathering factor not included)[b]		
			year one (mrem per pCi/m^2)	year two (mrem per pCi/m^2)	0-50 years (mrem per pCi/m^2)
Zr-95	1.54E+03	1.2E-08	3.8E-05	8.0E-07	3.9E-05
Nb-95	8.41E+02	1.3E-08	(b)	(b)	(b)
Ru-103	9.44E+02	8.2E-09	7.8E-06	0	7.8E-06
Ru-106	8.84E+03	3.4E-09	1.5E-05	7.6E-06	3.0E-05
Te-132	7.82E+01	4.0E-09	3.3E-06	0	3.3E-06
I-131	1.93E+02	6.6E-09	1.3E-06	0	1.3E-06
I-132	2.30E+00	3.7E-08	(b)	(b)	(b)
I-133	2.08E+01	1.0E-08	2.1E-07	0	2.1E-07
I-135	6.61E+00	2.4E-08	1.6E-07	0	1.6E-07
Cs-134	1.81E+04	2.6E-08	1.3E-04	9.6E-05	4.7E-04
Cs-137	2.65E+05	1.0E-08	6.0E-05	5.9E-05	1.8E-03
Ba-140	3.07E+02	3.2E-09	1.2E-05	0	1.2E-05
La-140	4.02E+01	3.5E-08	(b)	(b)	(b)

[a]Estimated exposure rate at 1 meter above contaminated ground surface. Based on data from reference (DO-88).

[b]Radionuclides that have short-lived daughters (Zr/Nb-95, Ru/Rh-106, Te/I-132, Cs-137/Ba-137m, Ba/La-140) are assumed to quickly reach equilibrium. The integrated dose factors listed are the effective gamma dose due to the parent and the daughter. Based on data from reference (DO-88).

of dose conversion factors through the use of data on the radionuclide mix, as determined from environmental measurements. These tables list the deposited radionuclides most likely to be the major contributors to dose from incidents at nuclear power facilities. In addition to providing integrated, effective doses per unit of surface concentration, they provide, in column three, the exposure rate (mR/h) in air per unit of surface contamination. All exposure rate values are based on those given in reference (DO-88). They were estimated from the total body photon dose rate conversion factors for exposure at 1 m above the ground surface. Since the ratio of effective dose to air exposure is about 0.7, dividing the effective dose rate by 0.7 results in an estimate of the exposure rate in air. The integrated effective doses are based on dose conversion factors also listed in reference (DO-88). Table 7-1 takes into account both radioactive decay and weathering, whereas the values in Table 7-2 include only radioactive decay. The effect of weathering is uncertain and will vary depending on the type of weather, type of surface, and the chemical form of the radionuclides. The user may choose either table depending on the confidence accorded the assumed weathering factors.

The following steps can be used to develop dose conversion factors to calculate projected future doses from gamma exposure rate measurements for specific mixes of radionuclides:

1. Using spectral analysis of gamma emissions from an environmental sample of deposited radioactivity, determine the relative abundance of the principal gamma emitting radionuclides. Analyses of uniform samples from several different locations may be necessary to determine whether the relative concentrations of radionuclides are constant. The results may be expressed as the activity (pCi) of each radionuclide in the sample.

2. Multiply each activity from step 1 by the corresponding values in column 3 of Table 7-1 or Table 7-2 (depending on whether or not weathering is to be considered) to determine the relative contribution to the gamma exposure rate (mR/h) at 1-meter height for each radionuclide. Sum the results for each sample.

3. Similarly, multiply each activity from step 1 by the corresponding values in columns 4, 5, and 6 to determine the 1st-year, 2nd-year, and 50-year relative integrated doses contributed by each radionuclide. Sum these results for each sample. Radionuclides listed in Tables 7-1 and 7-2 that have short-lived daughters (Zr/Nb-95, Te/I-132, Ru/Rh-106, Cs-137/Ba-137m, Ba/La-140) were assumed to be in equilibrium with their daughters when the tabulated values for integrated dose were calculated. Since the values for the parents include the total dose from the parent and the daughter, do not double count these daughters in the sum. (In the cases of Cs-137/Ba-137m, and Ru-106/Rh-106, the parents are not gamma emitters, so the listed exposure rates and doses are actually those from the daughters alone.)

4. Using the results from steps 2 and 3, the relevant dose conversion factors, *DCF*, for each sample are then given by:

$$DCF = \frac{\sum_{1}^{n} H_i}{\sum_{1}^{n} X_i}$$

where H_i = effective dose equivalent for radionuclide i (mrem),
X_i = gamma exposure rate for radionuclide i (mR/h)
n = the number of radionuclides in the sample.

Since the samples represented in the numerator and denominator are identical, the effect of the size of the sample cancels.

These dose conversion factors may be applied to any measured gamma exposure rate for which the relative concentrations of radionuclides are the same as those in the sample that was analyzed.

The following example demonstrates the use of the above procedures for calculating a DCF. For purposes of the example it is assumed that environmental measurements revealed a mix of radionuclides as shown in column 3 of Table 7-3. The (relative) exposure rate conversion factors in column 4 of Table 7-3 are taken from column 3 of Table 7-1. The (relative) exposure rates in column 5 are the products of columns 3 and 4. The (relative) doses for individual radionuclides in columns 6, 7, and 8 were calculated by multiplying the concentrations in column 3 by the dose conversion factors in columns 4, 5, and 6 of Table 7-1, respectively. (Columns 4, 5, and 6 of Table 7-2, which do not include weathering, could have been used instead of those in Table 7-1.)

For this example, the conversion factor for dose in the first year was obtained for the assumed radionuclide mix from the totals of columns 5 and 6 of Table 7-3, which indicate that a calculated dose of 0.023 mrem in the first year corresponds to an initial exposure rate of 1.5E-4 mR/h. Therefore, the first year dose conversion factor (DCF_1) for this example is 150 mrem for each mR/h measured at the beginning of the period.

This DCF may be multiplied by any gamma exposure rate measurement to estimate the dose in the first year for locations where the exposure rate is produced by a radionuclide mix the same as assumed for calculating the DCF, and where weathering affects the exposure rate in the same manner as assumed. For example, if a gamma exposure rate measurement were taken at the location where the contamination sample in Table 7-3 was taken, this exposure rate could be multiplied by the DCF calculated in the above example to obtain the projected first year dose at that point. Based on the example analysis and a relocation PAG of 2 rem, for this case the exposure rate at the boundary of the restricted zone should be no greater than

Table 7-3 Example[a] Calculation of Dose Conversion Factors for Gamma Exposure Rate Measurements Based on Measured Isotopic Concentrations[b]

Radionuclide	Half-life (hours)	Measured concentration (pCi/sample[d])	$\frac{mR/h^2}{pCi/m^2}$	Calculated Exposure rate at 1 m (mR/hr)	Calculated effective dose at 1 meter		
					year one (mrem)	year two (mrem)	50 years (mrem)
I-131	1.93E+2	2.6E+2	6.6E-9	1.7E-6	3.3E-4	0	3.3E-4
Te-132	7.8E+1	3.6E+3	4.0E-9	1.4E-5	1.2E-2	0	1.2E-2
I-132	2.3	3.6E+3	3.7E-8	1.3E-4	(e)	(e)	(e)
Ru-103	9.44E+2	2.2E+2	8.2E-9	1.8E-6	1.6E-3	0	1.6E-3
Rh-106[f]	8.84E+3	5.0E+1	3.4E-9	1.7E-7	5.8E-4	1.9E-4	9.2E-4
Cs-134	1.81E+4	6.8E+1	2.6E-8	1.8E-6	6.9E-3	3.2E-3	1.6E-2
Ba-137m[f]	2.65E+5	4.2E+1	1.0E-8	4.2E-7	1.9E-3	1.2E-3	2.6E-2
Totals				1.5E-4	2.3E-2	4.6E-3	5.6E-2

[a]The data in this table are only examples to demonstrate a calculational process. The results should not be used in the prediction of relationships that would exist following a nuclear incident.

[b]Calculations are based on data in Table 7-1, which includes consideration of both radioactive decay and weathering.

[c]External exposure rate factors at 1 meter above ground for a person standing on contaminated ground, based on data in Table 7-1.

[d]The size of the sample is not important for this analysis because only the relative concentrations are needed to calculate the ratio of integrated dose to exposure rate.

[e]The integrated dose from I-132 is not calculated separately because it is the short-lived daughter of Te-132, and is assumed to be in equilibrium with it. The assumed quantity present is that for a daughter in equilibrium with the parent.

[f]This is a short lived daughter of a parent that has no gamma emissions and the halflife given is that of the parent.

$$\frac{2000\ mrem}{150\ mrem/mR/h} = 13\ mR/h,$$

if the contribution to effective dose from inhalation of resuspended radioactive materials is zero (See Section 7.3.2). The example DCF for the second year and 50 years are obtained by a similar process, yielding DCFs of 31 and 370 mrem per mR/h, respectively.

The ratio of the second year to first year dose is 31/150 = 0.21. If this is the case, persons not relocated on the basis of a 2 rem PAG should, for this example, receive no more than 0.21 x 2 = 0.4 rem in year 2. Similarly, the dose in fifty years should be no more than 4.9 rem. Actual doses should be less than these values to the extent that exposure rates are reduced by shielding from structures and by decontamination.

Prior to reaching conclusions regarding the gamma exposure rate that would correspond to the relocation PAG, one would need to verify by multiple sampling the consistency of the relative abundance of specific radionuclides as well as the relative importance of the inhalation pathway.

Dose conversion factors will change as a function of the radiological makeup of the deposited material. Therefore, dose conversion factors must be calculated based on the best current information following the incident. Since the relative concentrations will change as a function of time due to different decay rates, dose conversion factors must be calculated for specific measurement times of interest. By calculating the decay of the original sample(s), a plot of dose conversion factors (mrem per mR/h) as a function of time after the incident can be developed. As weathering changes the radionuclide mix, and as more is learned about other dose reduction mechanisms, such predictions of dose conversion factors may require adjustment.

7.3.2 Inhalation Dose Projection

It can be shown, for the mixture of radionuclides assumed to be deposited from postulated reactor incidents, and an assumed average resuspension factor of 10^{-6} m^{-1}, that the effective dose from inhalation is small compared to the corresponding effective dose from external exposure to gamma radiation. However, air sample analyses should be performed for specific situations (e.g., areas of average and high dynamic activity) to determine the magnitude of possible inhalation exposure. The 50-year committed effective dose equivalent (H_{50}) resulting from the inhalation of resuspended airborne radioactive materials is calculated as follows:

$$H_{50} = I \times DCF \qquad (1)$$

where

I = total intake (μCi), and
DCF = committed effective dose equivalent per unit intake (rem/μCi).

It is assumed that the intake rate will decrease with time due to

radioactive decay and weathering. No model is available to calculate the effect of weathering on resuspension of deposited materials, so the model developed for calculating its effect on gamma exposure rate (NR-75) is assumed to be valid. This should provide conservative results. The total intake (I) from inhalation over time t may be calculated for each radionuclide, using the following equation:

$$I = BC_0 \left[\frac{0.63}{\lambda_1+\lambda_2} \left(1-e^{-(\lambda_1+\lambda_2)t}\right) + \frac{0.37}{\lambda_1+\lambda_3} \left(1-e^{-(\lambda_1+\lambda_3)t}\right) \right] \quad (2)$$

where

B = average breathing rate for adults
= 1.05E+4 m^3/a (EP-88),

C_o = initial measured concentration of the resuspended radionuclide in air (pCi/m^3),

t = time during which radionuclides are inhaled (a),

λ_1 = radioactive decay constant (a^{-1}),

λ_2 = assumed weathering decay constant for 63 percent of the deposited activity, taken as 1.13 a^{-1} (NR-75), and

λ_3 = assumed weathering decay constant for 37 percent of the deposited activity, taken as 7.48 E-3 a^{-1} (NR-75).

Table 7-4 tabulates results calculated using the above assumptions for weathering. The table contains factors relating the committed effective dose from exposure during the first and second years after the incident to an initial air concentration of 1 pCi/m^3 for each of the principal radionuclides expected to be of concern from reactor incidents. The dose conversion factors are taken from FGR-11 (EP-88). Parent radionuclides and their short lived daughters are grouped together because these dose conversion factors are based on the assumption that both parents and daughters will occur in equal concentrations and will decay with the half life of the parent. Therefore, measured concentrations of the short lived daughters should be ignored and only the parent concentrations should be used in calculating long term projected doses.

Table 7-4 lists factors which include the effects of both weathering and radioactive decay, as well as those that include only the effects of radioactive decay. Users of these data should decide which factors to use based on their confidence on the applicability of the weathering models used (NR-75) to their environment.

The committed effective dose equivalent is calculated by multiplying the measured initial air concentration (pCi/m^3) for each radionuclide of concern by the appropriate factor from the table and summing the results. This sum may then be added to the corresponding external whole body gamma dose to yield the total com-

Table 7-4 Dose Conversion Factors for Inhalation of Resuspended Material[a]

		Committed effective dose equivalent per unit air concentration at the beginning of year one (mrem per pCi/m^3)			
		Considering radioactive decay and weathering		Considering radioactive decay only	
Radionuclide[b]	Lung class[c]	Year one	Year two	Year one	Year two
Sr-90/Y-90	Y/Y	1.0E+1	5.5E 0	1.4E+1	1.3E+1
Zr-95/Nb-95	Y/Y	6.5E-2	-	7.9E-2	-
Ru-103	Y	1.3E-2	-	1.5E-2	-
Ru-106/Rh-106	Y/D	2.8E 0	1.0E 0	3.7E 0	1.9E 0
Te-132/I-132	W/D	1.3E-3	-	1.3E-3	-
I-131	D	1.1E-2	-	1.1E-2	-
Cs-134	D	3.1E-1	1.5E-1	4.1E-1	3.0E-1
Cs-137/Ba-137^m	D/D	2.5E-1	1.4E-1	3.3E-1	3.2E-1
Ba-140/La-140	D/W	4.4E-3	-	4.7E-3	-
Ce-144/Pr-144	Y/Y	2.0E 0	4.2E-1	2.7E 0	9.8E-1

[a]Calculated using the dose factors in EP-88, Table 2.1.

[b]Short lived daughters are not listed separately because the entries include the dose from both the daughter and the parent. These factors are based on the concentration of the parent only, at the beginning of the exposure period.

[c]The lung clearance class chosen is that which results in the highest dose conversion factor.

mitted effective dose equivalent from these two pathways.

The PAGs include a guide for dose to skin which is 50 times the magnitude of the PAG for effective dose. Analysis (AR-89) indicates that this guide is not likely to be controlling for radionuclide mixes expected to be associated with nuclear power plant incidents. Dose conversion factors are provided in Table 7-5 for use in case of incidents where the source term consists primarily of pure beta emitters. The skin dose from each radionuclide may be calculated by multiplying the measured concentration (pCi/m^2) by the corresponding dose conversion factor in the table. This will yield the first year beta dose to the skin at one meter height from exposure to deposited materials plus the estimated dose to the skin from materials deposited on the skin as a result of being in the contaminated area. These factors are calculated based on information in Reference AR-89, which used weathering factors that apply for gamma radiation and would, therefore, be conservative for application to beta radiation. Calculated doses based on these factors should be higher than the doses that would be received.

7.4 Priorities

In most cases protective actions during the intermediate phase will be carried out over a period of many days. It is therefore useful to consider what priorities are appropriate. Further, for situations where the affected area is so large that it is impractical to relocate all of the public, especially from areas exceeding the PAGs by only a small amount, priorities are needed for protective actions. The following priorities are appropriate:

1. As a first priority, assure that all persons are protected from doses that could cause acute health effects from all exposure pathways, including previous exposure to the plume.

2. Recommend the application of simple decontamination techniques and that persons remain indoors as much as possible to reduce exposure rates.

3. Establish priorities for relocation with emphasis on high exposure rate areas and pregnant women (especially those in the 8th to 15th week of pregnancy).

7.5 Reentry

After the restricted zone is established, persons will need to reenter for a variety of reasons, including recovery activities, retrieval of property, security patrol, operation of vital services, and, in some cases, care and feeding of farm and other animals. It may be possible to quickly decontaminate access ways to vital institutions and businesses in certain areas so that they can be occupied by adults either for living (e.g., institutions such as nursing homes, and hospitals) or for employment. Clearance of these areas for such occupancy will require dose reduction to comply with occupational exposure

Table 7-5 Skin Beta Dose Conversion Factors for Deposited Radionuclides[a]

Radionuclide	Dose conversion factor[b] (mrem per pCi/m^2)	
	Radioactive decay plus weathering	Radioactive decay only
Co-58	1.2E-7	1.4E-7
Co-60	4.2E-7	5.6E-7
Rb-86	6.3E-5	6.7E-5
Sr-89	1.5E-4	1.6E-4
Sr-90	1.2E-5	1.7E-5
Y-90	2.2E-4	2.9E-4
Y-91	1.6E-4	1.9E-4
Zr-95	7.2E-7	8.3E-7
Nb-95	6.1E-7	7.4E-7
Mo-99	4.4E-6	4.6E-6
Tc-99m	7.7E-9	7.7E-9
Ru-103	6.8E-7	7.8E-7
Ru-106[c]	6.4E-7	8.7E-7
Rh-105	6.5E-8	6.6E-8
Sb-127	3.4E-6	3.4E-6
Te-127	1.0E-6	1.0E-6
Te-127m	7.8E-7	9.5E-7
Te-129	5.0E-7	5.0E-7
Te-129m	3.4E-5	3.6E-5
Te-131m	2.9E-7	2.9E-7
Te-132	5.4E-9	5.4E-9
I-131	8.5E-7	8.7E-7
I-132	5.0E-5	5.0E-5
Cs-134	2.6E-5	3.3E-5
Cs-136[c]	1.4E-7	3.7E-7
Cs-137[c]	2.1E-5	2.9E-5
Ba-140	9.1E-6	9.6E-6
La-140	1.2E-5	1.3E-5
Ce-141	6.6E-7	7.1E-7

Table 7-5, Continued

Radionuclide	Dose conversion factors[b] (mrem per pCi/m^2)	
	Radioactive decay plus weathering	Radioactive decay only
Ce-143	2.3E-6	2.3E-6
Ce-144[c]	8.7E-7	1.1E-6
Pr-143	1.3E-5	1.4E-5
Nd-147	4.3E-6	4.5E-6
Np-239	3.4E-8	3.4E-8
Am-241	4.6E-8	6.4E-8

[a]Based on data from reference AR-89.

[b]Dose equivalent integrated for a one-year exposure at one meter height plus the estimated dose to the skin from materials deposited on the skin as a result of being in the contaminated area.

[c]Contributions from short-lived (one hour or less) decay products are included in dose factors for the parent radionuclides (i.e., Rh-106, Ba-136, Ba-137, and Pr-144).

limits (EP-87). Dose projections for individuals should take into account the maximum expected duration of exposure.

Persons working in areas inside the restricted zone should operate under the controlled conditions normally established for occupational exposure (EP-87).

7.6 Surface Contamination Control

Areas under the plume can be expected to contain deposited radioactive materials if aerosols or particulate materials were released during the incident. In extreme cases, individuals and equipment may be highly contaminated, and screening stations will be required for emergency monitoring and decontamination of individuals and to evaluate the need for medical evaluation. Equipment should be checked at this point and decontaminated as necessary to avoid the spread of contamination to other locations. This screening service would be required for only a few days following plume passage until all such

persons have been evacuated or relocated.

After the restricted zone is established, based on the PAGs for relocation, adults may reenter the restricted zone under controlled conditions in accordance with occupational exposure standards. Monitoring stations will be required along roadways to control surface contamination at exits from the restricted zone. Because of the possibly high background radiation levels at control points near exits, significant levels of surface contamination on persons and equipment may be undetectable at these locations. Therefore, additional monitoring and decontamination stations may be needed at nearby low background locations. Decontamination and other measures should be implemented to maintain low exposure rates at monitoring stations.

7.6.1 Considerations and Constraints

Surface contamination limits to control routine operations at nuclear facilities and to transport radioactive material are generally set at levels lower than are practical for situations involving high-level, widespread contamination of the environment.

The principal exposure pathways for loose surface contamination on persons, clothing, and equipment are (a) internal doses from ingestion by direct transfer, (b) internal doses from inhalation of resuspended materials, (c) beta dose to skin from contaminated skin or clothing or from nearby surfaces, and (d) dose to the whole body from external gamma radiation.

Because of the difficulties in predicting the destiny of uncontrolled surface contamination, a contaminated individual or item should not be released to an unrestricted area unless contamination levels are low enough that they produce only a small increment of risk to health (e.g., less than 20 percent), compared to the risk to health from the principle exposure pathway (e.g., whole body gamma dose) in areas immediately outside the restricted zone. On the other hand, a level of contamination comparable to that existing on surfaces immediately outside the restricted zone may be acceptable on materials leaving the restricted zone. Otherwise, persons and equipment occupying areas immediately outside the restricted zone would not meet the surface contamination limits. These two constraints are used to set permissible surface contamination limits.

The contamination limit should also be influenced by the potential for the contamination to be ingested, inhaled, or transferred to other locations. Therefore, it is reasonable to establish lower limits for surfaces where contamination is loose than for surfaces where the contamination is fixed except for skin. The expected period of fixed contamination on skin would be longer so a lower limit would be justified.

For routine (nonincident) situations, measurement of gross

beta-gamma surface contamination levels is commonly performed with a thin-window geiger counter (such as a CDV-700). Since beta-gamma measurements made with such field instruments cannot be interpreted in terms of dose or exposure rate, the guidance set forth below is related to the background radiation level in the area where the measurement is being made. Supplementary levels are provided for gamma exposure rates measured with the beta shield closed. Guidance levels expressed in this form should be easily detectable and should satisfy the above considerations. Corresponding or lower levels expressed in units related to instrument designations may be adopted for convenience or for ALARA determinations. Smears may also be used to detect loose surface contamination at very low levels. However, they are not considered necessary for emergency response and, therefore, such guidance is not provided.

