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Manual of Protective Action Guides and Protective Actions for Nuclear Incidents

September 1975

Environmental Protection Agency
Office of Radiation Programs
Environmental Analysis Division
Washington, D. C. 20460

Preface

This manual has been prepared to provide practical guidance to State, local, and other officials on criteria to use in planning protective actions for radiological emergencies that could present a hazard to the public. The guidance presented here is not intended as a substitute for, or an addemdum to, a State radiological emergency response plan. It is intended only to provide information for use in the development of such a plan.

In conformance with a Federal Register Notice of interagency responsibilities for nuclear incident response planning dated January 17, 1973, EPA is responsible for (1) establishment of protective action guidelines, (2) recommendations as to appropriate protective actions, (3) assistance to State agencies in the development of emergency response plans, and (4) establishment of radiation detection and measurement systems. This document is intended to be responsive to these assigned responsibilities.

The manual is organized to provide first, a general discussion of Protective Action Guides and their use in planning for the implementation of protective actions to protect the public. This is followed by chapters dealing with Protective Action Guides for specific exposure pathways and time periods. The application of Protective Action Guides and protective actions is discussed separately for various categories of source terms. Support information that has not been previously published is provided as appendices.

The loose leaf format was chosen for flexibility. Copies of additional or revised sections will be forwarded routinely to manual recipients designated as having responsibilities for developing or updating State radiological emergency response plans.

Users of this manual are encouraged to provide comments and suggestions for improving the content. Comments should be sent to the EPA Office of Radiation Programs, Environmental Analysis Division, Washington, D. C. 20460.

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CHAPTER 1

Perspectives for Protective Action

1.0 Introduction

In emergency preparedness planning for a nuclear incident with potential for exposing the general public to harmful radiation, public health officials require criteria to determine the need for protective actions and for choosing appropriate protective actions. EPA is responsible for providing these criteria and for assisting the States in preparing emergency response plans to implement these criteria.

After a nuclear incident occurs, an estimate is made of the radiation dose which affected population groups may potentially receive. This dose estimate is called the projected dose. A protective action is an action taken to avoid or reduce this projected dose when the benefits derived from such action are sufficient to offset any undesirable features of the protective action. The Protective Action Guide (PAG) is the projected dose to individuals in the population which warrants taking protective action.

A Protective Action Guide under no circumstances implies an acceptable dose. Since the PAG is based on a projected dose, it is used only in an ex post facto effort to minimize the risk from an event which is occurring or has already occurred.

Exposures to populations from an incident may well be above acceptable levels, in an absolute sense. However, since the event has occurred, PAGs should be implemented to ameliorate the impact on already exposed or yet-to-be exposed populations.

On this basis there is no direct relationship between acceptable levels of societal risk and Protective Action Guides. PAGs balance risks and costs against the benefits obtained from protective action, assuming that the projected threat will transpire. The responses made in a given situation should be based on PAGs and the spectrum of possible protective actions available at that time.

1.1 The Need for Planning

Within the general framework of providing maximum health protection for an endangered public, the public official charged with response to a hazardous situation may be faced with a number of decisions which must be made in a short time. A number of possible alternatives for action may be available, but the information needed to select the optimum alternative may not be available. In those situations where a public official must rapidly select the best of several alternatives, it is helpful if the number of decision points can be reduced during the accident response planning phase.

The efforts of planning activities can usually be based on the need for immediate response. Therefore, the objective is to minimize the number of possible responses so that resources are expended only on viable alternatives in emergency situations. During planning it is possible to assess value judgments and determine which steps in

response are not required, which steps can be answered on the basis of prior judgments, and which remain to be decided in an actual emergency. From this exercise, it is then possible to devise a set or several sets of operational plans which can be called out to answer the spectrum of hazardous situations which may develop.

In the case of an accident at a nuclear reactor, a hazardous situation could develop which may have public health implications over a large area with diverse populations and population densities. Probably little time will be available to make decisions. The availability of "action guides" based on advance planning will facilitate rational decisions in emergency situations. During the planning stage, the responsible public official must consider the total range of possible release scenarios and consider in each what goals are achievable keeping in mind both fiscal and societal costs. Because of this knowledge of local conditions, he will be aware of any constraints which may restrict his scope of response, such as specific industries, institutions, traffic patterns, etc. He will then be able to select the optimum response for each situation.

1.2 Nature of Protective Action Guides, Protective Action, and Restorative Action

Protective Action Guides are the numerical projected doses which act as trigger points to initiate protective action.

