MANUAL OF PROTECTIVE ACTION GUIDES

AND

PROTECTIVE ACTIONS

FOR NUCLEAR INCIDENTS

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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*	Sheltering Evacuation Decontamination of persons
5. External radiation from ground deposition of activity	*Intermediate*	Evacuation Relocation Decontamination of land and property
6. Ingestion of contaminated food and water	*Late*	Food and water controls
7. Inhalation of resuspended activity	*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.

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.

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

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 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