7.6.2 Numerical Relationships

As discussed in Section 7.3.1, a relationship can be established between projected first year doses and instantaneous gamma exposure rates from properly characterized surface contamination. Based on assumed radiological characteristics of releases from fuel melt accidents, gamma exposure rates in areas where the projected dose is equal to the relocation PAG of 2 rem in the first year may be in the range of 2 to 5 mR/h during the first few days following the deposition from a type SST-2 accident (See Section E.1.2). (This relationship must be determined for each specific release mixture.) Based on relationships in reference (DO-88) and a mixture of radionuclides expected to be typical of an SST-2 type accident, surface contamination levels of $2x10^8$ pCi/m^2 would correspond approximately to a gamma exposure rate of 1 mR/h at 1 meter height.

7.6.3 Recommended Surface Contamination Limits

Surface contamination must be controlled both before and after relocation PAGs are implemented. Therefore, this section deals with the control of surface contamination on persons and equipment being protected during both the early and intermediate phases of a nuclear incident.

For emergency situations, the following general guidance regarding surface contamination is recommended:

1. Do not delay urgent medical care for decontamination efforts or for time-consuming protection of attendants.

2. Do not waste effort trying to contain contaminated wash water.

3. Do not allow monitoring and decontamination to delay evacuation from high or potentially high exposure rate areas.

4. (Optional provision, for use only if a major contaminating event occurs, and rapid early screening is needed.)

After plume passage, it may be necessary to establish emergency contamination screening stations in areas not qualifying as low background areas. Such areas should be less than 5 mR/h gamma exposure rate. These screening stations should be used only during the early phase and for major releases of particulate materials to the atmosphere to monitor persons emerging from possible high exposure areas, provide simple (rapid) decontamination if needed, and make decisions on whether to send them for special care or to a monitoring and decontamination station in a lower background area. Table 7-6 provides guidance on surface contamination levels for use if such centers are needed.

5. Establish monitoring and personnel decontamination (bathing) facilities at evacuation centers or other locations in low background areas (less than 0.1 mR/h). Encourage evacuated persons who were exposed in areas where inhalation of particulate materials would have warranted evacuation to bathe, change clothes, wash clothes, and wash other exposed surfaces such as cars and trucks and their contents and then report to these centers for monitoring. Table 7-7 provides surface contamination guidance for use at these centers. These screening levels are examples derived primarily on the basis of easily measurable concentrations using portable instruments.

6. After the restricted zone is established, set up monitoring and decontamination stations at exits from the restricted zone. Because of the probably high background radiation levels at these locations, low levels of contamination may be undetectable. If contamination levels are undetectable, then they probably do not exceed those in some unrestricted areas occupied by the exposed population and no decontamination is required. Nevertheless, these individuals should be advised to bathe and change clothes at their first opportunity and certainly within the next 24 hours. If, after decontamination at the boundary of the restricted zone station, persons still exceed the limits for this station, they should be sent for further decontamination or for medical or other special attention. As an alternative to decontamination, contaminated items other than persons or animals may be retained in the restricted zone for radioactive decay.

7. Establish auxiliary monitoring and decontamination stations in low background areas (background less than 0.1 mR/h). These stations should be used to achieve ALARA surface contamination levels. Table 7-7 provides surface contamination screening levels for use at those stations.

Table 7-6 Recommended Surface Contamination Screening Levels for Emergency Screening of Persons and Other Surfaces at Screening or Monitoring Stations in High Background Radiation Areas (0.1 mR/h to 5 mR/h Gamma Exposure)[a]

Condition	Geiger-counter shielded-window reading	Recommended action
Before decontamination	<2X bkgd and <0.5 mR/h above background	Unconditional release
	>2X bkgd or >0.5 mR/h above background	Decontaminate Equipment may be stored or disposed of as appropriate.
After decontamination	<2X bkgd and <0.5 mR/h above background	Unconditional release
	>2X bkgd or >0.5 mR/h above background	Continue to decontaminate or refer to low background monitoring and d-con station. Equipment may also be stored for decay or disposed of as appropriate.

[a]Monitoring stations in such high exposure rate areas are for use only during the early phase of an incident involving major atmospheric releases of particulates. Otherwise use Table 7-7.

Table 7-7 Recommended Surface Contamination Screening Levels for Persons and Other Surfaces at Monitoring Stations in Low Background Radiation Areas (<0.1 mR/h Gamma Exposure Rate)

Condition	Geiger-counter thin window[a] reading	Recommended action
Before decontamination	<2X bkgd	Unconditional release
	>2X bkgd	Decontaminate
After simple[b] decontamination effort	<2X bkgd	Unconditional release
	>2X bkgd	Full decontamination
After full[c] decontamination effort	<2X bkgd	Unconditional release
	>2X bkgd	Continue to decontaminate persons
	<0.5 mR/h[d]	Release animals and equipment
After additional full decontamination effort	<2X bkgd	Unconditional full release
	>2X bkgd	Send persons for special evaluation
	<0.5 mR/h[d]	Release animals and equipment
	>0.5 mR/h[d]	Refer, or use informed judgment on further control of animals and equipment

[a]Window thickness of approximately 30 mg/cm^2 is acceptable. Recommended limits for open window readings are expressed as twice the existing background (including background) in the area where measurements are being made. Corresponding levels, expressed in units related to instrument designations, may be adopted for convenience. Levels higher than twice background

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(footnote continued)

(not to exceed the meter reading corresponding to 0.1 mR/h) may be used to speed the monitoring of evacuees in very low background areas.

[b] Flushing with water and wiping is an example of a simple decontamination effort.

[c] Washing or scrubbing with soap or solvent followed by flushing is an example of a full decontamination effort.

[d] Closed shield reading including background.

CHAPTER 8

Radiation Protection Guides for the Late Phase (Recovery)

(Reserved)

APPENDIX A

Glossary

APPENDIX A

Glossary

The following definitions apply specifically to terms used in this manual.

Acute health effects: Prompt radiation effects (those that would be observable within a short period of time) for which the severity of the effect varies with the dose, and for which a practical threshold exist.

Ablation: The functional destruction of an organ through surgery or exposure to large doses of radiation.

Buffer zone: An expanded portion of the restricted zone selected for temporary radiation protection controls until the stability of radioactivity levels in the area is confirmed.

Cloudshine: Gamma radiation from radioactive materials in an airborne plume.

Committed dose: The radiation dose due to radionuclides in the body over a 50-year period following their inhalation or ingestion.

Delayed health effects: Radiation effects which are manifested long after the relevant exposure. The vast majority are stochastic, that is, the severity is independent of dose and the probability is assumed to be proportional to the dose, without threshold.

Derived response level (DRL): A level of radioactivity in an environmental medium that would be expected to produce a dose equal to its corresponding Protective Action Guide.

Dose conversion factor: Any factor that is used to change an environmental measurement to dose in the units of concern.

Dose equivalent: The product of the absorbed dose in rad, a quality factor related to the biological effectiveness of the radiation involved and any other modifying factors.

Effective dose equivalent: The sum of the products of the dose equivalent to each organ and a weighting factor, where the weighting factor is the ratio of the risk of mortality from delayed health effects arising from irradiation of a particular organ or tissue to the total risk of mortality from delayed health effects when the whole body is irradiated uniformly to the same dose.

Evacuation: The urgent removal of people from an area to avoid or reduce high-level, short-term exposure, usually from the plume or from deposited activity. Evacuation may be a

preemptive action taken in response to a facility condition rather than an actual release.

Genetic effect: An effect in a descendant resulting from the modification of genetic material in a parent.

Groundshine: Gamma radiation from radioactive materials deposited on the ground.

Incident phase: This guidance distinguishes three phases of an incident (or accident): (a) early phase, (b) intermediate phase, and (c) late phase.

(a) Early phase: The period at the beginning of a nuclear incident when immediate decisions for effective use of protective actions are required, and must be based primarily on predictions of radiological conditions in the environment. This phase may last from hours to days. For the purpose of dose projection, it is assumed to last for four days.

(b) Intermediate phase: The period beginning after the incident 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 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.

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

Linear Energy Transfer (LET): A measure of the ability of biological material to absorb ionizing radiation; specifically, for charged particles traversing a medium, the energy lost per unit length of path as a result of those collisions with elections in which the energy loss is less than a specified maximum value. A similar quantity may be defined for photons.

Nuclear incident: An event or 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.

Prodromal effects: The forewarning symptoms of more serious health effects.

Projected dose: Future dose calculated for a specified time period on the basis of estimated or measured initial concentrations of radionuclides or exposure rates and in the absence of protective actions.

Protective action: An activity conducted in response to an incident or potential incident to avoid or reduce radiation dose to members of the public

(sometimes called a protective measure).

Protective Action Guide (PAG): The projected dose to reference man, or other defined individual, from an accidental release of radioactive material at which a specific protective action to reduce or avoid that dose is warranted.

Recovery: The process of reducing radiation exposure rates and concentrations of radioactive material in the environment to levels acceptable for unconditional occupancy or use.

Reentry: Temporary entry into a restricted zone under controlled conditions.

Relocation: The removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure.

Restricted zone: An area with controlled access from which the population has been relocated.

Return: The reoccupation of areas cleared for unrestricted residence or use.

Sheltering: The use of a structure for radiation protection from an airborne plume and/or deposited radioactive materials.

Short-lived daughters: Radioactive progeny of radioactive isotopes that have half-lives on the order of a few hours or less.

Weathering factor: The fraction of radioactivity remaining after being affected by average weather conditions for a specified period of time.

Weighting factor: A factor chosen to approximate the ratio of the risk of fatal cancer from the irradiation of a specific tissue to the risk when the whole body is irradiated uniformly to the same dose.

Whole body dose: Dose resulting from uniform exposure of the entire body to either internal or external sources of radiation.

APPENDIX B

Risks To Health From Radiation Doses That May Result From Nuclear Incidents

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APPENDIX B

Risks To Health From Radiation Doses That May Result From Nuclear Incidents

B.1 Introduction

This appendix reviews the risks from radiation that form the basis for the choice of Protective Action Guides (PAGs) for the response to a nuclear incident, as well as the choice of limits for occupational exposure during a nuclear incident.

B.1.1 Units of Dose

The objective of protective action is to reduce the risk to health from exposure to radiation. Ideally, one would like to assure the same level of protection for each member of the population. However, protective actions cannot take into account individual variations in radiosensitivity, since these are not known. Therefore, these PAGs are based on assumed average values of risk. We further assume that these risks are proportional to the dose, for any level of dose below the threshold for acute effects (see Section B.2.).

The dose from exposure to radioactive materials may be delivered during the period of environmental exposure only (e.g., external gamma radiation), or over a longer period (e.g., inhaled radionuclides which deposit in body organs). In the latter case, dose is delivered not only at the time of intake from the environment, but continues until all of the radioactive material has decayed or is eliminated from the body. Because of the variable time over which such doses may be delivered, the PAGs are expressed in terms of a quantity called the "committed dose." Conceptually, committed dose is the dose delivered over an individual's remaining lifetime following an intake of radioactive material. However, due to differences in physiology and remaining years of life, the committed dose to a child from internal radioactivity may differ from that to an adult. For simplicity, adult physiology and a remaining lifetime of 50 years are assumed for the purpose of calculating committed doses.

Another important consideration is that different parts of the body are at different risk from the same dose. Since the objective of protective actions is the reduction of health risk, it is appropriate to use a quantity called "effective dose." Effective dose is the sum of the products of the dose to each organ or tissue of the body and a weighting factor representing the relative risk. These weighting factors (IC-77) are chosen as the ratio of mortality (from delayed health effects) from irradiation of particular organs or tissues to the total risk of such

mortality when the whole body is irradiated uniformly at the same dose.

Finally, doses from different types of radiation (e.g. alpha, beta, gamma, and neutron radiation) have different biological effectiveness. These differences are customarily accounted for, for purposes of radiation protection, by multiplicative modifying factors. A dose modified by these factors is designated the "dose equivalent." The PAGs are therefore expressed in terms of committed effective dose equivalent. The PAGs are augmented by limits for a few specific organs (skin and thyroid) which exhibit special sensitivity. These are expressed in terms of committed dose equivalent (rem). In the process of developing PAG values, it is necessary to evaluate the threshold dose levels for acute health effects. These levels are generally expressed in terms of absorbed dose (rad) to the whole body from short term (one month or less) exposure. Other units (Roentgens, rem, and rets) are also used in information cited from various references. They are all approximately numerically equivalent to rads in terms of the risk of acute health effects from beta and gamma radiation.

PAGs are intended to apply to all individuals in a population other than workers performing emergency services. However, there may be identifiable groups that have different average sensitivity to radiation or, because of their living situation, will receive higher or lower doses. In addition, some groups may be at greater risk from taking a given protective action. These factors are separately considered, when it is appropriate, in establishing values for the PAGs.

B.1.2 Principles for Establishing Protective Action Guides

The following four principles provide the basis for establishing values for Protective Action Guides:

1. Acute effects on health (those that would be observable within a short period of time and which have a dose threshold below which they 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.

With the exception of the second, these principles are similar to those set forth by the International Commission

on Radiological Protection (IC-84b) as the basis for establishing intervention levels for nuclear accidents. We examine, below, the basis for estimating effects on health for use in applying the first two of these principles.

B.2 Acute Effects

This section provides information relevant to the first principle: avoidance of acute effects on health from radiation.

Acute radiation health effects are those clinically observable effects on health which are manifested within two or three months after exposure. Their severity depends on the amount of radiation dose that is received. Acute effects do not occur unless the dose is relatively large, and there is generally a level of dose (i.e., threshold) below which an effect is not expected to occur. Acute effects may be classified as severe or nonsevere clinical pathophysiological effects. Severe pathophysiological effects are those which have clinically observable symptoms and may lead to serious disease and death. Other pathophysiological effects, such as hematologic deficiencies, temporary infertility, and chromosome changes, are not considered to be severe, but may be detrimental in varying degrees. Some pathophysiological effects, such as erythema, nonmalignant skin damage, loss of appetite, nausea, fatigue, and diarrhea, when associated with whole body gamma or neutron exposure, are prodromal (forewarning of more serious pathophysiological effects, including death).

B.2.1 Review of Acute Effects

This section summarizes the results of a literature survey of reports of acute effects from short-term (arbitrarily taken as received in one month or less) radiation exposure in some detail. Many reports of observed effects at lower doses differ, and some are contradictory; however, most have been included for the sake of completeness. The results of the detailed review described in this Section are summarized in Section B.2.2.

The biological response to the rapid delivery of large radiation doses to man has been studied since the end of World War II. Dose-response relationships for prodromal (forewarning) symptoms and for death within 60 days have been developed from data on the Japanese A-bomb survivors, Marshall Island natives exposed to fallout, and patients undergoing radiotherapy. This work has been supplemented by a number of animal studies under controlled conditions.

The animal studies, usually using lethality as the end point, show that many factors can influence the degree of response. The rate at which the dose is delivered can affect the median lethal dose (LD_{50}) in many species, particularly at dose rates less than 5 R/min (PA-68a; BA-68). However, in primates there is less than a 50

percent increase in the LD_{50} as dose rates are decreased from 50 R/min to about 0.01 R/min (PA-68a). There is good evidence of species specificity (PA-68a; BO-69). The LD_{50} ranges from about 100 rad for burros to over 1000 rad for lagomorphs (e.g., rabbits). Response is modulated by: age (CA-68), extent of shielding (partial body irradiation) (BO-65), radiation quality (PA-68a; BO-69), diet, and state of health (CA-68).

While animal studies provide support and supplemental information, they cannot be used to infer the response for man. This lack of comparability of man and animals had already been noted by a review committee for the National Academy of Sciences as early as 1956, in considering the length of time over which acute effects might be expressed (NA-56): "Thus, an LD_{50}, 30-day consideration is inadequate to characterize the acute lethal dose response of man, and an LD_{50}, 60 days would be preferable."[1]

Several estimates of the levels at which acute effects of radiation occur in man have been published. For example, an early estimate of the dose-response curves for prodromal (forewarning) symptoms and for lethality was made in the first edition of "The Effects of Nuclear Weapons" (1957) (GL-57), and a more recent and well documented estimate is given in a NASA publication, "Radiobiological Factors in Manned Space Flight" (LA-67).

B.2.1.1 The Median Dose for Lethality

The radiation dose that would cause 50 percent mortality in 60 days was estimated as 450 Roentgens in early reports (NA-56; GL-57; RD-51). The National Commission on Radiation Protection and Measurements (NCRP) calculated that this would correspond to a midline absorbed dose of 315 rad (NC-74). The ratio of 315 rad to 450 Roentgens is 0.70, which is about the estimated ratio of the active marrow dose, in rads, to the tissue kerma in air, in rads (KE-80). The BEAR Committee noted that the customary reference to LD_{50} in animal studies, as if it were a specific property, independent of age, was not justifiable (NA-56): "...it is evident, now, that the susceptibility of a whole population is not describable by a single LD_{50}. The published values are usually obtained for young adults and are therefore maximal or nearly maximal for the strain. In attempts to estimate LD_{50} in man, this age dependence should be taken into consideration" (NA-56, pp.4-5). They observed that the LD_{50} approximately doubled as rats went from neonates to young adults and then decreased as the animals aged further. Finally, the BEAR

[1]The committee (known as the BEAR Committee) also noted "The reservation must be made here that the exposed Japanese population was heterogeneous with respect to age, sex, physical condition and degree of added trauma from burns or blast. The extent to which these factors affected the survival time has not been determined. In studies on laboratory animals the converse is true--homogeneous populations are studied" (NA-56, p.I-6).

Committee concluded: "The situation is complex, and it became evident that it is not possible to extrapolate with confidence from one condition of radiation exposure to another, or from animal data to man" (NA-56, p.I-8). Nevertheless, results from animal studies can aid in interpreting the human data that are available.

The NCRP suggested the $LD_{50/60}$ might be 10 to 20 percent lower for the old, very young, or sick, and somewhat greater for healthy adults of intermediate age (RD-51). Other estimates of adult $LD_{50/60}$ have ranged from about 300 rad to 243 $\pm$ 22 rad. These lower estimates are apparently based on a ratio of air to tissue dose similar to those calculated for midline organs in the body; 0.54 to 0.66 (KE-80; OB-76; KO-81).

A NASA panel examined all patient and accident studies, tried to remove confounding factors, and concluded, "On this basis, it may be assumed that the LD_{50} value of 286 rad obtained by a normal fit to the patient data is the preferred value for healthy man" (LA-67).

An $LD_{50/60}$ of 286 $\pm$ 25 rad (standard deviation) midline absorbed dose and an absorbed dose/air dose ratio of 0.66, suggested by the National Academy of Science (LA-67), is probably a reasonable value for healthy males. In the absence of more complete information, we assume that a value of 300 rad $\pm$ 30 rad is a reasonable reflection of current uncertainties for average members of the population.

B.2.1.2 Variation of Response for Lethality

Uncertainty in the dose-response function for acute effects has been expressed in various ways. The slope of the estimated dose-response function has most commonly been estimated on the basis of the percent difference in the LD_{50} and the $LD_{15.9}$ or $LD_{84.1}$ (one standard deviation from the LD_{50}), as was done by NASA (GL-57). These and other parameters derived in a similar manner describe the uncertainty in the central risk estimate for the dose-response function.

Another means is to use an estimate of upper and lower bounds for the central risk estimate, e.g., the 95 percent fiducial limits. At any given response point on the dose-response function, for example, the LD_{10}, the dose causing that response has a 95 percent probability of lying between the lower and upper bounds of the 95 percent fiducial limit for that point. To estimate this value, probit analyses were run for each species using data in published reports (KO-81; TA-71). This provided estimates for each species for comparability analyses. The 95 percent fiducial limits at the LD_{50} response for $LD_{50/30}$ studies averaged $\pm$9 percent (range -9 to +26 percent) and for $LD_{50/60}$ studies $\pm$17 percent (range -20 to +45 percent). At the LD_{15} response, values were $\pm$16 percent (range -12 to +50 percent) for $LD_{15/30}$ data and $\pm$26 percent (range -20 to +65 percent) for $LD_{15/60}$ data. For the LD_{85} response, values were $\pm$17 percent (range -36 to +36 percent) for the $LD_{85/30}$ data and

$\pm$24 percent (range -46 to +31 percent) for $LD_{85/60}$ data.

The differences in the magnitude of the fiducial limits are a function of the differences in age, sex, radiation quality, degree of homogeneity of the experimental animals, husbandry, and other factors. The estimates show that the fiducial limits, expressed as a percent of the dose at any response, get greater the farther from the LD_{50} the estimate is made. For the purpose of estimating fiducial limits for humans, the 95 percent fiducial limits will be considered to be LD_{15} $\pm$15 percent, LD_{50} $\pm$10 percent, and LD_{85} $\pm$15 percent. Beyond these response levels, the fiducial limits are too uncertain and should not be used.

If the median lethal dose, $LD_{50/60}$, is taken as 300 $\pm$30 rad midline absorbed dose, the response to higher and lower doses depends on the degree of biological variation in the exposed population. The NASA panel decided the wide variation in the sensitivity of patients was a reflection of the heterogeneity of the sample; and that the variation in sensitivity, the slope of the central estimate of the response function, would be stated in the form of one standard deviation calculated as 58 percent of the LD_{50}. They further decided the deviation in the patients (58 percent) was too great, and the standard deviation for "normal" man should be closer to that of dogs and monkeys (18 percent) (LA-67). (The rationale for selecting these species was not given.)

Jones attempted to evaluate the hematologic syndrome from mammalian lethality studies using the ratio of dose to LD_{50} dose as an indicator of the steepness of the slope of the dose-response function (JO-81). However, he evaluated LD_{50} studies only of species having a rather steep slope, i.e., dogs, monkeys, mice, and swine. He also looked at several different statistical models for dose-response functions and pointed out the problems caused by different models and assumptions, particularly in evaluating the tails of the dose-response function (less than LD_{10} and greater than LD_{90}). Jones recommended using a log-log model, which he felt provided a better fit at low doses (JO-81).

Scott and Hahn also evaluated acute effects from mammalian lethality, but suggested using a Weibull model (SC-80). One of the advantages of the Weibull model is that in addition to developing the dose-response function, it can also be used to develop hazard functions. These hazard functions, if developed using the same model, can be summed to find the joint hazard of several different types of exposure (SC-83). This would allow estimation of the total hazard from multiple organ exposures to different types of radiation.