PAGs must be provided for three broad pathways of radiation exposure:

(1) Exposure from airborne radioactive releases. This type of exposure could occur within a short period following an

incident as a result of inhalation of radioactive materials or from external whole body exposure.

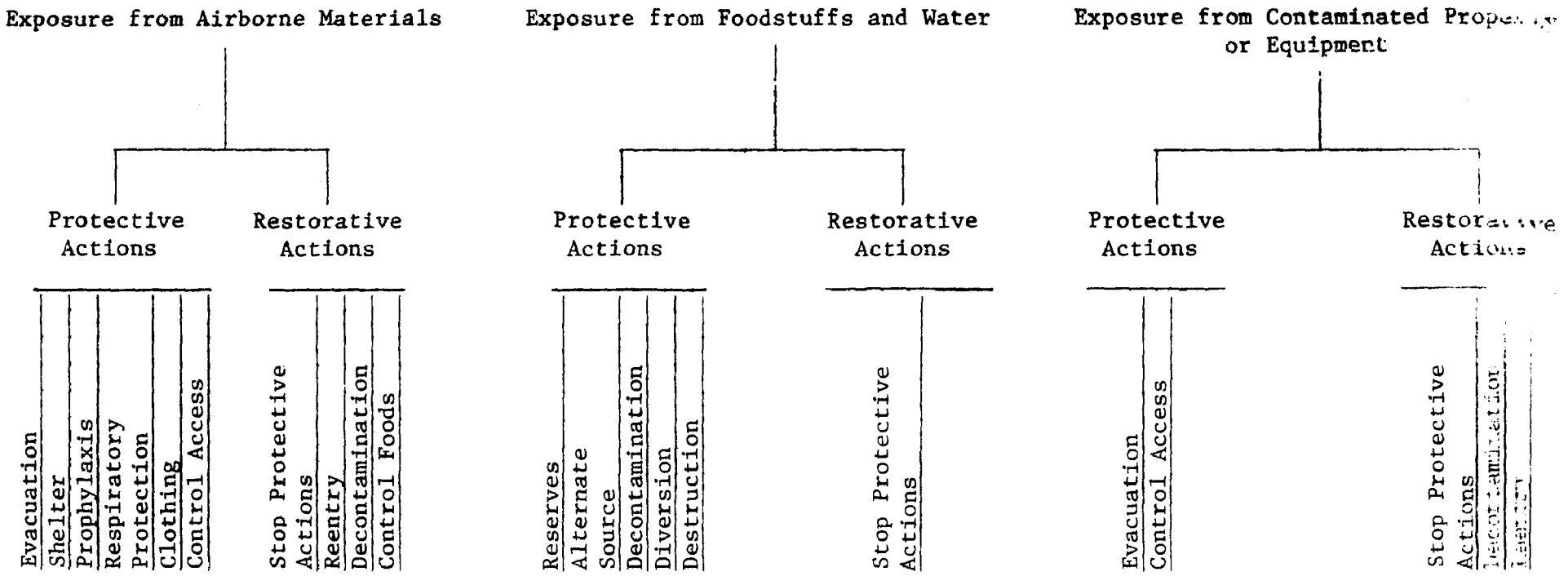
(2) Exposure through the food chain. This exposure will be from ingestion of contaminated foodstuff and water. It may commence shortly after the passage of airborne radioactive materials and may continue for a long or short time depending on the radionuclides involved.

(3) Exposure from radioactive materials deposited on the ground. Here we are dealing with a change in background radiation levels, and exposure pathways may include inhalation, ingestion, and external whole body exposures.

Different PAGs must be developed for each pathway of exposure since different criteria of risk, cost, and benefit are involved. Each exposure pathway would involve different sets of protective or restorative actions as indicated in table 1.1. Each action listed applies to the general population except for prophylaxis, respiratory protection, and protective clothing. These actions would primarily apply to emergency workers.

Exposure to the airborne plume is related to the duration of a release into the atmosphere. While release durations as long as 30 days or more are theoretically possible, for emergency purposes, release durations of a few hours up to a few days are more realistic. Protective action to be taken for this pathway may include any or all of the following:

Table 1.1 Exposure Pathways and Appropriate Responses



(1) evacuation,

(2) respiratory protection,

(3) shelter,

(4) prophylaxis (thyroid protection), and

(5) controlled access.

Restorative actions would then include:

(1) reentry first by survey and decontamination teams,

(2) removal of respiratory protection,

(3) exit from shelters,

(4) stopping prophylactic measures, and

(5) allowing free access by the population.