As mentioned earlier, the human median lethal dose is commonly reported in terms of the $LD_{50/60}$. Most laboratory animal median lethal doses are reported in terms of the $LD_{50/30}$. In those cases where estimates of both $LD_{50/30}$ and $LD_{50/60}$ are available, i.e.,

the burro (ST-69), the variation (that is, the slope of the dose-response curve) is greater in the $LD_{50/60}$ study than in the $LD_{50/30}$ study. Both the dog and the monkey data are for $LD_{50/30}$, and so are not appropriate for direct comparison to man.

If an estimate of the deviation is made for data from other studies and species, those where most of the fatalities occur within 30 days (like dogs and monkeys) have standard deviations of from around 20 percent [swine (x-ray) (ST-69), dogs (NA-66), hamsters (AI-65), primates (Macaca) (DA-65)] to 30 percent [swine (^{60}Co) (HO-68)]. Those in which most deaths occur in 60 days, like man, have deviations from around 20 percent [sheep (CH-64)] to 40 percent [goats (PA-68b), burros (TA-71)]. Nachtwey, et al. (NA-66) suggested the steepness of the slope of the exposure response curve depends on the inherent variability of the subjects exposed and any variation induced by uncontrolled factors, e.g., temperature, diurnal rhythm, and state of stimulation or arousal. So, while the slope of the response curve for the patients studied by the NASA panel may be unrealistically shallow for normal human populations, there is no reason to think it should be as steep as those for dogs and monkeys.

The average deviation for those species (burros, sheep, and goats) for which the standard deviation of the $LD_{50/60}$ is available has been used as an estimator for man. The mean value is 34 $\pm$ 13 percent. This is only slightly greater than the average value for all physically large animals (swine, burros, sheep, and goats), 32 $\pm$ 12 percent.

B.2.1.3 Estimated Lethality vs Dose for Man

As noted in Section B.2.1.1, dose-response estimates vary for a number of reasons. Some factors affecting estimates for humans are:

1. Age:
Studies on rats indicate the LD_{50} is minimal for perinatal exposure, rises to maximum around puberty, and then decreases again with increasing age (CA-68). The perinatal LD_{50} is about one-third of that for the healthy young adult rats; that for the geriatric rat is about one-half of that for the young adult rat.

2. Sex:
Females are slightly more sensitive than males in most species (CA-68).

3. Health:
Animals in poor health are usually more sensitive than healthy animals (CA-68), unless elevated hematopoietic activity is occurring in healthy animals (SU-69).

While these and other factors will affect the $LD_{50/60}$ and the response curve for man, there are no numerical data available.

The variation in response at a given dose level increases as the population at risk becomes more heterogeneous and as the length of time over which mortality is expressed

increases. In general, larger species show greater variance and longer periods of expression than do small mammals, e.g., rodents. It is likely that the human population would show at least the same amount of variation as do the larger animals, i.e., a coefficient of variation of about one-third.

The degree of variation exhibited in animal studies follows a Gaussian distribution as well as or better than a log normal distribution over that range of mortality where there are reasonable statistics. We have assumed here that the functional form of human response is Gaussian. Generally, sample sizes for extreme values (the upper and lower tails of the distribution) are too small to give meaningful results. Therefore, we have not projected risks for doses more than two standard deviations from the $LD_{50/60}$. We recognize that estimates of acute effects may not be reliable even beyond one standard deviation for a population containing persons of all ages and states of health. However, in spite of these uncertainties, previous estimates have been made of the acute effects caused by total body exposure to ionizing radiation as a function of the magnitude of the exposure (NC-71; LU-68; FA-73; NA-73).

Given the large uncertainties in the available data, a median lethal dose value of about 300 rad at the midline, with a standard deviation of 100 rad, may be assumed for planning purposes. Such risk estimates should be assumed to apply only in the interval from 5 percent to 95 percent fatality, as shown in Figure B-1. (See also section B.2.1.4.)

Figure B-1 is based on the following values:

Dose (rad)	Percent fatalities
<140	none[2]
140	5
200	15
300	50
400	85
460	95

For moderately severe prodromal (forewarning) effects, we believe the dose at which the same percentage of exposed would show effects would be approximately half of that causing fatality. This yields the following results (see also Figure B-1):

Dose (rad)	Percent affected
50	<2
100	15
150	50
200	85
250	98

Although some incidence of prodromal effects has been observed at doses in the range of 15 to 20 rads in patients (LU-68) and in the 0 to 10 rads range of dose in Japanese A-bomb survivors (SU-80a; GI-84),

[2]The risk of fatality below 140 rad is not necessarily zero; rather, it is indeterminate and likely to remain so. This also applies to prodromal effects below 50 rad.

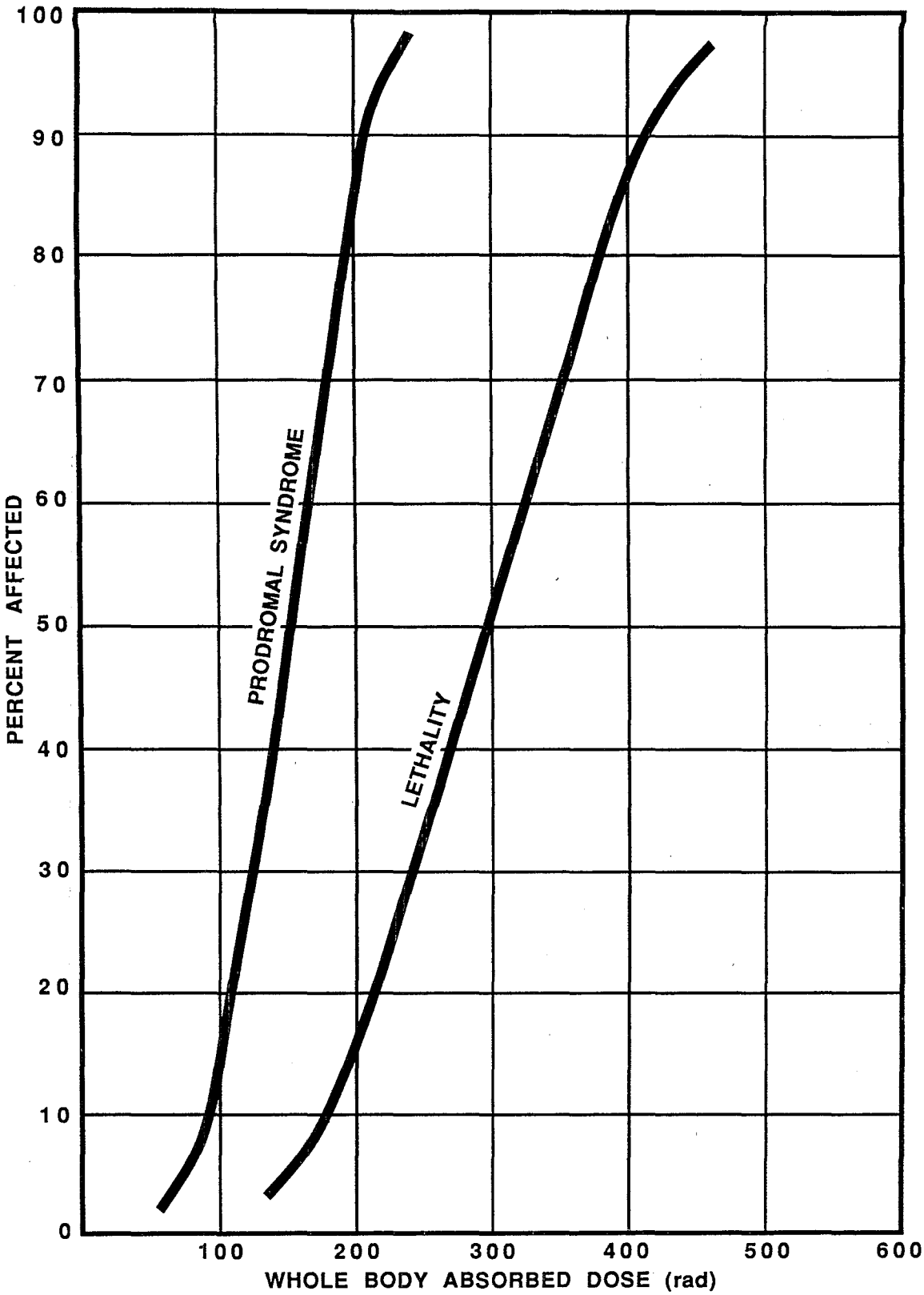

FIGURE B-1. ACUTE HEALTH EFFECTS AS A FUNCTION OF WHOLE BODY DOSE.

there is great uncertainty in interpreting the data. Patients may be abnormally sensitive, so that the dose-response function in patients may represent the lower bound of doses that would show a response in a healthy population (LU-67). The response of Japanese survivors in the low dose ranges is complicated by the blast and thermal exposure that occurred at the same time (SU-80b). For these reasons, care should be taken in applying estimates of prodromal effects. The prodomal dose-response function listed above is more likely to overestimate the proportion of persons affected than to underestimate it.

These estimated ranges and effects are in agreement with estimates made for manned space flights (LA-67; LU-67), which included consideration of the effect of abnormal physiology or sickness in the patients to which the data apply. Uncertainty in estimates of the biological effects of radiation exposure is great. It is probably due in part to variation in the health of individuals in exposed populations. These estimates assume a healthy young adult population and may not be a conservative estimate of risk for other population groups, such as children or the elderly. Lushbaugh, et al. (LU-68) found that prodromal effects probably occur in both healthy and ill persons in about the same dose range. However, Lushbaugh, et al. (LU-68) and NATO (NA-73) suggest that acute mortality in a population which is ill, injured, or in other ways debilitated will occur in 50 percent of that population at doses of 200-250 rad in about 60 days ($LD_{50/60}$), in contrast to an $LD_{50/60}$ from doses of 220-310 rad for a healthy young adult population. Thus, the ill or injured are assumed to have an increased risk of acute mortality at high doses.

The above estimates for $LD_{50/60}$ are also based on the assumption of minimal medical care following exposure. UNSCEAR (UN-88) estimates that the threshold for mortality would be about 50 percent higher in the presence of more intense medical care.

B.2.1.4 Threshold Dose Levels for Acute Effects

This section summarizes information available in the literature regarding thresholds for health effects. It also reviews actions that have been taken as a result of radiation exposure to provide insight on dose levels at which actions to avoid dose may be appropriate.

Some acute effects, such as cellular changes, may occur at low doses with no dose threshold. Most such effects have a minimum threshold of detectability; for example, five rad is about the lower limit of whole body dose which causes a cellular effect detectable by chromosome or other special analyses (NC-71; FA-73). This value is recommended by UNSCEAR as the starting point for biological dosimetry (UN-69). Purrott, et al. have reported a lower limit of detection of chromosome aberrations of 4 rad for x-rays and 10 rad for gamma rays (PU-75).

More recent advanced chromosome banding techniques permit detection of increased incidence of chromosome abnormalities from continuous exposure to systematically deposited radioisotopes or radioisotopes deposited in the lung at very low levels, e.g., body burdens of 100 to 1200 pCi of plutonium-239 (BR-77). While the exact dose associated with such burdens is not known, it is probably on the order of 10 to 100 millirem per year. Lymphocytes exposed to 5 rem in vitro show severe metabolic dysfunction and interphase cell death (ST-64). The extent to which similar effects occur after in vivo exposure is unknown. While chromosome abnormalities in circulating lymphocytes are reported to persist for long periods (UN-69), the significance of such abnormalities is not known (BR-77).

Hug has suggested 5 rem as the lower limit of exposure which might produce acute effects (WH-65). Five rad is also in the low dose, short-term exposure range defined by Cronkite and Haley, and is below the 10 rad which they thought would cause only a slight detectable physiological effect of unknown clinical significance (CR-71).

Although the ICRP has suggested that annual doses of 15 rad would not impair the fertility of normal fertile men (IC-69), an acute dose of 15 rad causes "moderate" oligospermia (approximately 70 percent reduction in sperm count) which lasts for some months (LA-67). Popescu and Lancranjan reported alterations of spermatogenesis and impaired fertility in men exposed to from 500 millirad to 3 rad per year for periods varying from 2 to 22 years (PO-75). The shortest exposure period in which abnormal spermatogenesis was reported was 31 to 41 months (PO-75); at the highest dose rate reported (3 rad/a), this is a cumulative dose of 8 to 10 rem. While more study is required, these results suggest the need to restrict acute doses to below 10 rem to avoid this effect, because a given acute dose is anticipated to be more effective than the same cumulative dose given over a longer period of time (NA-56; UN-58).

Many observations have indicated that doses of 10 rem or more to the pregnant woman are hazardous to the fetus. Mental retardation due to exposure of the fetus is discussed in Section B.3; this discussion is restricted to acute effects. The World Health Organization (WHO) indicates that there is no evidence of teratogenic effects from short term exposure of the fetus to a dose less than 10 rad during the early phase of gestation, the period when the fetus is most sensitive to these effects (WH-84).

A number of authorities have recommended that exposures of 10 roentgens or higher be considered as an indication for carrying out induced abortion (HA-59, DE-70, BR-72, NE-76). Brent and Gorson also suggest that 10 rad is a "practical" threshold for induction of fetal abnormalities (BR-72). The Swedish Government Committee on Urban Siting of Nuclear Power Stations stated the situation as follows: "What we have called unconditional indication of abortion involves the exposure of pregnant

women where radiation dose to the fetus is higher than 10 rad. When such doses are received in connection with medical treatment, it has hitherto been assumed that the probability of damage to the fetus is so high that an abortion is recommended. The probability for such injury is still moderate compared with the normal frequency of similar fetal injuries, and the probability is particularly reduced when the dose is received late in the pregnancy" (NA-74).

B.2.1.5 Acute Effects in the Thyroid

Acute effects are produced in the thyroid by doses from radioiodine on the order of 3,000 to 100,000 rad. Ablation of the thyroid requires doses of 100,000 rad (BE-68). The thyroid can be rendered hypothyroid by doses of about 3,000 to 10,000 rad (IC-71). A thyroid dose from radioiodines of 1000 rad in adults and 400 rad in children implies an associated whole body dose of about 1 rad due to radioiodines circulating in the blood. Following inhalation of ^{131}I, the committed thyroid dose is about one rad/µCi intake of ^{131}I in adults. In the developing fetus, the thyroid dose ranges from one to six rad per µCi of ^{131}I entering the mother's body (IL-74).

Although acute clinical effects are only observed at high doses, subclinical acute thyroid radiation effects may occur at lower doses (DO-72). Impaired thyroid capability may occur above a threshold of about 200 rad (DO-72).

Effects of radiation exposure of the thyroid have been shown in animal experiments. Walinder and Sjoden found that doses in excess of 3,000 rad from ^{131}I caused noticeable depression of fetal and juvenile mouse thyroid development (WA-69). Moore and Calvin, working with the Chinese hamster, showed that an exposure as low as 10 roentgens (x-rays) would give rise to 3 percent aberrant cells when the thyroid was cultured (MO-68). While the direct relationship of these results to human effects is not certain, mammalian thyroid cells can be injured at exposures as low as 10 roentgens.

B.2.1.6 Acute Effects in the Skin

The first stage of skin reaction to radiation exposure is erythema (reddening) with a threshold of from 300 to 800 rad. Acute exudative radiodermatitis results from doses of 1,200 to 2,000 rad (WH-84).

B.2.1.7 Clinical Pathophysiological Effects

A large amount of anecdotal information is available on the injury of organ tissues by high doses of radiation. Acute injury to tissue includes swelling and vacuolation of the cells which make up the blood vessels, increased permeability of vessels to fluids so that exudates form, formation of fibrin clots and thrombi, fibrinoid thickening in the walls of blood vessels, and swelling and vacuolization of parenchymal cells. In summary, there is an initial exudative

reaction followed in time by fibrosis and sclerosis (WH-76, CA-76).

Estimates of radiation doses necessary to cause severe tissue response in various organs are given in Table B-1. These tissue dose estimates are based on response to radiotherapy treatment, which is normally given on a fractionated dose basis, but also may be given as a continuous exposure. Therefore, these estimates must be adjusted to the equivalent single radiation dose for use in the present analysis. The formalism of Kirk, et al. (KI-71) is used to estimate the equivalent dose for a single acute exposure in rad-equivalent therapy units (rets: the dose calculated from the fractionated exposure which is equivalent to a single acute exposure for a specific biological endpoint.) Table B-2 lists acute exposure equivalents in rets for various organs.

With the exception of bone marrow, the exposures required to cause 5 percent injury within 5 years (TD 5/5) in internal organs are in the range of 1,000 to 5,000 rad. Since, with this type of injury, the dose response is nonlinear and has a threshold (i.e., is nonstochastic), there is an exposure below which injury is not expected. If the shape of the injury dose-response curve is the same for all internal organs as it is for the lung, plotting the two acute exposure equivalents (TD 50/5 and 5/5) for each organ on log probability paper allows a crude estimation of the number of clinical pathophysiological effects per 1000 persons exposed as a function of dose level. If one acute effect per 1000 persons within 5 years (TD 0.1/5) is taken as the threshold for the initiation of clinical pathophysiological effects in organs other than thyroid, the equivalent dose level for most organs is 550 rets or more; testes 440 $\pm$ 150 rets, ovary 170 $\pm$ 70 rets, and bone marrow 165 rets.

The radiation exposure to organs in rad units that will cause clinical pathophysiological effects within 5 years to 0.1 percent of the exposed population as a function of the duration of a continuous level of exposure can then be estimated by using Goitein's modification of the Kirk methodology (GO-76). This relationship is shown in Table B-3.

Bone marrow is an organ of particular concern because radionuclides known to concentrate in this organ system occur in nuclear incidents. The acute lethality due to the hematologic syndrome (LA-67) is estimated to occur in the range of 200 to 1,000 rad, so that the difference is small between exposure levels that might cause acute lethality and exposure levels that might cause only "severe clinical pathophysiology," as derived from radiotherapy data.

In summary, organ systems are not expected to show symptoms of severe clinical pathophysiology for projected short-term exposure doses less than a few hundred rad. Projected doses to bone marrow at this high level are relatively more serious and more likely to result in injury than doses to other organ systems.

Table B-1 Radiation Doses Causing Acute Injury to Organs (RU-72, RU-73)

Organ	Volume or area of exposure[a]	Risk of injury in five years: 5 percent (rad)	Risk of injury in five years: 50 percent (rad)	Type of injury
Bone marrow	whole	250	450	aplasia and pancytopenia
Liver	segment whole	3000 2500	4000 4000	acute and chronic hepatitis
Stomach	100 cm^2	4500	5500	ulcer, perforation, hemorrhage
Intestine	400 cm^2 100 cm^2	4500 5000	5500 6500	ulcer, perforation, hemorrhage
Lung	whole 100 cm^2	1500 3000	2500 3500	acute and chronic pneumonitis
Kidney	whole	2000	2500	acute and chronic nephrosclerosis
Brain	whole	6000	7000	infarction, necrosis
Spinal cord	10 cm	4500	5500	infarction, necrosis
Heart	60 percent	4500	5500	pericarditis and pancarditis
Skin	---	5500	7000	ulcers, fibrosis
Fetus	whole	200	400	death
Lens of eye	whole	500	1200	cataracts
Ovary	whole	200-300	625-1200	permanent sterilization
Testes	whole	500-1500	2000	permanent sterilization

[a]Dose delivered in 200-rad fractions, 5 fractions/week.

--- Unspecified.

Table B-2 Acute Radiation Exposure as a Function of Rad Equivalent Therapy Units (rets)

Organ	Volume or area of exposure	Risk of injury in five years	
		5 percent (rets)	50 percent (rets)
Bone marrow	whole	230	340
	segment	1135	1360
Liver	whole	1000	1360
Stomach	100 cm^2	1465	1665
Intestine	400 cm^2	1465	1665
	100 cm^2	1570	1855
Lung	whole	720	1000
	100 cm^2	1135	1245
	75 percent	770[b]	---
Kidney	whole	875	1000
Brain	whole	1770	1950
Spinal cord	10 cm	1465	1665
Heart	60 percent	1465	1665
Skin	---	1665	1950
Fetus	whole	200	315
Lens of eye	whole	355	620
Ovary	whole	200-430[a]	410-875[a]
Testes	whole (sterilization)	340-720[a]	410-875[a]

[a]For a 200-rad/treatment, 5 treatments/week schedule (LU-76).

[b]Reference WA-73.

--- Unspecified.

Table B-3 Radiation Exposure to Organs Estimated to Cause Clinical Pathophysiological Effects within 5 Years to 0.1 Percent of the Exposed Population (GO-76)

Duration of exposure (days)	Ovary (rad)	Bone marrow (rad)	Testes (rad)	Other organs (rad)
(acute)	(170 rets)[a]	(165 rets)	(440 rets)	(550 rets)
1	315	300	810	1020
2	390	380	1010	1260
4	470	450	1210	1510
7	550	540	1430	1790
30	840	820	2190	2740
365[b]	1740	1690	4510	5640

[a]The dose in rets is numerically equal to the dose in rads.

[b]Assuming tissue recovery can continue at the same rate as observed during 30- to 60-day therapeutic exposure courses.

Even if severe clinical pathophysiological effects can be avoided, there is still a possibility of clinical pathophysiological effects of a less severe or transitory nature. The 1982 UNSCEAR report (UN-82) reviewed much of the data on animals and man. In the animal studies, there were reports of: changes in stomach acid secretion and stomach emptying at 50 to 130 rad; stunting in growing animals at the rate of 3 to 5 percent per 100 rad; degeneration of some cells or functions in the brain at 100 rad, particularly in growing animals; temporary changes in weight of hematopoietic tissues at 40 rad; and more damage in ovaries and testes caused by fractionated doses rather than acute doses. Some of the effects are transitory, others are long-lasting, but with only minor reductions in functional capacity.

Human data are limited and are reported primarily in the radiotherapy literature. The data suggest most tissues in man are more radiation resistant than those in animals. However, the human hematopoietic system shows a transient response, reflected by decreased circulating white cells and platelets, at about 50 rad. Temporary sterility has been observed after doses of 150 rad to the ovaries and 10 rad to the testes, when given as fractionated doses.

There is not sufficient data to determine dose-response functions

nor to describe the duration and severity of dysfunction expected.

B.2.2 Summary and Conclusions Regarding Acute Effects

Based on the foregoing review of acute health effects and other biological effects from large doses delivered over short periods of time, the following whole body doses from acute exposure provide useful reference levels for decisionmaking for PAGs:

50 rad - Less than 2 percent of the exposed population would be expected to exhibit prodromal (forewarning) symptoms.

25 rad - Below the dose where prodromal symptoms have been observed.

10 rad - The dose level below which a fetus would not be expected to suffer teratogenesis (but see Section B.3, Mental Retardation.).

5 rad - The approximate minimum level of detectability for acute cellular effects using the most sensitive methods. Although these are not severe pathophysiological effects, they may be detrimental.

Based on the first principle to be satisfied by PAGs (paragraph B.1.6), which calls for avoiding acute health effects, values of 50 rem for adults and 10 rem for fetuses appear to represent upper bounds.

B.3 Mental Retardation

Brain damage to the unborn is a class of injury reported in atomic bomb survivors which does not fall into either an acute or delayed effect category, but exhibits elements of both. What has been observed is a significant, dose-related increase in the incidence and severity of mental retardation, microencephaly (small head size), and microcephaly (small brain size) in Japanese exposed to radiation in utero during the 8th to 15th week after conception (BL-73; MI-76). While the actual injury may be acute, it is not identified until some time after birth.

In an early study Mole (MO-82) suggested that, although radiation may not be the sole cause of these conditions, it is prudent to treat the phenomenon as radiation-related. More recently, Otake and Schull (OT-83) have concluded: (1) there is no risk to live-born due to doses delivered up to 8 weeks after conception, (2) most damage occurs at the time when rapid proliferation of neuronal elements occurs, i.e., 8 to 15 weeks of gestational age, (3) the dose-response function for incidence during this period appears to fit a linear model, (4) the risk of occurrence is about five times greater during the period 8-15 weeks of gestation than in subsequent weeks, and (5) in later stages of gestation, e.g., after the 15th week, a threshold for damage may exist.

In their published reports, Otake and Schull (OT-83) evaluated the incidence of severe mental retardation

using the T-65 dosimetry and the dosimetry estimates developed in the ongoing dose reassessment program for the atomic bomb survivors, and using two tissue dose models. Their estimated ranges of risk were:

8 to 15 weeks after gestation: $3\text{-}4 \times 10^{-3}$ cases/rad;

16 or more weeks after gestation: $5\text{-}7 \times 10^{-4}$ cases/rad.

The higher values are based on the T-65 dosimetry and the Oak Ridge National Laboratory estimate of tissue dose. The lower values are based on Oak Ridge National Laboratory dosimetry and the Japanese National Institute of Radiological Sciences estimates of tissue dose. Later estimates based on the dose reassessment completed in 1986 are consistent with these published results (SC-87).

In view of the foregoing, the risk of mental retardation from exposure of a fetus in the 8th to 15th week of pregnancy is taken to be about 4×10^{-3} per rad. Because of this relatively high risk, special consideration should be given to protection of the fetus during this period. The risk to a fetus exposed after the 15th week is taken as 6×10^{-4} per rad. For the cases studied (OT-84), no increased incidence of mental retardation was observed for exposure during the 1st to the 7th week of pregnancy.

Federal Radiation Protection Guidance, adopted in 1987, recommends that dose to occupationally exposed pregnant women be controlled to keep the fetal dose below 0.5 rem over the entire term of pregnancy, and that no dose be delivered at more than the uniform monthly rate that would satisfy this limit (i.e., approximately 50-60 mrem/month)(EP-87). The NCRP has, for many years, recommended a limit of 0.5 rem (NC-71). ICRP recommends controlling exposure of the fetus to less than 0.5 rem in the first 2 months to provide appropriate protection during the essential period of organogenesis (IC-77).

B.4 Delayed Health Effects

This section addresses information relevant to the second principle (paragraph B.1.5) for establishing PAGs, the risk of delayed health effects in exposed individuals. The following subsections summarize the estimated risks of cancer and genetic effects, the two types of delayed effects caused by exposure to radiation.

B.4.1 Cancer

Because the effects of radiation on human health have been more extensively studied than the effects of many other environmental pollutants, it is possible to make numerical estimates of the risk as a result of a particular dose of radiation. Such estimates, may, however, give an unwarranted aura of certainty to estimated radiation risks. Compared to the baseline incidence of cancer and genetic defects, radiogenic cancer and

genetic defects do not occur very frequently. Even in heavily irradiated populations, the number of cancers and genetic defects resulting from radiation is known with only limited accuracy. In addition, all members of existing exposed populations have not been followed for their full lifetimes, so data on the ultimate numbers of effects is not yet available. Moreover, when considered in light of information gained from experiments with animals and from various theories of carcinogenesis and mutagenesis, the observed data on the effects of human exposure are subject to a number of interpretations. This, in turn, leads to differing estimates of radiation risks by individual scientists and expert groups. In summary, the estimation of radiation risks is not a fully mature science and the evaluation of radiation hazards will continue to change as additional information becomes available.

Most of the observations of radiation-induced carcinogenesis in humans are on groups exposed to low-LET radiations. These groups include the Japanese A-bomb survivors and medical patients treated with x-rays for ankylosing spondylitis in England from 1935 to 1954 (SM-78). The National Academy of Science Committee on the Biological Effects of Ionizing Radiations (BEIR) (NA-80) and UNSCEAR (UN-77) have provided knowledgeable and exhaustive reviews of these and other data on the carcinogenic effects of human exposures. The most recent of the BEIR studies was published in 1980 and is here designated BEIR-3 to distinguish it from previous reports of the BEIR committee.

The most important epidemiological data on radiogenic cancer is that from the A-bomb survivors. The Japanese A-bomb survivors have been studied for more than 40 years, and most of them have been followed in a major, carefully planned and monitored epidemiological survey, the Life Span Study Sample, since 1950 (KA-82, WA-83). They were exposed to a wide range of doses and are the largest group that has been studied. They are virtually the only group providing extensive information on the response pattern at various levels of exposure to low-LET radiation.

The estimated cancer risk from low-LET, whole body, lifetime exposure presented here is based on a life table analysis using a linear response model. We use the arithmetic average of relative and absolute risk projections (the BEIR-3 L-L model) for solid cancers, and an absolute risk projection for leukemia and bone cancer (the BEIR-3 L-L model). For whole body dose, this yields an estimated 280 (with a possible range of 120 to 1200) fatalities per million person-rem for a population cohort representative of the 1970 U.S. population. We assume this estimate also applies to high-LET radiation (e.g. alpha emitters); no reduction has been applied for dose rate. (The rounded value, 3×10^{-4} fatalities[3] per person-rem, has been selected for this analysis.)

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[3]Preliminary reviews of new results from studies of populations exposed at Hiroshima

Whole body dose means a uniform dose to every organ in the body. In practice, such exposure situations seldom occur, particularly for ingested or inhaled radioactivity. Inhaled radioactive particulate materials may be either soluble or insoluble. Soluble particulate materials deposited in the lung will be rapidly absorbed, and the radionuclides associated with them distributed throughout the body by the bloodstream. As these radionuclides are transported in the blood, they irradiate the entire body. Usually, they then redeposit in one or more organs, causing increased irradiation of that organ. Insoluble particulate materials, on the other hand, are only partially absorbed into body fluids. (This fraction is typically assumed to be about 8 percent.) This absorption occurs over a period of years, with a portion entering the bloodstream and another retained in the pulmonary lymph nodes. The balance (92 percent) of inhaled insoluble particulate materials are removed from the lung within a few days by passing up the air passages to the pharynx where they are swallowed. Inhaled insoluble particulate materials thus irradiate both the lung and the gastrointestinal tract, with a small fraction being eventually absorbed into the bloodstream (TG-66). These nonuniform distributions of dose (and therefore risk) are taken into account through use of the weighting factors for calculating effective dose.

There is a latent period associated with the onset of radiation-induced cancers, so the increased risk is not immediately apparent. The increased risk is assumed to commence 2 to 10 years after the time of exposure and continue the remainder of the exposed individual's lifespan (NA-80).

For uniform exposure of the whole body, about 50 percent of radiation-induced cancers in women and about 65 percent in men are fatal (NA-80). Therefore, 1 rem of low-LET radiation would be expected to cause a total of about 500 cancer cases if delivered to a population of one million. (In the case of thyroid and skin, the ratio of nonfatal to fatal cancers are much higher. These are addressed separately below.) This corresponds to an average annual individual probability of developing cancer of about 7×10^{-6} per year. For perspective, the average annual risk of dying of cancer from all causes in the United States, in 1982, was 1.9×10^{-3}.

B.4.1.1 Cancer Risk Due to Radiation Exposure of the Thyroid

Exposure of the thyroid to extremely high levels of radiation may cause it to degenerate. At moderate levels of exposure some loss of thyroid function will occur. At lower levels of exposure, there are delayed health

(footnote continued)

and Nagasaki indicate that these risk estimates may be revised upwards significantly in the near future, particularly for acute exposure situations. EPA has recently used a slightly higher value, 4×10^{-4} fatalities in standards for air emissions under the Clean Air Act. We will revise these risk estimates to reflect new results following appropriate review.

effects, which take the form of both thyroid nodules and thyroid malignancies (NA-72; NA-80). Doses as low as 14 rad to the thyroid have been associated with thyroid malignancy in the Marshall Islanders (CO-70). The increased risk of radiation-induced cancer is assumed to commence about 10 years after initial exposure and to continue for the remaining lifespan of an exposed individual.

The true nature of thyroid nodules cannot be established until they are surgically removed and examined histologically, and those that are malignant can lead to death if not surgically removed (SA-68; DE-73; PA-74). Although thyroid malignancies are not necessarily fatal, effects requiring surgical removal of the thyroid cannot be considered benign. In this analysis, all thyroid cancers, both fatal and nonfatal, are counted for the purpose of estimating the severity of thyroid exposures.

Based on findings in BEIR-3, we estimate that 1 rem of thyroid exposure carries a risk of producing a thyroid cancer of 3.6×10^{-4}, of which a small fraction (on the order of 1 in 10) will be fatal (NA-80). Since the calculation of effective dose equivalent does not include consideration of nonfatal thyroid cancers and the severity of the medical procedures for their cure, it is appropriate to limit the dose to the thyroid by an additional factor beyond that provided by the PAG expressed in terms of effective dose equivalent. Protective action to limit dose to thyroid is therefore recommended at a thyroid dose 5 times the numerical value of the PAG for effective dose.

B.4.1.2 Cancer Risk Due to Radiation Exposure of the Skin

The risk of fatal skin cancer is estimated to be on the order of one percent of the total risk of fatal cancer for uniform irradiation of the entire body (IC-78). However, since the weighting scheme for calculating effective dose equivalent does not include skin, the PAG expressed in terms of effective dose does not provide protection against radionuclides which primarily expose skin. As in the case of the thyroid, the ratio of nonfatal to fatal cancers from irradiation of the skin is high (on the order of 100 to 1). It would not be appropriate to ignore this high incidence of nonfatal skin cancers by allowing 100 times as much dose to the skin as to the whole body. For this reason, evacuation is recommended at a skin dose 50 times the numerical value of the PAG for effective dose.

B.4.1.3 Cancer Risk Due to Radiation Exposure of the Fetus

The fetus is estimated to be 5 to 10 times as sensitive to radiogenic cancer as an adult (FA-73; WH-65). Stewart reports increased relative incidence of childhood cancers following prenatal x-ray doses as low as 0.20 to 0.25 rem and doubling of childhood cancers between 1-4 rem (ST-73). She concluded that the fetus is about equally sensitive to cancer induction in

each trimester. Her findings are supported by similar results reported by MacMahon and Hutchinson (MA-64), Kaplan (KA-58), Polhemus and Kock (PO-59), MacMahon (MA-63), Ford, et al. (FO-59), Stewart and Kneale (ST-70b), and an AEC report (AE-61). MacMahon reported that although there were both positive and negative findings, the combination of weighted data indicates a 40 percent increase in childhood cancer mortality after in vivo exposure to diagnostic x rays (1.0 to 5.0 rad): about 1 cancer per 2,000 exposed children in the first 10 years after birth (MA-63). He concluded that although the range of dose within which these effects are observed is wide, effects will be fewer at 1 rad than at 5 rad.

Graham, et al., investigating diagnostic x-ray exposure, found a significantly increased relative risk of leukemia in children: by a factor of 1.6 following preconception irradiation of mothers or in utero exposure of the fetus; by a factor of 2 following postnatal irradiation of the children; and by a factor of 2 following preconception irradiation of the mother and in utero exposure of the child (GR-66).

B.4.1.4 Age Dependence of Doses

Almost all dose models are based on ICRP "Reference Man," which adopts the characteristics of male and female adults of working age. ICRP-30 dosimetric models, which use "Reference Man" as a basis, are therefore appropriate for only adult workers and do not take into account differences in dose resulting from the differences in physiological parameters between children and adults, e.g., intake rates, metabolism, and organ size. Although it is difficult to generalize for all radionuclides, in some cases these differences tend to counterbalance each other. For example, the ratio of volume of air breathed per unit time to lung mass is relatively constant with age, so that the ICRP adult model for inhaled materials provides a reasonably good estimate of the dose from a given air concentration of radioactive material throughout life.

The thyroid is an exception because the very young have a relatively high uptake of radioiodine into a gland that is much smaller than the adult thyroid (see Section B.4.2.2.). This results in a larger childhood dose and an increased risk which persists throughout life. We have examined this worst case situation. Age-specific risk coefficients for fatal thyroid cancer (See Table 6-8 of "Risk Assessment Methodology" (EP-89)) are about 1.9 higher per unit dose for persons exposed at ages 0 to 9 years than for the general population. Age-dependent dose factors (see NRPB-R162 (GR-85)) for inhalation of I-131, are a factor of about 1.7 higher for 10 year olds than for adults. Therefore, the net risk of fatal thyroid cancer from a given air concentration of I-131 is estimated to be a factor of about 3 higher for young children than for the remainder of the population. This difference is not considered large enough, given the uncertainties of exposure estimation for implementing

protective actions, to warrant establishing age-dependent PAGs.

B.4.2 Genetic Risk

An average parental dose of 1 rem before conception has been estimated to produce 5 to 75 significant genetically-related disorders per million liveborn offspring (NA-80). For this analysis we use the geometric mean of this range, i.e. 1.9×10^{-5}. This estimate applies to effects in the first generation only, as a result of dose to parents of liveborn offspring. The sum of effects over all generations is estimated to be approximately twelve times greater; that is, 2.3×10^{-4}. In addition, since any radiation dose delivered after a parent's last conception has no genetic effect, and not all members of the population become parents, less than half of the entire dose in an average population is of genetic significance. Taking the above factors into account, we estimate that the risk of genetically-related disorders in all generations is 1×10^{-4} per person-rem to a typical population.

Although the overall severity of the genetic effects included as "significant" in the above estimates is not well known, rough judgements can be made. The 1980 BEIR report referred to "....disorders and traits that cause a serious handicap at some time during lifetime" (NA-80). From the types of defects reported by Stevenson (ST-59), it can be estimated that, of all radiation-induced genetic effects, 50 percent lead to minor to moderate medical problems (i.e., hair or ear anomalies, polydactyl, strabismus, etc.), 25 percent lead to severe medical problems (i.e., congenital cataracts, diabetes insipidus, deaf mutism, etc.), 23 percent would require extended hospitalization (i.e., mongolism, pernicious anemia, manic-depressive psychoses, etc.), and 2 percent would die before age 20 (i.e., anencephalus, hydrocephalus, pancreatic fibrocytic disease, etc.).

B.4.3 Summary of Risks of Delayed Effects

Table B-4 summarizes average lifetime risks of delayed health effects based on results from the above discussion. Because of the nature of the dose-effect relationships assumed for delayed health effects from radiation (linear, nonthreshold), there is no dose value below which no risk can be assumed to exist.

B.4.4 Risks Associated with Other Radiation Standards

A review of radiation standards for protection of members of the general population from radiation shows a range of values spanning several orders of magnitude. This occurs because of the variety of bases (risk, cost, practicability of implementation, and the situations to which they apply) that influenced the choice of these standards. Some source-specific standards are relatively protective, e.g., the EPA standard limiting exposure of the public from nuclear power operations (25 mrem/y) from all path-

Table B-4 Average Risk of Delayed Health Effects in a Population[a]

	Effects per person-rem		
	Whole Body	Thyroid[c]	Skin
Fatal cancers	2.8E-4[b]	3.6E-5	3.0E-6
Nonfatal cancers	2.4E-4[b]	3.2E-4	3.0E-4
Genetic disorders (all generations)	1.0E-4		

[a] We assume a population with the same age distribution as that of the U.S. population in 1970.

[b] Risk to the fetus is estimated to be 5 to 10 times higher.

[c] Risk to young children is estimated to be about two to three times as high.

ways combined corresponds to a risk (for cancer death) of $5x10^{-4}$ for lifetime exposure. Similarly, regulations under the Clean Air Act limit the dose due to emissions of radionuclides to air alone from all DOE and NRC facilities to 0.01 rem per year, which corresponds to a cancer risk of $2x10^{-4}$ for lifetime exposure. Other guides permit much higher risks. For example, the level at which the EPA recommends action to reduce exposure to indoor radon (0.02 working levels) corresponds to a risk of about $2x10^{-2}$ (for fatal lung cancer) for lifetime exposure. All of these standards and guides apply to nonemergency situations and were based on considerations beyond a simple judgement of acceptable risk.

Federal Radiation Protection Guidance for nonemergency situations recommends that the dose from all sources combined (except from exposure to medical and natural background radiation) to individuals in the population not exceed 0.5 rem in a single year (FR-60) and that the dose to the fetus of occupationally-exposed mothers not exceed 0.5 rem during the 9-month gestation period (EP-87). This dose corresponds to an annual incremental risk of fatal cancer to members of the general population of about $1.4x10^{-4}$. If exposure of the fetus is limited to one ninth of 0.5 rem per month over a 9-month gestation period, as recommended, the risk of severe mental retardation in liveborn is limited to about $7x10^{-4}$.

The International Commission on Radiation Protection recommends that the dose to members of the public not exceed 0.5 rem per year due to nonrecurring exposure to all sources of radiation combined, other than natural sources or beneficial medical uses of

radiation (IC-77). They also recommend a limiting dose to members of the public of 0.1 rem per year from all such sources combined for chronic (i.e., planned) exposure (IC-84a). These upper bounds may be taken as representative of acceptable values for the situations to which they apply. That is, these are upper bounds of individual risk that are acceptable for the sum of all sources and exposure pathways under international recommendations, for circumstances that are justified on the basis of public benefit, and when actual doses from individual sources are "as low as reasonably achievable" (ALARA) within these upper bounds.

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APPENDIX C

Protective Action Guides for the Early Phase:

Supporting Information

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APPENDIX C

Protective Action Guides for the Early Phase: Supporting Information

C.1 Introduction

This appendix sets forth supporting information for the choice of Protective Action Guides (PAGs) for the early phase of the response to a nuclear incident involving the release of airborne radioactive material. It then describes application of the basic principles for selection of response levels set forth in Chapter 1 to the guidance on evacuation and sheltering in Chapters 2 and 5.

Response to a radiological emergency will normally be carried out in three phases, as discussed in Chapter 1. Decisions during the first (early) phase will usually be based on predicted or potential radiological conditions in the environment, rather than on actual measurements. The principal protective action is evacuation, with sheltering serving as a suitable alternative under some conditions. This appendix examines the potential magnitudes and consequences of predicted exposures of populations during the early phase, for selected nuclear reactor accident scenarios, in relation to the benefits and detrimental consequences of evacuation and sheltering. Nuclear reactor facilities are chosen for evaluation because, due to their number, size of source, and energy available to drive a release, they are most likely to provide an upper bound on the magnitude of the variety of possible sources of nuclear incidents. Although atmospheric releases from other types of nuclear incidents are likely to involve smaller consequences, the affected populations, and therefore the costs and benefits of protective action are each expected to scale in roughly the same proportion for lesser magnitude incidents. Thus, basic conclusions developed for responses to reactor facilities are assumed to remain valid for other types of nuclear incidents. Supplementary protective actions, such as washing and change of clothing to reduce exposure of the skin and use of stable iodine to reduce uptake of radioiodine to the thyroid, are also considered, but in less detail.

C.1.1 Existing Federal Guidance

In the 1960's, the Federal Radiation Council (FRC) defined PAGs and established limiting guides for ingestion of strontium-89, strontium-90, cesium-137, and iodine-131 (FR-64; FR-65). That guidance applied to restricting the use of food products that had become contaminated as the result of release of radioactivity to the stratosphere from weapons testing. During the period immediately following an incident at any domestic nuclear facility, when the

critical source of exposure is expected to be a nearby airborne plume, the principal protective actions are evacuation or sheltering. The PAGs developed here thus do not supersede previous guidance, but provide additional guidance for prompt exposure pathways specific to a domestic nuclear incident.

C.1.2 Principal Exposure Pathways

The immediate exposure pathway from a sub-stratospheric airborne release of radioactive materials is direct exposure from the cloud of radioactive material carried by prevailing winds. Such a plume can contain radioactive noble gases, iodines, and/or particulate materials, depending on the source involved and conditions of the incident. These materials emit gamma rays, which are not significantly absorbed by air, and will expose the entire bodies of nearby individuals.

Another immediate exposure pathway occurs when people are submerged in the cloud of radioactive materials. In this case radioactive materials are inhaled, and the skin and clothes may be contaminated. Inhaled radioactive materials, depending on their solubility in body fluids, may either remain in the lungs or move via the blood to other organs. Many radionuclides which enter the bloodstream tend to be predominantly concentrated in a single organ. For example, if radioiodines are inhaled, a significant fraction will tend to move rapidly from the lungs through the bloodstream to the thyroid gland where much of the iodine will be deposited and most of the dose[1] will be delivered. Although dose to skin from materials deposited on the skin and clothing could be significant, it will be less important in terms of risk of fatal cancer than dose from inhalation, if early protective actions include washing of exposed skin and changes of clothing.