Exposure through the food chain may be either short term or chronic depending on the characteristics and half-lives of the radionuclides involved. Control of this pathway of exposure would be by:

(1) control of access to contaminated animal feeds,

(2) decontamination of certain foodstuffs,

(3) diversion and storage to allow decay of short half-life radionuclides, and

(4) destruction of contaminated foods.

Exposure from materials deposited on the ground might also be either short term or chronic depending on the radionuclides involved. Protective actions would include:

(1) evacuation, and

(2) controlled access.

Since the problem for ground contamination involves an increase in background levels, denial of access might continue for extended periods of time. Decontamination may then be the only action which will allow free access to and utilization of contaminated areas within a short time. Restorative actions would be reentry, decontamination, and lifting of controls.

The PAGs are to provide standardized criteria for selecting predetermined actions at the sacrifice of some flexibility in balancing the risk of health effects versus the effects of protective actions during an emergency. The loss of flexibility in response is expected to be within the limits of accuracy of determining the factors involved. The loss of flexibility is also offset by the advantage of being able to respond to the immediacy of the risks in the case of an emergency.

The range of PAG values allows consideration for local constraints during planning for implementation. PAGs should be assigned for each site to assure that local constraints are properly introduced.

1.3 Protective Action Decision Making

A nuclear incident as defined herein refers to a series of events leading to the release of radioactive materials into the environment of sufficient magnitude to warrant consideration of protective actions. Protective actions are those actions taken following a nuclear incident

that are intended to minimize the radiation exposure of the general public resulting from incidents.

The decision to initiate a protective action may be a complex process with the benefits of taking the action being weighed against the risks and constraints involved in taking the action. In addition, the decision will likely be made under difficult emergency conditions, probably with little detailed information available. Therefore, considerable planning is necessary to reduce to manageable levels the types of decisions leading to effective responses to protect the public in the event of a nuclear incident.

1.3.1 Action Factors

Within the context of nuclear incidents, a wide variety of possible situations may develop. Some perspective of the needs of the responsible planning officer can be shown in a brief description of the factors involved. Basically, the officer must balance problems involving identification of the magnitude of the release, possible pathways to the population at risk, how much time is available to take action, what action to take, and what the effects might be.

1.3.2 Incident Determinations

The first problem to arise will be that of identifying the type of incident and the magnitude of the release. Nuclear incidents may be extremely variable and may range from very small releases having no measurable consequences offsite to large scale releases possibly involving large populations and areas. Responses must be appropriate to the incident reported.

One of the variables will be the source term, which refers to the characteristics and release rate of the radioactive material. The amounts and types of radionuclides available for release should be immediately calculable by site personnel. What is actually being released to the environment can be estimated but may not be confirmed for some time after the incident.

The magnitude and duration of the release may be estimated by site personnel from plant conditions or from knowledge of the type of incident that has occurred. However, the estimate may be highly uncertain and must be updated on the basis of onsite and offsite monitoring observations and operational status of engineered safeguards.

If source term information is not available immediately, default values should be available from planning efforts. These values could be based on accident scenarios from WASH-1400 (1), design basis accidents evaluated in the NRC safety evaluation report for individual facilities, or other scenarios appropriate for a specific facility.

The second major variable will be where the released material is expected to go. Meteorology and geography will affect this variable. Current meteorological conditions can be observed directly at the site and relevant locations. However, complete meteorological data will never be available, and extension of observed data must be made to predict the course of released material.

Current weather conditions may restrict the options for response, e.g., evacuation in a blizzard may be reduced or impossible. Weather

forecasts have all of the inherent uncertainty of the current condition estimates since they are derived from these.

Geography is important both in its influence on meteorology and on demography and in its influence on value judgments to be made. The planning for a coastal site or a river valley site may be different due to road patterns and methods for communicating or applying protective actions.

Demography is a variable to be considered during the planning stage. Demography is of most importance in helping to assess the possible impact of an incident. Population numbers, age distribution, distribution within an area, etc., will have some influence on responses available in any situation.

Providing for the ability to detect and measure a release are important factors for planning. Although it may be possible to detect releases and measure release rates at the site, information from environmental measurements will be needed to confirm any estimates made on the basis of onsite measurements. Detection and measurement at locations offsite are necessary to update and/or confirm predictions about the movement of the release in the environment. Locations for installed equipment must be planned, probably on the basis of average area meteorology. Instrumentation needs are discussed in more detail in Appendix A.

The source term, meteorology, and geography parameters are utilized in making a prediction of the path and time profile for the

release. This prediction, in combination with demography data, will be used to select the best responses for the situation. The most reasonable approach is to plan path and time profiles (isopleths) for unit release situations and then to modify them as real data are obtained.