As the plume passes over an area, radioactive materials may settle onto the ground and other surfaces. People remaining in the area will then continue to be exposed through ingestion and external radiation, and through inhalation of resuspended materials. The total dose from such deposited materials may be more significant than that due to direct exposure to the plume, because the term of exposure can be much longer. However, since the protective actions considered here (evacuation and/or sheltering) may not be appropriate or may not apply for this longer term exposure, doses from these exposures beyond the early phase are not included in the dose considered in the PAGs for the early phase. It is assumed that, within four days after an incident, the population will be

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[1]In this and all subsequent references, the word "dose" means the committed dose equivalent to the specified organ, or, if no organ is specified, the sum of the committed effective dose equivalent from intake of radionuclides and the effective dose equivalent from external sources of radiation. (Section B.1.1 contains a more detailed discussion of units of dose for PAGs.)

protected from these subsequent doses on the basis of the PAGs for relocation and for contaminated food and water. (See Chapters 3 and 4.)

Based on the foregoing considerations, the PAGs for the early phase are expressed in terms of estimated doses from exposure due to external radiation, inhalation, and contamination of the skin only during the early phase following an incident.

C.2 Practicality of Implementation

Whereas Appendix B deals with the risk associated with the projected dose that could be avoided by any protective action, this section addresses the costs and risks associated with evacuation itself. That is, these analyses relate to Principles 3 and 4 for deriving PAGs, set forth in Chapter 1, which address the practicality of protective actions, rather than acceptability of risks under Principles 1 and 2, which is evaluated in Appendix B.

The principal relevant protective actions during the early phase are, as noted earlier, evacuation and sheltering. In some cases, washing and changing of clothing, or thyroid blocking may also be appropriate actions. The costs, risks, and degrees of protection associated with evacuation are generally higher than those for sheltering. Although there may be some costs and risks associated with the other protective actions, they are small and not readily quantifiable. Therefore, only the costs and risks associated with evacuation will be evaluated here. These factors are evaluated to determine whether the costs are low enough to justify lower PAGs than would be required to satisfy upper bounds of acceptable risk under Principles 1 and 2.

C.2.1 Cost of Evacuation

Costs incurred to reduce the radiation risk from nuclear incidents can be considered to fall into several major categories. The first category includes the design, construction, and operation of nuclear facilities in such a manner as to minimize the probability and consequences of radiological incidents. It is recognized that the probability and consequences of such incidents usually cannot be reduced to zero. Therefore, a second category is necessary: the development of emergency response plans to invoke actions which would reduce exposure of potentially exposed populations, and consequently their risks, if a major nuclear incident should occur.

Both of the above categories of cost are properly attributed to the cost of design and operation of a nuclear facility. A third category of costs is the actual expenses incurred by taking protective actions as the result of an incident. In general, the choice of levels for PAGs will affect only this third category of costs. That is, all costs in the first two categories are assumed to be unaffected by decisions on the levels of PAGs. (This will be the case unless the PAGs were to be set so high as to never require protective action, in which case response plans

would be unnecessary.) Therefore, the costs associated with implementing the PAGs are evaluated only in terms of the actual cost of response. In a similar manner, the risk incurred by protective actions is compared only to the risk associated with the radiation dose that would be avoided by the action, and is unaffected by any other measures taken to reduce risks that fall in the first two categories of cost identified above.

C.2.1.1 Cost Assumptions

The analyses in this section are based on evaluation of the costs of evacuation and the doses that would be received in the absence of protective actions for nuclear reactor incidents. These were calculated as a function of offsite location, meteorological condition, and incident type (TA-87). Dose and cost data are based on the following assumptions:

1. Airborne releases are those associated with fuel melt accidents at nuclear reactor facilities followed by containment failure.

2. Meteorological conditions range from stable to unstable, and windspeeds are those typical of the stability class.

3. Plume dispersion follows a Gaussian distribution, with a 0.01 m/s dry deposition velocity for iodine and particulate materials.

4. Doses are those incurred from whole body gamma radiation from the plume, inhalation of radioactive material in the plume, and from four days exposure to deposited radioactive material.

5. Population distributions are the average values observed around 111 nuclear power reactor plants, based on 1970 data.

6. The cost of evacuation is $185 per person for a 4-day evacuation involving a 100-mile round trip, with an average of 3 persons per household. These evacuation costs include wages and salaries of personnel directing the evacuation, transportation costs of evacuees to and from the staging location, food and shelter for the evacuees during the evacuation period, loss of personal and corporate income during the evacuation period, and the costs of any special supplies (TA-87).

The estimated costs and doses avoided are based on the following idealized evacuation area model (see Figure C.1.):

1. All people within a 2-mile radius of the incident are evacuated for all scenarios.

2. People are also evacuated from a downwind area bounded by equivalent rays on either side of the center line of the plume, which define the angular spread (70, 90, or 180 degrees) of the area evacuated by an arc at the distance beyond which the evacuation dose would not be exceeded on the plume centerline.

Figure C-1 shows the relationship between the area in which the evacuation dose would be exceeded and the larger area that might be evacuated. The figure shows the plume centered in an idealized evacuation area.

C.2.1.2 Analysis

Evaluation of costs for evacuation and doses to populations as a function of the area evacuated depends on a variety of assumptions. Three fuel-melt accident categories, six meteorological stability classes, and the three evacuation area models discussed above were examined. Detailed assumptions and data are reported elsewhere (EP-87a). Selected data, including the cost per unit of collective dose to the population Figure C.1 (person-rem) avoided, are presented in Tables C-1, C-2, and C-3, for three stability classes, for the median nuclear accident category examined (SST-2). (SST accident categories are described in Section E.1.2).

The data are presented for both the total area and the incremental area evacuated for each change in dose level examined. When evaluating the cost per person-rem avoided for a specific set of circumstances, it is appropriate to assess the ratio of the total cost to the total dose avoided to calculate the average cost per person-rem avoided. However, when one is comparing the cost versus dose avoided to make a judgment between a variety of different limiting dose values, it is appropriate to compare the dose savings and costs at the margin, since the cost of evacuating the additional area is incurred to avoid the incremental collective dose. Therefore, the appropriate quantities are the cost and risk for the additional area evacuated. Results of analyses on both a total and incremental basis are presented in Tables C-1, C-2, and C-3 for accident category SST-2. This is the smallest category of fuel melt accident yielding effective dose equivalents during the first 4 days of exposure that are greater than 0.5 rem outside the assumed 2-mile evacuation circle for all stability classes. Data on costs versus dose saved for all three accident categories are summarized in Table C-4 in the next section.

Changes in population density would not affect the above results, since both cost and collective dose are proportional to the size of the population affected. Factors that could affect these results are different assumptions for cost of evacuation, accident scenarios, and evacuation area models. The results will be directly proportional to different assumptions for the cost of evacuation. Some data on the variation with accident scenario are presented in the next section. In situations where different widths of evacuation area are assumed, the change in cost per unit dose avoided will be approximately proportional to the change in width in degrees. This approximation is more accurate for the higher stability classes (E and F). Evacuation within a 2 mile radius circle and a 90 degree sector in the downwind direction is generally considered to be adequate for release

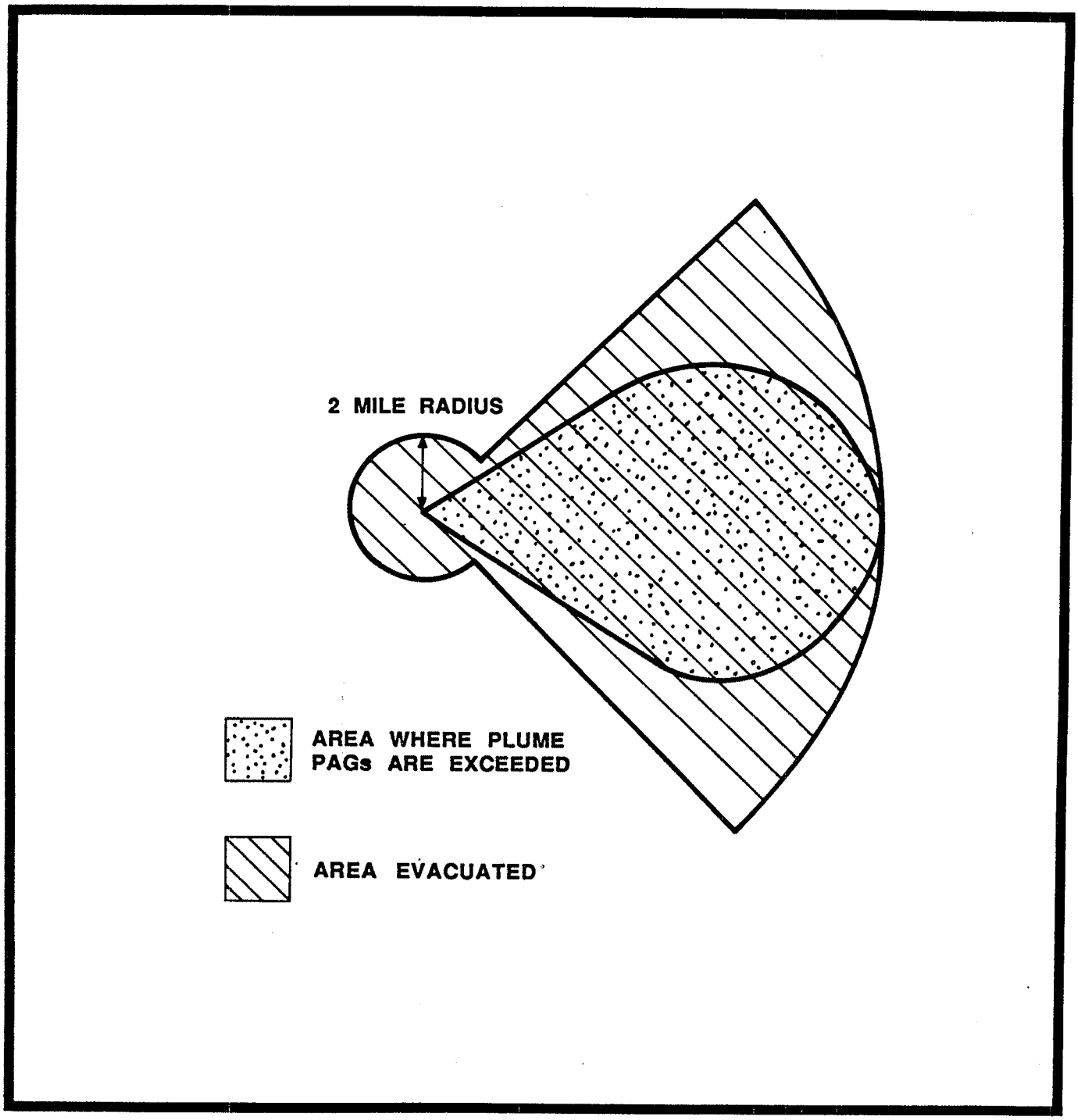

FIGURE C-1. EVACUATION MODEL.

Table C-1 Costs for Implementing Various PAGs for an SST-2 Type Accident (Stability Class A)

Evacuation angle (degrees)	PAG value (rem)	Total Area			Marginal Area		
		Cost (dollars)	Dose avoided (person-rem)	Dollars/ person-rem avoided	Δ Cost (dollars)	Δ Dose avoided (person-rem)	Δ Dollars/ Δperson-rem avoided
70	0.5	2.83E+7	8.97E+4	315			
	1	6.68E+6	4.06E+4	164	2.16E+7	4.91E+4	440
	2	1.49E+6	1.73E+4	88	5.19E+6	2.33E+4	223
	5	2.99E+5	5.22E+3	57	1.19E+6	1.21E+4	98
	10	(a)	(a)	(a)	9.70E+4	2.44E+3	40
90	0.5	3.63E+7	9.29E+4	391			
	1	8.54E+6	4.24E+4	201	2.78E+7	5.05E+4	550
	2	1.86E+6	1.82E+4	102	6.68E+6	2.42E+4	276
	5	3.26E+5	5.41E+3	60	1.54E+6	1.28E+4	120
	10	(a)	(a)	(a)	1.25E+5	2.63E+3	47
180	0.5	7.16E+7	9.33E+4	767			
	1	1.67E+7	4.27E+4	391	5.49E+7	5.06E+4	1080
	2	3.48E+6	1.84E+4	190	1.32E+7	2.43E+4	543
	5	4.48E+5	5.46E+3	82	3.04E+6	1.29E+4	235
	10	(a)	(a)	(a)	2.47E+5	2.68E+3	92

[a] The 4-day dose does not exceed the PAG outside the 2-mile radius of the accident site. The total cost of evacuation within this radius is 2.02E+5 dollars; the total dose avoided is 2.78E+3 person-rem; and the total cost per person-rem avoided is $73.

Table C-2 Costs for Implementing Various PAGs for an SST-2 Type Accident (Stability Class C)

Evacuation angle (degrees)	PAG value (rem)	Total Area			Marginal Area		
		Cost (dollars)	Dose avoided (person-rem)	Dollars/ person-rem avoided	Δ Cost (dollars)	Δ Dose avoided (person-rem)	Δ Dollars/ Δperson-rem avoided
70	0.5	4.95E+7	1.13E+5	439			
	1	1.23E+7	6.31E+4	195	3.71E+7	4.95E+4	750
	2	2.46E+6	3.73E+4	66	9.87E+6	2.58E+4	382
	5	7.82E+5	2.71E+4	29	1.68E+6	1.02E+4	165
	10	3.93E+5	2.10E+4	19	3.89E+5	6.15E+3	63
	20	2.60E+5	1.62E+4	16	1.32E+5	4.75E+3	28
	50	(a)	(a)	(a)	3.40E+4	2.50E+3	10
90	0.5	6.35E+7	1.13E+5	564			
	1	1.58E+7	6.32E+4	250	4.77E+7	4.95E+4	964
	2	3.11E+6	3.74E+4	83	1.27E+7	2.58E+4	491
	5	9.48E+5	2.72E+4	35	2.16E+6	1.02E+4	212
	10	4.47E+5	2.10E+4	21	5.00E+5	6.16E+3	81
	20	2.77E+5	1.63E+4	17	1.70E+5	4.76E+3	36
	50	(a)	(a)	(a)	3.40E+4	2.50E+3	14
180	0.5	1.25E+8	1.13E+5	1110			
	1	3.10E+7	6.32E+4	491	9.44E+7	4.95E+4	1910
	2	5.95E+6	3.74E+4	159	2.51E+7	2.58E+4	971
	5	1.68E+6	2.72E+4	62	4.28E+6	1.02E+4	419
	10	6.87E+5	2.10E+4	33	9.90E+5	6.16E+3	161
	20	3.51E+5	1.63E+4	22	3.36E+5	4.77E+3	70
	50	(a)	(a)	(a)	6.70E+4	2.50E+3	27

[a] The 4-day dose does not exceed the PAG outside the 2-mile radius of the accident site. The total cost of evacuation within this radius is 2.02E+5 dollars; the total dose avoided is 2.78E+3 person-rem; and the total cost per person-rem avoided is $73.

Table C-3 Costs for Implementing Various PAGs for an SST-2 Type Accident (Stability Class F)

Evacuation angle (degrees)	PAG value (rem)	Total Area			Marginal Area		
		Cost (dollars)	Dose avoided (person-rem)	Dollars/ person-rem avoided	Δ Cost (dollars)	Δ Dose avoided (person-rem)	Δ Dollars/ Δ person-rem avoided
70	0.5	8.95E+7	4.61E+5	194			
	1	4.95E+7	4.41E+5	112	4.01E+7	1.98E+4	2020
	2	2.83E+7	4.19E+5	67	2.12E+7	2.17E+4	977
	5	1.23E+7	3.83E+5	32	1.59E+7	3.66E+4	436
	10	6.68E+6	3.53E+5	19	5.65E+6	2.93E+4	193
	20	3.65E+6	3.22E+5	11	3.03E+6	3.18E+4	95
	50	1.49E+6	2.68E+5	5.6	9.70E+5	3.10E+4	32
90	0.5	1.15E+8	4.61E+5	250			
	1	6.35E+7	4.41E+5	144	5.15E+7	1.98E+4	2600
	2	3.63E+7	4.19E+5	87	2.72E+7	2.17E+4	1260
	5	1.58E+7	3.83E+5	41	2.05E+7	3.66E+4	560
	10	8.54E+6	3.53E+5	24	7.26E+6	2.93E+4	248
	20	4.64E+6	3.22E+5	14	3.90E+6	3.18E+4	123
	50	1.86E+6	2.68E+5	6.9	1.30E+6	3.10E+4	41
180	0.5	2.27E+8	4.61E+5	493			
	1	1.25E+8	4.41E+5	285	1.02E+8	1.99E+4	5120
	2	7.16E+7	4.19E+5	171	5.39E+7	2.17E+4	2480
	5	3.10E+7	3.83E+5	81	4.05E+7	3.66E+4	1110
	10	1.67E+7	3.53E+5	47	1.44E+7	2.92E+4	492
	20	8.98E+6	3.22E+5	28	7.71E+6	3.18E+4	242
	50	3.51E+6	2.68E+5	13	2.40E+6	3.10E+4	80

durations not exceeding a few hours and where reliable wind direction forecasts are available.

C.2.1.3 Conclusions

As shown in Tables C-1, C-2, and C-3 for an SST-2 accident, the cost per unit dose avoided is greatest for wide angle evacuation and for the most stable conditions, class (F). Although a few emergency plans call for evacuation over wider angles (up to 360 degrees), the model shown in Figure C-1 with a 90 degree angle is most common.

To estimate an upper bound on dose for evacuation based on cost, we first consider common values placed on avoiding risk. As one input into its risk management decisions, EPA has used a range of $400,000 to $7,000,000 as an acceptable range of costs for avoiding a statistical death from pollutants other than radiation. For a risk of $3x10^{-4}$ cancer deaths per person-rem (see Appendix B), these dollar values are equivalent to a range of from about $120 to $2,000 per person-rem avoided. These values can be compared to the marginal cost-effectiveness (dollars per person-rem) of evacuation over an angle of 90 degrees. The resulting ranges of upper bounds on dose are shown in Table C-4 for SST-1, SST-2, and SST-3 accident scenarios. The maximum upper bounds (based on minimum costs for avoiding risk) range from 1 to 10 rem, with most values being approximately 5 rem. The minimum upper bounds (based on maximum costs for avoiding risk) range from 0.15 to 0.8 rem, with 0.5 rem being representative of most situations. From these data we conclude that, based on the cost of evacuation, a PAG larger than the range of values 0.5 to 5 rem would be incompatible with Principle 3.

C.2.2 Risk of Evacuation

Principle 4 requires that the risk of the protective action not exceed the risk associated with the dose that will be avoided. Risk from evacuation can come from several sources, including (1) transportation incidents for both pedestrians and vehicle passengers, (2) exposure to severe weather conditions or a competing disaster, and (3), in the case of immobile persons, anxiety, unusual activity, and separation from medical care or services. The first source, transportation incidents, is the only category for which the risk has been quantified. An EPA report (HA-75) evaluated the risk of transportation fatalities associated with emergency evacuations that have actually occurred and concluded that the risk of death per mile traveled is about the same as that for routine automobile travel. Using this as a basis, the risk of death from travel is about $9x10^{-8}$ deaths per person-mile, or $9x10^{-6}$ deaths per person for the 100-mile round trip assumed for evacuation. Assuming a risk of fatal cancer from radiation of approximately $3x10^{-4}$ per person-rem, such an evacuation risk is equivalent to a dose of about 0.03 rem.

Table C-4 Upper Bounds on Dose for Evacuation, Based on the Cost of Avoiding Fatalities[a]

Accident Category	Atmospheric Stability Class	Dose Upper Bounds[b,c] Maximum (rem)	Minimum (rem)
SST-1	A	5	0.4
	C	5	0.4
	F	10	0.8
SST-2	A	1	0.15
	C	3.5	0.25
	F	10	0.7
SST-3	A	(d)	(d)
	C	(d)	(d)
	F	5	0.45

[a] Based on data from EP-87a.

[b] Windspeeds typical of each stability class were chosen.

[c] Based on an assumed range of $400,000 to $7,000,000 per life saved.

[d] For stability classes A and C, the dose from an SST-3 accident is not predicted to exceed 0.5 rem outside a 2-mile radius. It is assumed that evacuation inside this radius would be carried out based on the emergency condition on the site. No differential evacuation costs were calculated within this area.

In comparing this risk (or, more exactly, its equivalent in dose) to the risk avoided by evacuation, it is important to note that protective action must be implemented over a larger population than will actually be exposed at the level of the PAG. Because of uncertainty or unpredictable changes in wind direction, the exact location of the plume will not be precisely known. Dose projections are made for the maximum exposed individuals - those at the assumed location of the plume centerline. To assure that these individuals will be protected, it is necessary that others on either side take protective action at exposures that are less than at the plume centerline, and, in some cases, are zero. Thus, the entire evacuated population could incur, on the average, a risk from the protective action which exceeds the risk of the radiation dose avoided. Although it is not possible to assure that no individuals incur risks from evacuation greater than their radiation risks, we can assure that this does not

occur, on the average, at the outer margin of the evacuation area. For this reason, we also examined the average dose avoided for the incrementally evacuated population for various choices of evacuation levels. Table C-5 presents the results, which are derived from the data in Tables C-1, C-2, and C-3. For the levels analyzed, the average dose avoided is always significantly greater than 0.03 rem. We conclude, therefore, that the choice of PAGs will not be influenced by Principle 4, for persons in the general population whose risk from evacuation is primarily the normal risk of transportation, if the centerline dose avoided is at or above 0.5 rem.

As previously discussed, hazardous environmental conditions (e.g., severe weather or a competing disaster) could create transportation risks from evacuation that would be higher than normal. It is therefore appropriate to make an exception to allow higher projected doses for evacuation decisions under these circumstances. In the absence of any definitive information on such higher risks from evacuation, we have arbitrarily assumed that it would be appropriate to increase the recommended projected dose for evacuation of the general population under hazardous environmental conditions up to a factor of 5 higher than that used under normal environmental conditions.

Table C-5 Average Dose Avoided per Evacuated Individual for Incremental Dose Levels for Evacuation

Centerline dose (rem)	Average dose avoided (rem per individual) by stability class		
	A	C	F
0.5 to 1	0.34	0.19	0.07
1 to 2	0.67	0.38	0.15
2 to 5		0.87	0.33
5 to 10			0.75

It is also recognized that those persons who are not readily mobile are at higher risk from evacuation than are average members of the population. It would be appropriate to adopt higher PAGs for evacuation of individuals who would be at greater risk from evacuation itself than for the typically healthy members of the population, who are at low risk from evacuation. In the absence of definitive information

on the higher risk associated with the evacuation of this group, we have arbitrarily assumed that it is appropriate to adopt PAGs a factor of five higher for evacuation of high risk groups under normal environmental conditions. If both conditions exist, (high risk groups and hazardous environmental conditions) projected doses up to 10 times higher than the PAGs for evacuation of the general population under normal conditions may be justified. These doses are expected to satisfy Principle 4 without violating Principles 1 and 3. Although they violate Principle 2, Principle 4 becomes, for such cases, the overriding consideration.

C.2.3 Thyroid Blocking

The ingestion of stable potassium iodide (KI) to block the uptake of radioiodine by the thyroid has been identified as an effective protective action. The Food and Drug Administration (FDA) analyzed available information on the risk of radioiodine-induced thyroid cancers and the incidence and severity of side effects from potassium iodide (FD-82). They concluded "...risks from the short-term use of relatively low doses of potassium iodide for thyroid blocking in a radiation emergency are outweighed by the risks of radioiodine-induced thyroid nodules or cancer at a projected dose to the thyroid gland of 25 rem. FDA recommends that potassium iodide in doses of 130 milligrams (mg) per day for adults and children above 1 year and 65 mg per day for children below 1 year of age be considered for thyroid blocking in radiation emergencies in those persons who are likely to receive a projected radiation dose of 25 rem or greater to the thyroid gland from radioiodines released into the environment. To have the greatest effect in decreasing the accumulation of radioiodine in the thyroid gland, these doses of potassium iodide should be administered immediately before or after exposure. If a person is exposed to radioiodine when circumstances do not permit the immediate administration of potassium iodide, the initial administration will still have substantial benefit even if it is taken 3 or 4 hours after acute exposure". Evacuation and sheltering are, however, preferred alternatives for most situations because they provide protection for the whole body and avoid the risk of misapplication of potassium iodide.

The Federal Emergency Management Agency has published a Federal policy developed by the Federal Radiological Preparedness Coordinating Committee regarding the use of KI as a protective action (FE-85). In summary, the policy recommends the stock-piling of KI and distribution during emergencies to emergency workers and institutionalized persons, but does not recommend requiring stockpiling or distribution to the general public. The policy recognizes, however, that options on the distribution and use of KI rests with the States and, hence, the policy statement permits State and local governments, within the limits of their authority, to take measures beyond

those recommended or required nationally.

C.2.4 Sheltering

Sheltering means staying inside a structure with doors and windows closed and, generally, with exterior ventilation systems shut off. Sheltering in place (i.e. at or near the location of an individual when the incident occurs) is a low-cost, low-risk protective action that can provide protection with an efficiency ranging from almost 100 percent to zero, 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. The degree of protection provided by a structure is governed by attenuation of radiation by structural components (the mass of walls, ceilings, etc.) and by its outside/inside air-exchange rate. These two protective characteristics are considered separately.

The protection factor may be characterized by a dose reduction factor (DRF), defined as:

$$\text{DRF} = \frac{\text{dose with protective action}}{\text{dose without protective action}}$$

The shielding characteristics of most structures for gamma radiation can be categorized based on whether they are "small" or "large." Small structures are primarily single-family dwellings, and large structures include office, industrial, and commercial buildings. The typical attenuation factors given in Table C-6 show the importance of the type of structure for protection from external gamma radiation (EP-78a). If the structure is a wood frame house without a basement, then sheltering from gamma radiation would provide a DRF of 0.9; i.e., only 10 percent of the dose would be avoided. The DRFs shown in Table C-6 are initial values prior to infiltration of contaminated air, and therefore apply only to short duration plumes. The values will increase with increasing time of exposure to a plume because of the increasing importance of inside-outside air exchange. However, this reduction

Table C-6 Representative Dose Reduction Factors for External Radiation

Structure	DRF	Effectiveness (percent)
Wood frame house (first floor)	0.9	10
Wood frame house (basement)	0.6	40
Masonry house	0.6	40
Large office or industrial building	0.2 or less	80 or better

in efficiency is not dramatic for source terms involving primarily gamma radiation, because most of the dose arises from outside, not from the small volume of contaminated air inside a shelter. Therefore, most shelters will retain their efficiency as shields against gamma radiation, even if the concentration inside equals the concentration outside.

The second factor is the inside/outside air exchange rate. This factor primarily affects protection against exposure by inhalation of airborne radionuclides with half lives long compared to the air exchange rate. The factor is expressed as the number of air exchanges per hour, L (h^{-1}), or the volume of fresh air flowing into and out of the structure per hour divided by the volume of the structure. Virtually any structure that can be used for sheltering has some degree of outside/inside air exchange due to natural ventilation, forced ventilation, or uncontrollable outside forces, primarily wind.

Assuming constant atmospheric and source conditions and no effects from filtration, deposition, or radioactive decay, the following model can be used to estimate the buildup of indoor concentration of radioactivity, for a given outdoor concentration, as a function of time after appearance of the plume and of ventilation rate:

$$C_i = C_o(1 - e^{-Lt}),$$

where C_i = concentration inside,

C_o = concentration outside,

L = ventilation rate (h^{-1}), and

t = elapsed time (h).

Typical values for ventilation rates range from one-fifth to several air exchanges per hour. In the absence of measurements, an air exchange rate of 1.0/h may be assumed for structures with no special preparation except for closing the doors and windows. An air exchange rate of 0.3/h is appropriate for relatively air-tight structures, such as well-sealed residences, interior rooms with doors chinked and no windows, or large structures with ventilation shut off. Using the above model to calculate indoor concentration relative to outdoor concentration after one, two, and four complete air exchanges, the indoor concentration would be about 64 percent, 87 percent, and 98 percent of the outside concentration, respectively. It is apparent that staying in a shelter for more time than that required for one or two complete air exchanges is not very effective for reducing inhalation exposure.

The inhalation DRF is equal to the ratio of the average inside to outside air concentration over the period of sheltering. Studies have been conducted of typical ventilation rates for dwellings (EP-78a) and for large commercial structures (GR-86). In each case the rate varies according to the air tightness of the structure, windspeed, and the indoor-to-outdoor temperature difference. For the purpose of deriving PAGs, average ventilation rates were chosen for the two types of structures that are of

greatest interest. Table C-7 shows calculated dose reduction factors for inhalation exposure as a function of plume duration, for beta-gamma source terms, assuming average ventilation rates for these structures.

A potential problem with sheltering is that persons may not leave the shelter as soon as the plume passes and, as a result, will receive exposure from radioactive gases trapped inside. The values for DRFs tabulated in Table C-7 ignore this potential additional contribution. This effect is generally minor for gamma dose (generally less than a 10 percent increase in the dose received during plume passage, (EP-78b)), but can be greater for inhalation dose.

Doses from inhalation during sheltering can be reduced in several ways, including reducing air exchange rates by sealing cracks and openings with cloth or weather stripping, tape, etc., and filtering the inhaled air with commonly available items like wet towels and handkerchiefs. Analyses for some hypothesized accidents, such as short-term transuranic releases, show that sheltering in residences and other

Table C-7 Dose Reduction Factors for Sheltering from Inhalation of Beta-Gamma Emitters

Ventilation rate (air changes/h)	Duration of plume exposure(h)	DRF
0.3[a]	0.5	0.07
	1	0.14
	2	0.25
	4	0.41
	6	0.54
1.0[b]	0.5	0.21
	1	0.36
	2	0.56
	4	0.75
	6	0.83

[a]Applicable to relatively "airtight" structures such as well- sealed residences, interior rooms with chinked doors and no windows, or large structures with outside ventilation shut off.

[b]Applicable to structures with no special preparation except for closing of doors and windows.

buildings can be more effective than for beta-gamma emitters, may provide adequate protection, and may be more effective than evacuation when evacuation cannot be completed before plume arrival (DO-90). However, sheltering effectiveness for the inhalation exposure pathway can be reduced drastically by open windows and doors or by forced air ventilation. Therefore, reliance on protection assumed to be afforded based on large dose reduction factors for sheltering should be accompanied by cautious examination of possible failure mechanisms, and, except in very unusual circumstances, should not be relied upon at projected doses greater than 10 rem. Such analysis should be based on realistic or "best estimate" dose models and include consideration of unavoidable dose if evacuation were carried out.

C.3 Recommended PAGs for Exposure to a Plume during the Early Phase

The four principles which form the basis for the selection of PAG values are presented in Chapter 1. The risks of health effects from radiation that are relevant to satisfying Principles 1 and 2 are presented in Appendix B and analyses of the costs and risks associated with evacuation relative to Principles 3 and 4 have been presented in this appendix. These results, for application to the early phase, are summarized in Table C-8.

The following describes how these results lead to the selection of the PAGs. Conformance to Principle 1 (avoidance of acute health effects) is assured by the low risk required to satisfy Principle 2, and thus requires no additional consideration. Principle 2 (acceptable risk of delayed health effects) leads to the choice of 0.5 rem as an upper bound on the avoided dose below which evacuation of the general population is justified under normal conditions. This represents a risk of about 2E-4 of fatal cancer. Maximum lifetime risk levels considered acceptable by EPA from routine operations of individual sources range from 1E-6 to 1E-4. Risk levels that are higher than this must be justified on the basis of the emergency nature of a situation. In this case, we judge that up to an order of magnitude higher combined risk from all phases of an incident may be justifiable. The choice of 0.5 rem avoided dose as an appropriate criterion for an acceptable level of risk during the early phase is a subjective judgment that includes consideration of possible contributions from exposure during other phases of the incident, as well as the possibility that risk estimates may increase moderately in the near future as a result of current reevaluations of radiation risk.

Principle 4 (risk from the protective action must be less than that from the radiation risk avoided) supplies a lower bound of 0.03 rem on the dose at which evacuation of most members of the public is justified. Finally, under Principle 3 (cost/risk considerations) evacuation is justified only at values equal to or greater than 0.5 rem. This will be limiting unless lower values are required for purely health-based

Table C-8 Summary of Considerations for Selecting the Evacuation PAGs.

Dose (rem)	Consideration	Principle	Section
50	Assumed threshold for acute health effects in adults.	1	B.2.1.4
10	Assumed threshold for acute health effects in the fetus.	1	B.2.1.4
5	Maximum acceptable dose for normal occupational exposure of adults.	2	C.5
5	Maximum dose justified to average members of the population, based on the cost of evacuation.	3	C.2.1.3
0.5	Maximum acceptable dose to the general population from all sources from nonrecurring, non-accidental exposure.	2	B.4.4
0.5	Minimum dose justified to average members of the population, based on the cost of evacuation.	3	C.2.1.3
0.5	Maximum acceptable dose[a] to the fetus from occupational exposure of the mother.	2	C.5
0.1	Maximum acceptable dose to the general population from all sources from routine (chronic), nonaccidental exposure.	2	B.4.4
0.03	Dose that carries a risk assumed to be equal to or less than that from evacuation.	4	C.2.2

[a]This is also the dose to the 8- to 15-week-old fetus at which the risk of mental retardation is assumed to be equal to the risk of fatal cancer to adults from a dose of 5 rem.

reasons (Principle 2). But this is not the case. The single lower purely health-based value, 0.1 rem, is only valid as a health-based criterion for chronic exposure.

In summary, we have selected the value 0.5 rem as the avoided dose which justifies evacuation, because 1) it limits the risk of delayed effects on health to levels adequately protective of public health under emergency conditions, 2) the cost of implementation of a lower value is not justified, and 3) it satisfies the two bounding requirements to avoid acute radiation effects and to avoid increasing risk through the protective action itself. We note that this choice also satisfies the criterion for acceptable risk to the fetus of occupationally exposed mothers (as well as falling well below dose values at which abortion is recommended).

As noted in Section C.2.4, we assume that the dose normally avoidable by evacuation (the dose that is not avoided by the assumed alternative of sheltering) is one half of the projected dose. The value of the PAG for evacuation of the general public under normal circumstances is therefore chosen as one rem projected sum of the committed effective dose equivalent from inhalation of radionuclides and effective dose equivalent from exposure to external radiation.

The above considerations apply to evacuation of typical members of the population under normal circumstances, and apply to effective doses (i.e. the weighted sum of doses to all organs). As discussed in previous sections, it may be appropriate to further limit dose to the thyroid and skin, to adjust the value for special groups of the population at unusually high risk from evacuation, and to provide for situations in which the general population may be at higher than normal risk from evacuation. These are addressed, in turn, below.

In the case of exposure of the thyroid to radioiodine, action based solely on effective dose would not occur until a thyroid dose about 33 times higher than the corresponding effective dose to the entire body. As noted in Section B.4.1.1, because the weighting factor for thyroid used to calculate effective dose does not reflect the high ratio of curable to fatal thyroid cancers, protective action to limit dose to the thyroid is recommended at a thyroid dose 5 times the numerical value of the PAG.

Similarly, since effective dose does not include dose to the skin, and for other reasons discussed in Section B.4.1.2, protective action to limit dose to skin is recommended at a skin dose 50 times the numerical value of the PAG. As in the case of the thyroid, this includes consideration of the risk of both curable and noncurable cancers.

Special risk groups include fetuses, and persons who are not readily mobile. As noted in Sections B.4.1.3 and B3, we assume that the risk of radiation-induced cancer is about 5 to 10 times higher for fetuses than for adults and that the risk of mental

retardation in fetuses exposed during the 8th to 15th weeks of gestation is about 10 times higher than the risk of fatal cancer in equivalently exposed adults. However, due to the difficulty of rapidly evacuating only pregnant women in a population, and the assumed higher-than-average risk associated with their evacuation, it is not considered appropriate to establish separate PAGs for pregnant women. We note that the PAG is chosen sufficiently low to satisfy Federal guidance for limiting exposure of the fetus in pregnant workers.

Higher PAGs for situations involving higher risks from evacuation were discussed in Section C.2.2. Under normal, low-risk, environmental conditions, PAGs for evacuation of groups who present higher than average risks from evacuation (e.g., persons who are not readily mobile) are recommended at projected doses up to 5 rem. Evacuation of the general population under high-risk environmental conditions is also recommended at projected doses up to 5 rem. If evacuation of high risk groups under hazardous environmental conditions is being considered, projected doses up to 10 rem may, therefore, be justified.

Short-term sheltering is recognized as a low-cost, low-risk, protective action primarily suited for protection from exposure to an airborne plume. Sheltering will usually be clearly justified to avoid projected doses above 0.5 rem, on the basis of avoidance of health risks. However, data are not available to establish a lower level at which sheltering is no longer justified because of its cost or the risk associated with its implementation. Sheltering will usually have other benefits related to emergency communication with members of the public. It is expected that protective action planners and decision authorities will take into account the added benefits of sheltering (e.g., communication and established planning areas) for decisions on sheltering at levels below 0.5 rem.

Bathing and changing of clothing are effective for reducing beta dose to the skin of persons exposed to an airborne plume of radioactive materials. Since these are also low-cost, low-risk actions, no PAG is recommended for initiating their implementation. It is expected that any persons exposed in areas where evacuation is justified based on projected dose from inhalation will be routinely advised by emergency response officials to take these actions within 12 hours after exposure.

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 where evacuation cannot be implemented. If procedures are included in the applicable emergency response plan, use of stable iodine should be considered for any such situation in which evacuation or sheltering will not be effective in preventing thyroid doses of 25 rem (see also C.2.3).

C.4 Comparison to Previous PAGs

This section compares the level of protection provided by the previously published PAGs for evacuation (one rem external gamma dose from the plume and 5 rem committed dose to the thyroid from inhalation, under normal evacuation circumstances) with this PAG. The effective dose addressed by this PAG, as well as skin, thyroid, and external gamma doses from the plume during the early phase from the three major exposure pathways for an airborne release were calculated for radionuclide mixes postulated for three nuclear power plant accident sequences. The doses were then normalized for each accident so that they represent a location in the environment where the controlling dose would be equal to the current PAG. These results are shown in Table C-9.

Based on the results shown in Table C-9, the following conclusions are

Table C-9. Comparison of Projected Doses for Various Reactor Accident Scenarios[a]

Accident category[b]	Effective dose equivalent[c] (rem)	Skin dose[d] (rem)	Thyroid dose[e] (rem)	External dose[f] (rem)
SST-1	0.7	6	5	0.02
SST-2	1	5	5	0.4
SST-3	0.4	6	5	0.1

[a]Doses are normalized to the limiting PAG.

[b]See Table E-1 for a description of these accident scenarios.

[c]The dose is the sum of doses from 4-day exposure to external gamma radiation from deposited materials, external exposure to the plume, and the committed effective dose equivalent from inhalation of the plume.

[d]The dose equivalent from external beta radiation from the plume and from 12 hours exposure to materials deposited on skin and clothing.

[e]Committed dose equivalent to the thyroid from inhalation.

[f]External gamma dose equivalent from the plume.

apparent, for the accident sequences analyzed:

1. The PAG for the thyroid is controlling for all three accident categories. For the SST-2 category, effective dose is also controlling. Thus,application of the previous PAG (5 rem) for thyroid would provide the same protection as the revised PAG for all three accident categories.

2. Skin doses will not be controlling for any of the accident sequences (if bathing and change of clothing is completed within 12 hours of plume passage, as assumed).

3. Gamma dose from direct exposure to the plume is small compared to the effective dose from the three major exposure pathways combined.

In summary, for the accident sequences analyzed, the old PAGs provide the same level of protection as the new PAGs. For releases that contain a smaller fraction radioiodines than these accident scenarios the new PAGs are slightly more protective.

C.5 Dose Limits for Workers Performing Emergency Services

Dose limits for workers during emergencies are based on avoiding acute health effects and limiting the risk of delayed health effects, in the context of the need to assure protection of the population and of valuable properties. It is assumed that most such workers are accustomed to accepting an element of risk as a condition of their employment. Examples of occupations that may be affected include law enforcement, firefighting, radiation protection, civil defense, traffic control, health services, environmental monitoring, animal care, and transportation services. In addition, selected workers at utility, industrial, and at farms and other agribusinesses 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 during emergencies.

Radiation exposure of workers during an emergency should normally be governed by the Federal Radiation Protection Guidance for Occupational Exposure (EP-87). This guidance specifies an upper bound of five rem committed effective dose equivalent per year for most workers. (Pregnant women, who, under this guidance should not normally engage in work situations that involve more than approximately 50 mrem/month, would normally be evacuated as part of the general population.) The guidance also specifies that doses to workers should be maintained as low as reasonably achievable; that doses should be monitored; and that workers should be informed of the risks involved and of basic principles for radiation protection.

There are some emergency situations, however, for which higher doses may be justified. These include lifesaving operations and the protection of valuable property. International guidance (IC-77) recognizes two

additional dose levels for workers under specially justified circumstances: two times the annual limit for any single event, and five times the annual limit in a lifetime. The dose limits recommended here adopt the former value (10 rem) for operations limited to the protection of valuable property. The latter value (25 rem) may be permitted for situations involving lifesaving operations or activities that are essential to preventing substantial risks to populations. In this context "substantial risks" means collective doses that are significantly larger than those incurred through the protective activities engaged in by the workers. Workers should not operate under dose limits higher than five rem unless the following conditions are satisfied:

1. Lower doses through the rotation of workers or other commonly-used dose reduction methods are not possible, and

2. Instrumentation is available to measure their exposure.

In addition to the limitation on effective dose equivalent, the dose equivalent received in any year by workers under normal occupational conditions is limited to 15 rem to the lens of the eye and 50 rem to any other organ, tissue (including skin), or extremity of the body. (Extremity is defined as the forearms and hands or the lower legs and feet (EP-87).) By analogy to these dose limits for organs and extremities, the limits for workers performing the various categories of emergency services are established at numerical values that are 5 times the limits for effective dose to the lens of the eye and 10 times the limits for effective dose to any other organ, tissue (including skin), or extremity of the body.

Situations may occur in which a dose in excess of 25 rem would be required for lifesaving operations. It is not possible to prejudge the risk that one person should be allowed to take to save the life of another. However, persons undertaking an emergency mission in which the dose would 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.

The risk of acute health effects is discussed in B.2. Table C-10 presents estimated cancer mortality rates for a dose of 25 rem, as a function of age at the time of exposure. The risk of cancer from moderately higher doses will increase proportionately. These values were calculated using risk estimates from BEIR-3 (NA-80) as discussed in Section B.4, and life table analyses that assume the period of cancer risk lasts for the worker's lifetime (BU-81). The risk was calculated for the midpoint of each age range. Roughly equivalent risks of nonfatal cancer and serious genetic effects (if gonadal tissue is exposed) will also be incurred.

The dose limits of 75 rem to the whole body previously recommended by EPA and 100 rem that has been

recommended by NCRP (GL-57) for lifesaving action represents a very high level of risk of acute and delayed health effects. A dose of 100 rem is expected to result in an approximately 15 percent risk of temporary incapacity from nonlethal acute effects and an indeterminate, but less than 5 percent, chance of death within 60 days. This is in addition to a risk of about 1 in 30 of incurring fatal cancer. Such high risk levels can only be accepted by a recipient who has been made aware of the risks involved. Therefore, no absolute dose limit for lifesaving activities is offered.

Table C-10 Cancer Risk to Emergency Workers Receiving 25 Rem Whole Body Dose

Age of the emergency worker at time of exposure (years)	Approximate 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

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APPENDIX D

Background for Protective Action Recommendations: Accidental Radioactive Contamination of Food and Animal Feeds*

*This background document concerning food and animal feeds was published by the Food and Drug Administration in 1982.

APPENDIX E

Protective Action Guides for the Intermediate Phase

(Relocation)

Background Information

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Appendix E

Protective Action Guides for the Intermediate Phase (Relocation) Background Information

E.1 Introduction

This Appendix provides background information for the choice of Protective Action Guides (PAGs) for relocation and other protective actions to reduce exposure to deposited radioactive materials during the intermediate phase of the response to a nuclear incident. The resulting PAGs and associated implementing guidance are provided in Chapters 4 and 7, respectively.

This analysis is based on the assumption that an airborne plume of radioactive material has already passed over an area and left a deposit of radioactive material behind, or that such material exists from some other source, and that the public has already been either sheltered or evacuated, as necessary, on the basis of PAGs for the early phase of a nuclear incident, as discussed in Chapters 2 and 5. PAGs for subsequent relocation of the public and other protective actions, as well as dose limits for persons reentering the area from which the public is relocated, are addressed in this Appendix.

We first set forth the assumptions used to derive information pertinent to choosing the dose level at which relocation of the public is appropriate. This is followed by an examination of information relevant to this decision, and selection of the PAG for relocation. The Appendix concludes with a brief discussion of the basis for dose limits for persons temporarily reentering areas from which the public has been relocated.

E.1.1 Response Duration

In order to decide whether to initiate relocation of the public from specific areas it is necessary to predict the dose that would be avoided. One factor in this prediction is the duration of the exposure to be avoided. Relocation can begin as soon as patterns of exposure from deposited radioactivity permit restricted areas to be identified. For the purpose of this analysis, relocation of persons who have not already been evacuated from the restricted zone is assumed to take place on the fourth day after the incident. Return of evacuated persons to their residences outside the restricted zone and transition to relocation status of persons already evacuated is assumed to occur over a period of a week or more.

The period of exposure avoided by relocation ends when the relocated person either returns to his property or is permanently resettled in a new

location. At the time of relocation decisions, it will usually not be possible to predict when either of these actions will occur. Therefore, for convenience of dose projection, it is assumed that the period of exposure avoided is one year and that any extension beyond this period will be determined on the basis of recovery criteria. This assumption corresponds to emergency response planning guidance by ICRP (IC-84) and IAEA (IA-85).

E.1.2 Source Term

The "source term" for this analysis is comprised of the quantities and types of particulate radioactive material found in the environment following a nuclear incident. Nuclear incidents can be postulated with a wide range of release characteristics. The characteristics of the source terms assumed for the development of these PAGs are those postulated for releases from various types of fuel-melt accidents at nuclear power plants (SN-82). Table E-1 provides brief descriptions of these accident types. Radionuclide releases have been estimated for the three most severe accident types (SST-1, SST-2, SST-3) based on postulated core inventories and release fractions (Table E-2). The other types (SST-4 and SST-5) would generally not produce offsite doses from exposure to deposited material sufficient to warrant consideration of relocation.

Table E-1 Brief Descriptions Characterizing Various Nuclear Power Plant Accident Types (SN-82)

Type	Description
SST-1	Severe core damage. Essentially involves loss of all installed safety features. Severe direct breach of containment.
SST-2	Severe core damage. Containment fails to isolate. Fission product release mitigating systems (e.g., sprays, suppression pool, fan coolers) operate to reduce release.
SST-3	Severe core damage. Containment fails by base-mat melt-through. All other release mitigation systems function as designed.
SST-4	Modest core damage. Containment systems operate in a degraded mode.
SST-5	Limited core damage. No failures of engineered safety features beyond those postulated by the various design basis accidents. Containment is assumed to function for even the most severe accidents in this group.

Table E-2 Release Quantities for Postulated Nuclear Reactor Accidents

Principal radionuclides contributing to dose from deposited materials	Half-life (days)	Estimated quantity released[a] (Curies)		
		SST-1	SST-2	SST-3
Zr-95	6.52E+1	1.4E+6	4.5E+4	1.5E+2
Nb-95	3.50E+1	1.3E+6	4.2E+4	1.4E+2
Ru-103	3.95E+1	6.0E+6	2.4E+5	2.4E+2
Ru-106	3.66E+2	1.5E+6	5.8E+4	5.8E+1
Te-132	3.25	8.3E+7	3.9E+6	2.6E+3
I-131	8.05	3.9E+7	2.6E+5	1.7E+4
CS-134	7.50E+2	8.7E+6	1.2E+5	1.3E+2
CS-137	1.10E+4	4.4E+6	5.9E+4	6.5E+1
Ba-140	1.28E+1	1.2E+7	1.7E+5	1.7E+2
La-140	1.67	1.5E+6	5.1E+4	1.7E+2

[a]Based on the product of reactor inventories of radionuclides and estimated fractions released for three accident categories (SN-82).

For other types of source terms, additional analysis may be necessary to assure adequate protection. For example, if the release includes a large proportion of long-lived radionuclides, doses will continue to be delivered over a long period of time, and, if no remedial actions are taken, the dose delivered in the first year may represent only a small portion of the total dose delivered over a lifetime. On the other hand, if the release consists primarily of short-lived radionuclides, almost the entire dose may be delivered within the first year.

From the data in Table E-2, it is apparent that, for the groups of accidents listed, both long and short lived radionuclides would be released. Consequently, doses due to deposited materials from such accidents would be relatively high during the first year followed by long term exposures at lower rates.

E.1.3 Exposure Pathways

The principal exposure pathway to members of the public occupying land contaminated by deposits of radioactive materials from reactor incidents is expected to be exposure of the whole body to external gamma radiation. Although it is normally expected to be of only minor importance, the inhalation pathway would contribute

additional doses to internal organs. The health risks from other pathways, such as beta dose to the skin and direct ingestion of dirt, are also expected to be minor in comparison to the risks due to external gamma radiation (AR-89). Skin and inhalation dose would, however, be important exposure pathways for source terms with significant fractions of pure beta emitters, and inhalation dose would be important for source terms with significant fractions of alpha emitters.

Since relocation, in most cases, would not be an appropriate action to prevent radiation exposure from ingestion of food and water, these exposure pathways have not been included in this analysis. They are addressed in Chapters 3 and 6. In some instances, however, where withdrawal of food and/or water from use would, in itself, create a health risk, relocation may be an appropriate alternative protective action. In this case, the committed effective dose equivalent from ingestion should be added to the projected dose from deposited radionuclides via other pathways, for decisions on relocation.

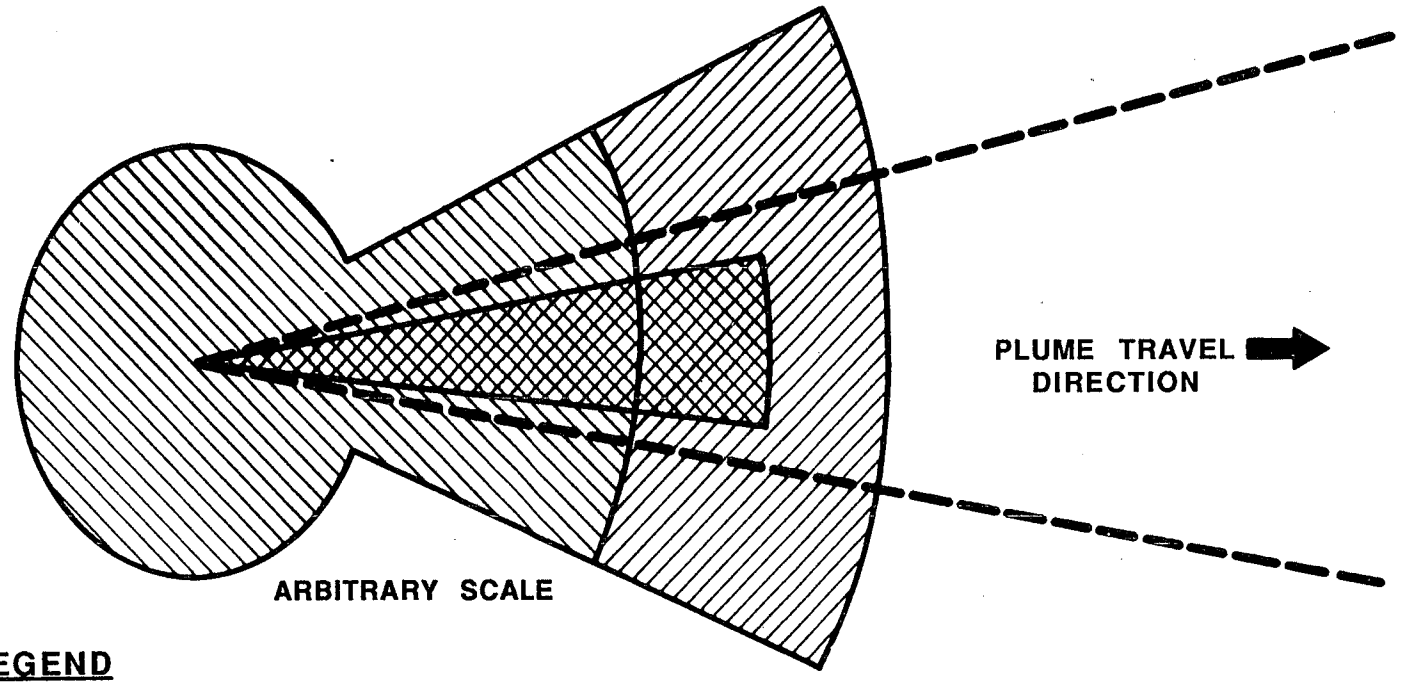
E.1.4 Response Scenario

This section defines the response zones, population groups, and the activities assumed for implementation of protective actions during the intermediate phase.

After passage of the radioactive plume, the results of environmental monitoring will become available for use in making decisions to protect the public. Sheltering, evacuation, and other actions taken to protect the public from the plume will have already been implemented. The tasks immediately ahead will be to (1) define the extent and characteristics of deposited radioactive material and identify a restricted zone in accordance with the PAG for relocation, (2) relocate persons from and control access to the restricted zone, (3) allow persons to return to areas outside the restricted zone, (4) control the spread of and exposure to surface contamination, and (5) apply simple decontamination and other low-cost, low-risk techniques to reduce the dose to persons who are not relocated.

Because of the various source term characteristics and the different protective actions involved (evacuation, sheltering, relocation, decontamination, and other actions to reduce doses to "as low as reasonably achievable" levels), the response areas for different protective actions may be complex and may vary in size with respect to each other. Figure E-1 shows a generic example of some of the principal areas involved. The area covered by the plume is assumed to be represented by area 1. In reality, variations in meteorological conditions would almost certainly produce a more complicated shape.

Based on plant conditions or other considerations prior to or after the release, members of the public are assumed to have already been evacuated from area 2 and sheltered in area 3. Persons who were evacuated or



LEGEND

1. PLUME DEPOSITION AREA.
2. AREA FROM WHICH POPULATION IS EVACUATED.
3. AREA IN WHICH POPULATION IS SHELTERED.
4. AREA FROM WHICH POPULATION IS RELOCATED (RESTRICTED ZONE).

FIGURE E-1. RESPONSE AREAS.

sheltered as a precautionary action for protection from the plume but whose homes are outside the plume deposition area (area 1) are assumed to return to their homes or discontinue sheltering when environmental monitoring verifies the outer boundary of area 1.

Area 4 is the restricted zone and is defined as the area where projected doses are equal to or greater than the relocation PAG. The portion of area 1 outside of area 4 is designated as a study zone and is assumed to be occupied by the public. However, contamination levels may exist here that would be of concern for continued monitoring and decontamination to maintain radiation doses "as low as reasonably achievable" (ALARA).

The relative positions of the boundaries shown in Figure E-1 are dependent on areas evacuated and sheltered. For example, area 4 could fall entirely inside area 2 (the area evacuated) so that relocation of persons from additional areas would not be required. In this case, the relocation PAG would be used only to determine areas to which evacuees could return.

Figure E-2 provides, for perspective, a schematic representation of the response activities expected to be in progress in association with implementation of the PAGs during the intermediate phase of the response to a nuclear incident.

E.2 Considerations for Establishing PAGs for the Intermediate Phase

The major considerations in selecting values for these PAGs for relocation and other actions during the intermediate phase are the four principles that form the basis for selecting all PAGs. Those are discussed in Section E.2.1. Other considerations (Federal radiation protection guidance and risks commonly confronting the public) are discussed in Sections E.2.2 and E.5.

In addition, a planning group consisting of State, Federal, and industry officials provided recommendations in 1982 which EPA considered in the development of the format, nature, and applicability of PAGs for relocation. Abbreviated versions of these recommendations are as follows:

a. The PAGs should apply to commercial, light-water power reactors.

b. The PAGs should be based primarily on health effects.

c. Consideration should be given to establishing a range of PAG values.

d. The PAGs should be established as high as justifiable because at the time of the response, it would be possible to lower them, if justified, but it probably would not be possible to increase them.

e. Only two zones (restricted and unrestricted) should be established to simplify implementation of the PAGs.

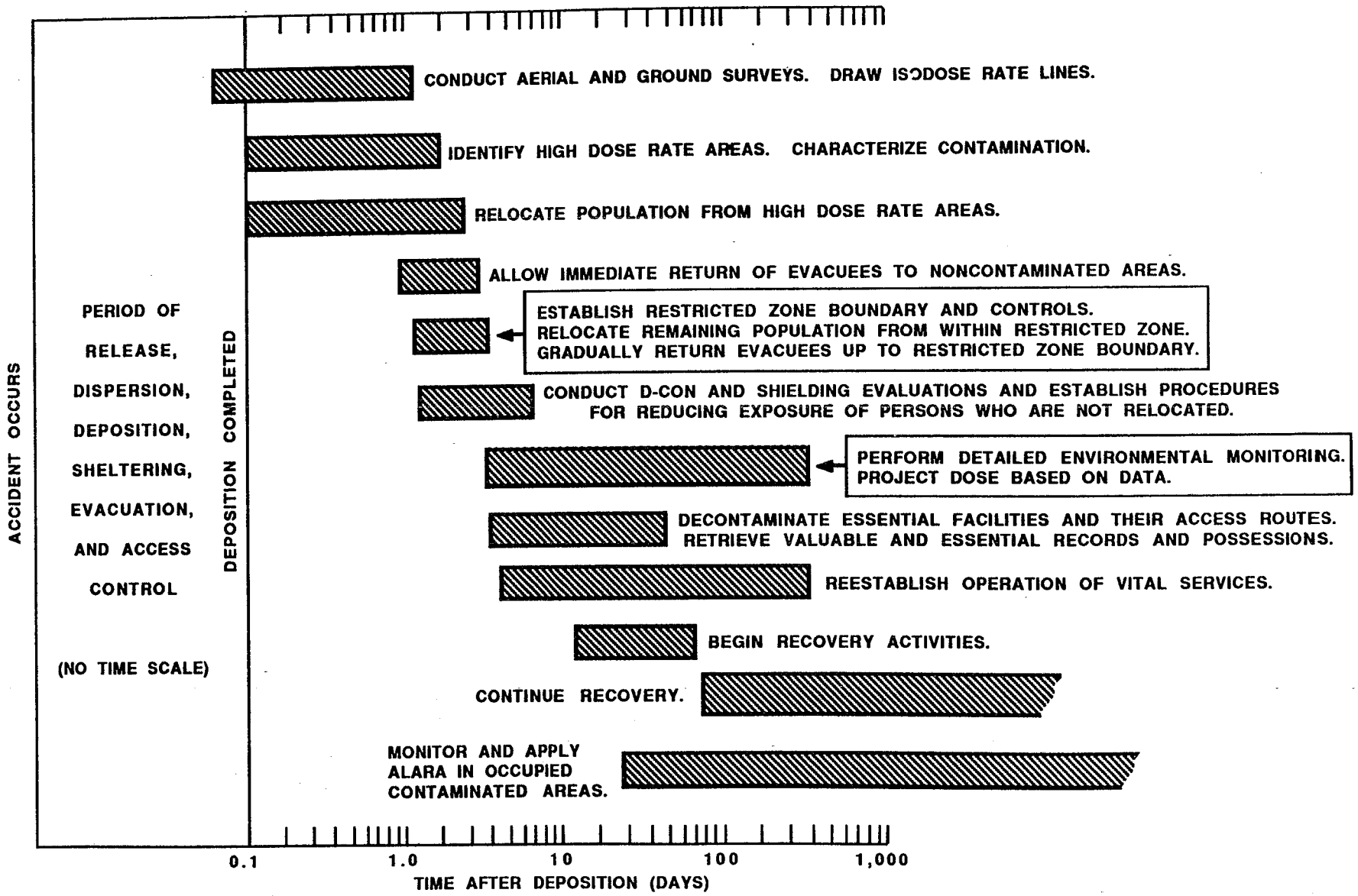


FIGURE E-2 POTENTIAL TIME FRAME OF RESPONSE TO A NUCLEAR INCIDENT.

f. The PAGs should not include past exposures.

g. Separate PAGs should be used for ingestion pathways.

h. PAGs should apply only to exposure during the first year after an incident.

Although these PAGs apply to any nuclear incident, primary consideration was given to the case of commercial U.S. reactors. In general, we have found it possible to accommodate most of the above recommendations.

E.2.1 Principles

In selecting values for these PAGs, EPA has been guided by the principles that were set forth in Chapter 1. They are repeated here for convenience:

1. Acute effects on health (those that would be observable within a short period of time and which have a dose threshold below which they 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.

Appendix B analyzed the risks of health effects as a function of dose (Principles 1 and 2). Considerations for selection of PAGs for the intermediate phase of a nuclear incident differ from those for selection of PAGs for the early phase primarily with regard to implementation factors (i.e., Principles 3 and 4). Specifically, they differ with regard to cost of avoiding dose, the practicability of leaving infirm persons and prisoners in the restricted zone, and avoiding dose to fetuses. Although sheltering is not generally a suitable alternative to relocation, other alternatives (e.g., decontamination and shielding) are suitable. These considerations are reviewed in the sections that follow.

E.2.1.1 Cost/Risk Considerations

The Environmental Protection Agency has issued guidelines for internal use in performing regulatory impact analyses (EP-83). These include consideration of the appropriate range of costs for avoiding a statistical death. The values are inferred from the additional compensation associated with employment carrying a higher than normal risk of mortality and are expressed as a range of $0.4 to $7

million per statistical death avoided. The following discussion compares these values to the cost of avoiding radiation-induced fatal cancers through relocation.

The basis for estimating the societal costs of relocation are analyzed in a report by Bunger (BU-89). Estimated incremental societal costs per day per person relocated are shown below. (Moving and loss of inventory costs are averaged over one year.)

Moving	$1.70
Loss of use of residence	2.96
Maintain and secure vacated property	0.74
Extra living costs	1.28
Lost business and inventories	14.10
Extra travel costs	4.48
Idle government facilities	1.29
Total	$26.55

The quantity of interest is the dose at which the value of the risk avoided is equal to the cost of relocation. Since the above costs are expressed in dollars/person-day, it is convenient to calculate the dose that must be avoided per-person day. The equation for this is:

$$H_E = \frac{C}{VR}$$

where:

H_E = dose
C = cost of relocation
V = value of avoiding a statistical death
R = statistical risk of death from radiation dose

Using the values cited above, and a value for R of $3x10^{-4}$ deaths/rem (See Appendix B), one obtains a range of doses of about 0.01 to 0.2 rem/day. Thus, over a period of one year the total dose that should be avoided to justify the cost of relocation would be about 5 to 80 rem.

These doses are based on exposure accumulated over a period of one year. However, exposure rates decrease with time due to radioactive decay and weathering. Thus, for any given cumulative dose in the first year, the daily exposure rate continually decreases, so that a relocated person will avoid dose more rapidly in the first part of the year than later. Figure E-3 shows the effect of changing exposure rate on the relationship between the cost of avoiding a statistical death and the time after an SST-2 accident (See Table E-1) for several assumed cumulative annual doses. The curves represent the cost per day divided by the risk of fatality avoided by relocation per day, at time t, for the annual dose under consideration, where t is the number of days after the accident. The right ordinate shows the gamma exposure rate (mR/h) as a function of time for the postulated radionuclide mix at one meter height.

The convex downward curvature results from the rapid decay of short-lived radionuclides during the first few weeks following the accident. Since the cost per day for relocation is assumed to be constant and the dose avoided per day decreases, the cost effectiveness of relocation decreases with time. For this reason it is cost

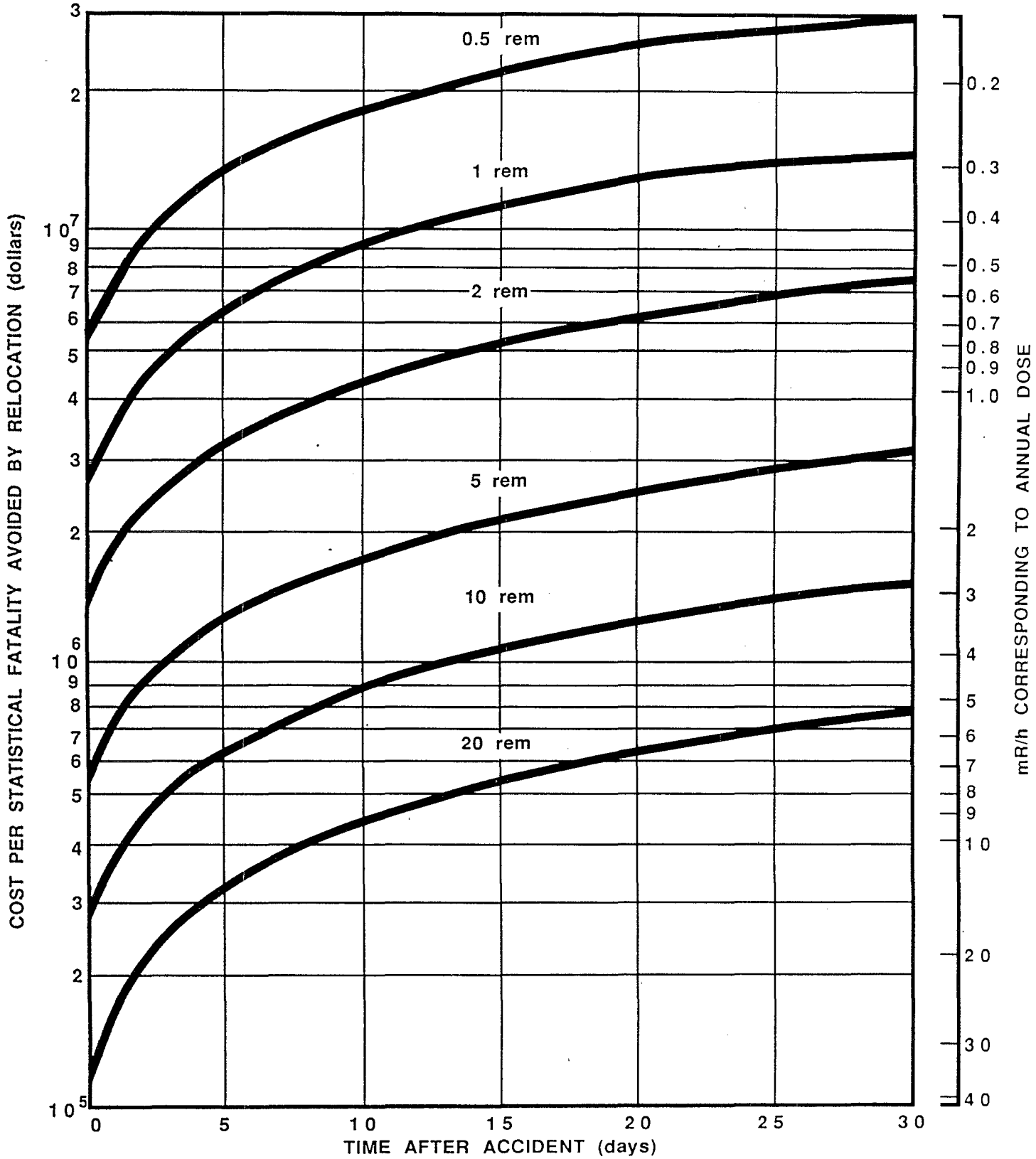


FIGURE E-3. COST OF AVOIDING STATISTICAL FATALITIES AND EXPOSURE RATES CORRESPONDING TO VARIOUS TOTAL FIRST YEAR DOSES (ASSUMES AN SST-2 ACCIDENT AND A $27 PER PERSON-DAY COST OF RELOCATION).

effective to quickly recover areas where the population has been relocated at projected doses only marginally greater than the PAG.

Only trends and general relationships can be inferred from Figure E-3 because it applies to a specific mix of radionuclides. However, for this radionuclide mix, cost analysis supports relocation at doses as low as one rem for the first week and two rem for up to 25 days after an accident.

E.2.1.2 Protection of Special Groups

Contrary to the situation for evacuation during the early phase of an incident, it is generally not practical to leave a few persons behind when most members of the general population have been relocated from a specified area for extended periods of time. Further, no data are available on differing risks of relocation for different population groups. In the absence of such data, we have assumed that these risks will be similar to those from evacuation. Those risks were taken as equivalent to the health risk from doses of 30 mrem for members of the general population and of 150 mrem for persons at high risk from evacuation (see Appendix C). Therefore, to satisfy Principle 4 for population groups at high risk, the PAG for relocation should not be lower than 150 millirem. Given the arbitrary nature of this derivation, it is fortunate that this value is much lower than the PAG selected, and is therefore not an important factor in its choice.

Fetuses are a special group at greater risk of health effects from radiation dose than is the general population, but not at significantly greater risk from relocation itself. The risk of mental retardation from fetal exposure (see Appendix B) is significant. It is affected by the stage of pregnancy relative to the assumed one-year exposure, because the 8th to 15th week critical period during which the risk is greatest, must be considered in relation to the rapidly changing dose rate. Taking these factors into account, it can be postulated that the risk of mental retardation due to exposure of the fetus during the intermediate phase will range from one to five times the cancer risk of an average member of the public, depending upon when conception occurs relative to the time of the incident. The elevated risk of radiation-induced cancer from exposure of fetuses is less significant, as discussed in Appendix B.

It will usually be practicable to reduce these risks by establishing a high priority for efforts other than relocation to reduce the dose in cases where pregnant women reside near the boundary of the restricted zone. However, women who are less than seven months pregnant may wish to relocate for the balance of their pregnancy if the projected dose during pregnancy cannot be reduced below 0.5 rem.

E.2.2 Federal Radiation Protection Guides

The choice of a PAG at which relocation should be implemented does not mean that persons outside the boundary of the restricted zone should not be the subject of other protective actions to reduce dose. Such actions are justified on the basis of existing Federal radiation protection guidance (FR-65) for protecting the public, including implementation of the principle of maintaining doses "as low as reasonably achievable" (ALARA).

The intended actions to protect the public from radiation doses on the basis of Radiation Protection Guides (RPGs) are those related to source control. Although it is reasonable for members of the public to receive higher exposure rates prior to the source term being brought under control, the establishment of acceptable values for relocation PAGs must include consideration of the total dose over the average remaining lifetime of exposed individuals (usually taken as 50 years).

The nationally and internationally recommended upper bound for dose in a single year from man-made sources, excluding medical radiation, is 500 mrem per year to the whole body of individuals in the general population (IC-77, FR-65). These recommendations were not developed for nuclear incidents. They are also not appropriate for chronic exposure. The ICRP recommends an upper bound of 100 mrem per year, from all sources combined, for chronic exposure (IC-77). The corresponding 50-year dose at 100 mrem/yr is 5 rem. We have chosen to limit: a) the projected first year dose to individuals from an incident to the Relocation PAG, b) the projected second year dose to 500 mrem, and c) the dose projected over a fifty-year period to 5 rem. Due to the extended duration of exposures and the short half-life of important radioiodines, no special limits for thyroid dose are needed.

E.3. Dose from Reactor Incidents

Doses from an environmental source will be reduced through the natural processes of weathering and radioactive decay, and from the shielding associated with part time occupancy in homes and other structures. Results of dose calculations based on the radiological characteristics of releases from three categories of postulated, fuel-melt, reactor accidents (SST-1, SST-2, and SST-3) (SN-82) and a weathering model from WASH-1400 (NR-75) are shown in Table E-3. This table shows the relationship between annual doses for the case where the sum, over fifty years, of the effective dose equivalent from gamma radiation and the committed effective dose equivalent from inhalation of resuspended materials is 5 rem. Radioactive decay and weathering reduces the second year dose from reactor incidents to 20 to 40 percent of the first year dose, depending on the radionuclide mix in the release.

Based on studies reported in WASH-1400 (NR-75), the most conservative dose reduction factor for

Table E-3 Annual Doses Corresponding to 5 Rem in 50 Years[a]

Year	Dose According to Accident Category[b] (rem)		
	SST-1	SST-2	SST-3
1	1.25	1.60	1.91
2	0.52	0.44	0.38
3	0.33	0.28	0.24
4	0.24	0.20	0.17
5	0.18	0.16	0.13
6	0.14	0.12	0.11
7	0.12	0.11	0.090
8	0.10	0.085	0.070
9	0.085	0.075	0.065
10	0.080	0.070	0.060
11	0.070	0.060	0.050
12	0.060	0.055	0.050
15	0.055	0.045	0.040
20	0.045	0.040	0.030
25	0.040	0.035	0.025
30	0.030	0.030	0.025
40	0.025	0.020	0.020
50	0.020	0.015	0.010

[a]Whole body dose equivalent from gamma radiation plus committed effective dose equivalent from inhalation assuming a resuspension factor of 10^{-6} m^{-1}. Weathering according to the WASH-1400 model (NR-75) and radioactive decay are assumed.

[b]Radionuclide abundance ratios are based on reactor inventories from WASH-1400 (NR-75). Release quantities for accident categories SST-1, SST-2 and SST-3 are shown in Table E-2. Initial concentrations are assumed to have decayed for 4 days after reactor shutdown.

structures (frame structures) is about 0.4 (dose inside divided by dose outside) and the average fraction of time spent in a home is about 0.7. Combining these factors yields a net dose reduction factor of about 0.6. In most cases, therefore, structural shielding would be expected to reduce the dose to persons who are not relocated to 60 percent (or less) of the values shown in Table E-3 before the application of decontamination.

E.4. Alternatives to Relocation

Persons who are not relocated, in addition to dose reduction provided by

partial occupancy in homes and other structures, can reduce their dose by the application of various techniques. Dose reduction efforts can 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 would be most appropriate to reduce exposure rates for persons living in contaminated areas outside the restricted zone. Many of these can be carried out by the residents with support from officials for monitoring, guidance on appropriate actions, and disposal. The more difficult processes will usually be appropriate for recovery of areas from which the population is relocated.

Decontamination experiments involving radioactive fallout from nuclear weapons tests have shown reduction factors for simple decontamination methods in the vicinity of 0.1 (i.e., exposure rate reduced to 10 percent of original values). However, recent experiments at the Riso National Laboratory in Denmark (WA-82, WA-84), using firehoses to flush asphalt and concrete surfaces contaminated with radioactive material of the type that might be deposited from reactor accidents, show decontamination factors for radionuclides chemically similar to cesium that are in the range of 0.5 to 0.95, depending on the delay time after deposition before flushing is applied. The factor for ruthenium on asphalt was about 0.7 and was independent of the delay of flushing. The results of these experiments indicate that decontamination of the important reactor fission products from asphalt or concrete surfaces may be much more difficult than decontamination of nuclear weapons fallout. Other simple dose reduction methods listed above would be effective to varying degrees. The average dose reduction factor for gamma radiation from combinations of simple decontamination methods is estimated to be at least 0.7. Combining this with the 40 percent reduction estimated above for structural shielding indicates that the doses listed in Table E-3 may be more than twice as high as those which would actually be received by persons who are not relocated.

E.5 Risk Comparisons

Many hazardous conditions and their associated risks are routinely faced by the public. A lingering radiation dose will add to those risks, as opposed to substituting one risk for another, and, therefore, radiation protection criteria cannot be justified on the basis of the existence of other risks. It is, however, useful to review those risks to provide perspective. This section compares the risks associated with radiation doses to those associated with several other risks to which the public is commonly exposed.

Figure E-4 compares recent statistics for the average lifetime risk of accidental death in various occupations to the estimated lifetime risk of fatal cancer for members of the general population exposed to radiation doses ranging up to 25 rem. Non-radiation risk values are derived from information in reference (EP-81) and radiation risk values are from Appendix B. These comparisons show, for example, that the lifetime cancer risk associated with a dose of 5 rem is comparable to the lifetime risk of accidental death in some of the safest occupations, and is well below the average lifetime risk of accidental death for all industry.

Risks of health effects associated with radiation dose can also be compared to other risks facing individuals in the general population. The risks listed in Table E-4 are expressed as the number of premature deaths and the average reduction of life-span due to these deaths within a group of 100,000 persons. For purposes of comparison, a dose of 5 rem to each member of a population group of 100,000 persons representative of the average U.S. population carries an estimated lifetime risk of about 150 fatal cancers (see Appendix B). The number of deaths resulting from the various causes listed in Table E-4 is based on data from mortality records.

In summary, the risk of premature death normally confronting the public from specific types of accidents ranges from about 2 to 1000 per 100,000 population. The estimated radiation doses required to produce a similar risk of death from radiation-induced cancer range from about 0.07 to 33 rem.

E.6 Relocation PAG Recommendations

Previous sections have reviewed data, standards, and other information relevant to establishing PAGs for relocation. The results are summarized in Table E-5, in relation to the principles set forth in Section E.2.1.

Based on the avoidance of acute effects alone (Principle 1) 50 rem and 10 rem are upper bounds on the dose at which relocation of the general population and fetuses, respectively, is justified. However, on the basis of control of chronic risks (Principle 2) a lower upper bound is appropriate. Five rem is taken as an upper bound on acceptable risk for controllable <u>lifetime</u> exposure to radiation, including avoidable exposure to accidentally deposited radioactive materials. This corresponds to an average of 100 mrem per year for fifty years, a value commonly accepted as an upper bound for chronic <u>annual</u> exposure of members of the public from all sources of exposure combined, other than natural background and medical radiation (IC-77). In the case of projected doses from nuclear reactor accidents, a five rem lifetime dose corresponds to about 1.25 to 2 rem from exposure during the first year and 0.4 to 0.5 rem from exposure during the second year.

Analyses based on Principle 3 (cost/risk) indicate that considering cost

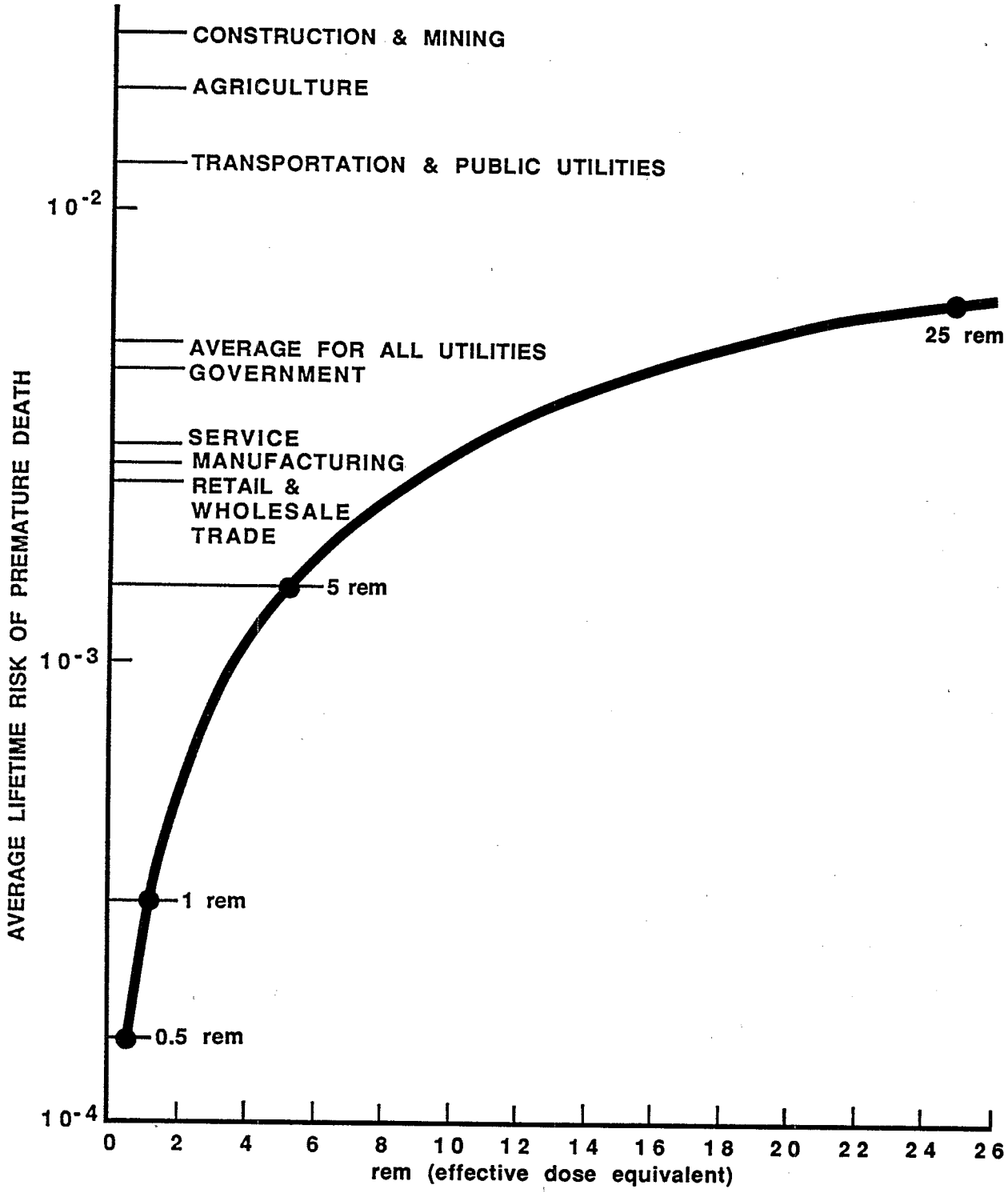


FIGURE E-4. AVERAGE LIFETIME RISK OF DEATH FROM WHOLE BODY RADIATION DOSE COMPARED TO THE AVERAGE RISK OF ACCIDENTAL DEATH FROM LIFETIME (47 YEARS) OCCUPATION IN VARIOUS INDUSTRIES.

Table E-4 Measure of Lifetime Risk of Mortality from a Variety of Causes[a] (Cohort Size = 100,000)

Nature of accident	Premature deaths	Aggregate years of life lost to cohort	Reduction of life expectancy at birth (years)	Average years of life lost to premature deaths
Falls	1,000	12,000	0.12	11
Fires	300	7,600	0.076	26
Drowning	190	8,700	0.087	45
Poisoning by drugs and medicaments	69	2,500	0.025	37
Cataclysm[b]	17	490	0.005	30
Bites and stings[c]	8	220	0.002	27
Electric current in homes[d]	8	290	0.003	37

[a]All mortality effects shown are calculated as changes from the U.S. Life Tables for 1970 to life tables with the cause of death under investigation removed. These effects also can be interpreted as changes in the opposite direction, from life tables with the cause of death removed to the 1970 Life Table. Therefore, the premature deaths and years of life lost are those that would be experienced in changing from an environment where the indicated cause of death is not present to one where it is present. All values are rounded to no more than two significant figures.

[b]Cataclysm is defined to include cloudburst, cyclone, earthquake, flood, hurricane, tidal waves, tornado, torrential rain, and volcanic eruption.

[c]Accidents by bite and sting of venomous animals and insects include bites by centipedes, venomous sea animals, snakes, and spiders; stings of bees, insects, scorpions, and wasps; and other venomous bites and stings. Other accidents caused by animals include bites by any animal and nonvenomous insect; fallen on by horse or other animal; gored; kicked or stepped on by animal; ant bites; and run over by horse or other animal. It excludes transport accidents involving ridden animals; and tripping, falling over an animal. Rabies is also excluded.

[d]Accidents caused by electric current from home wiring and appliances include burn by electric current, electric shock or electrocution from exposed wires, faulty appliances, high voltage cable, live rail, and open socket. It excludes burn by heat from electrical appliances and lighting.

Table E-5 Summary of Considerations for Selecting PAGs for Relocation

Dose (rem)	Consideration	Principle
50	Assumed threshold for acute health effects in adults.	1
10	Assumed threshold for acute health effects in the fetus.	1
6	Maximum projected dose in first year to meet 0.5 rem in the second year[a].	2
5	Maximum acceptable annual dose for normal occupational exposure of adults.	2
5	Minimum dose that must be avoided by one year relocation based on cost.	3
3	Minimum projected first-year dose corresponding to 5 rem in 50 years[a].	2
3	Minimum projected first-year dose corresponding to 0.5 rem in the second year[a].	2
2	Maximum dose in first year corresponding to 5 rem in 50 years from a reactor incident, based on radioactive decay and weathering only.	2
1.25	Minimum dose in first year corresponding to 5 rem in 50 years from a reactor incident based on radioactive decay and weathering only.	2
0.5	Maximum acceptable single-year dose to the general population from all sources from non-recurring, non-incident exposure.	2
0.5	Maximum acceptable dose to the fetus from occupational exposure of the mother.	2
0.1	Maximum acceptable annual dose to the general population from all sources due to routine (chronic), non-incident, exposure.	2
0.03	Dose that carries a risk assumed to be equal to or less than that from relocation.	4

[a]Assumes the source term is from a reactor incident and that simple dose reduction methods are applied during the first month after the incident to reduce the dose to persons not relocated from contaminated areas.

alone would not drive the PAG to values less than 5 rem. Analyses in support of Principle 4 (risk of the protective action itself) provide a lower bound for relocation PAGs of 0.15 rem.

Based on the above, 2 rem projected committed effective dose equivalent from exposure in the first year is selected as the PAG for relocation. Implementation of relocation at this value will provide reasonable assurance that, for a reactor accident, a person relocated from the outer margin of the relocation zone will, by such action, avoid an exposure rate which, if continued over a period of one year, would result in a dose of about 1.2 rem. This assumes that 0.8 rem would be avoided without relocation through normal partial occupancy of homes and other structures. This PAG will provide reasonable assurance that persons outside the relocation zone, following a reactor accident, will not exceed 1.2 rem in the first year, 0.5 rem in the second year, and 5 rem in 50 years. The implementation of simple dose reduction techniques, as discussed in section E-4, will further reduce dose to persons who are not relocated from contaminated areas. Table E-6 summarizes the estimated maximum dose that would be received by these persons for various reactor accident categories with and without the application of simple dose reduction techniques. In the case of non-reactor accidents these doses will, in general, differ, and it may be necessary to apply more restrictive PAGs to the first year in order to assure conformance to the second year and lifetime objectives noted above.

Since effective dose does not include dose to the skin (and for other reasons discussed in Appendix B) protective action to limit dose to skin is recommended at a skin dose 50 times the numerical value of the PAG for effective dose. This includes consideration of the risk of both curable and fatal cancers.

E.7 Criteria for Reentry into the Restricted Zone

Persons may need to reenter the restricted zone for a variety of reasons, including radiation monitoring, recovery work, animal care, property maintenance, and factory or utility operation. Some persons outside the restricted zone, by nature of their employment or habits, may also receive higher than average radiation doses. Tasks that could cause such exposures include: 1) changing of filters on air handling equipment (including vehicles), 2) handling and disposal of contaminated vegetation (e.g., grass and leaves) and, 3) operation of control points for the restricted zone.

Individuals who reenter the restricted zone or who perform tasks involving exposure rates that would cause their radiation dose to exceed that permitted by the PAGs should do so in accordance with existing Federal radiation protection guidance for occupationally exposed workers (EP-87). The basis for that guidance has been provided elsewhere (EP-87).

Table E-6 Estimated Maximum Doses to Nonrelocated Persons From Areas Where the Projected Dose is 2 REM[a]

Accident Category	Dose (rem)					
	No additional dose reduction			Early simple dose reduction[b]		
	Year 1	Year 2	50 years	Year 1	Year 2	50 years
SST-1	1.2	0.5	5.0	0.9	0.35	3.5
SST-2	1.2	0.34	3.9	0.9	0.24	2.7
SST-3	1.2	0.20	3.3	0.9	0.14	2.3

[a]Based on relocation at a projected dose of 2 rem in the first year and 40 percent dose reduction to nonrelocated persons from normal, partial occupancy in structures. No dose reduction is assumed from decontamination, shielding, or special limitations on time spent in high exposure rate areas.

[b]The projected dose is assumed to be reduced 30 percent by the application of simple dose reduction techniques during the first month. If these techniques are completed later in the first year, the first year dose will be greater.

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APPENDIX F

Radiation Protection Criteria for the Late Phase

Background Information

(Reserved)

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