1.3.3 Exposure Pathways

The next decision after the determination of an accident situation will probably concern identification of important pathways of radionuclides to the population. Exposure pathways of immediate importance and the time available to interrupt them can be decided to a large extent on the basis of planning judgments.

The single most important pathway during the emergency phase is probably by air. The air pathway will be via inhalation of either gases or particulates and whole body exposure to the plume. Released gases will be either radioactive noble gases, organic iodides, inorganic iodides, or volatile inorganic materials. Particles will probably form by the condensation of vaporized material.

Water is a pathway for exposure by ingestion or immersion. Released material may enter the water directly or in the form of fallout or rainout followed by surface runoff. The immersion pathway of exposure is unlikely to have significance except in very specialized circumstances. Ingestion of water is probably only a minor pathway

of exposure in the short run. However, the gastrointestinal system must be considered for longer term ingestion of contaminated drinking water.

Ingestion of food is an important exposure pathway. However, with the possible exception of drinking water, milk, and contaminated leafy vegetables, entry of released materials into food and passage along this pathway is delayed. Identification of sensitive points for control should be made during planning.

Characterization of release materials involved in air, water, and food pathways will not be done for some time after an accident. The initial decisions will have to be made on the basis of estimates developed in planning and modified as real information becomes available.

Direct external whole body radiation exposure may be a hazard. Released material deposited in soil or water or suspended in air and material still at the site serve as sources of direct radiation, mostly by gamma and beta radiations. Although exposure rate may be measured directly at specific locations, the distribution must be estimated and the estimates updated on the basis of monitoring data. Fairly complete monitoring will be needed during implementation of restorative actions.

Soil contamination, in addition to providing part of the direct whole body exposure, also provides a contribution to the air pathway. Released material deposited on soil can be resuspended, thus possibly

entering the air, water, and food pathways. Evaluation of these hazards will be particularly important in deciding appropriate actions during the restoration phase, e.g., level of decontamination needed.

1.3.4 Populations at Risk

The next consideration of importance to the responsible official is what population is to be protected. Prior judgment and planning based on the geography and demography of the area around the site and on critical pathways are essential to identifying populations at greatest risk.

The average population is made up of persons with varying sensitivities to radiation exposure, and responses may be keyed to the most sensitive, or responses may be restricted, depending on characteristics of the local population.

(1) For purposes of response planning, the general population will be evaluated on the basis of risk to individuals within the population, usually on the basis of avoiding clinical effects. However, the population as a whole will also be considered in planning some responses on the basis of statistical risk of somatic and/or genetic effects.

(2) Sensitive populations may be considered on a special basis. Children, including the fetus and unborn children, are generally more sensitive than healthy adults. For this reason, such members of the population may be selected

either as the most sensitive receptors or as a special group for protection.

(3) Selected populations will also be present. These populations may be selected on voluntary or involuntary bases. Workers at a nuclear facility are classified as radiation workers and fall under different criteria for protection than the general population. Those persons who are engaged in public service activities during or after the accident are voluntarily placing themselves under different criteria for protection than the general population. Finally, some persons are involuntarily included under different criteria because the risk of taking action is different than for the general population. This involuntarily selected population may include bedridden and critically ill patients, patients in intensive care units, prisoners, etc.

1.3.5 Radiation Effects

A final parameter which must be considered is radiation effects. These may fall into two categories, early or delayed, but are not mutually exclusive.

(1) Early (acute) effects, occurring within 90 days, may include fatalities, symptoms of radiation sickness, or clinically detectable changes. Efforts to protect selected populations will extend to prevention of fatalities, minimization of

symptoms of radiation sickness in radiation workers and public service personnel, and prevention of clinically detectable changes of uncertain significance in the rest of the population. The basis for decisions regarding early effects is not hard to justify because of the imminence of such effects. However, they must be made rapidly under conditions of competing needs to protect the public.

(2) Delayed statistical effects (i.e., biological effects which can only be observed on a statistical basis) will occur at random in a population after exposure to released materials. These effects may be fatalities or disabilities of somatic or genetic origin. The incidence of these effects is estimated on the basis of statistical evaluation of epidemiological studies in groups of people who had been exposed to radiation. Decisions concerning statistical effects on populations will be more difficult because of the lack of immediacy of the effects. But in the long run, these effects might cause the greatest impact on the general population.

The response times, actions to consider, and possible health effects for each pathway are shown in table 1.2 for a typical population.

Effects on animals, vegetation, or real estate are also possible but may be controlled or alleviated to the extent that decontamination is employed or that destruction of the affected items is employed.

Table 1.2 Action and Health Effects Versus Exposure Pathways

Exposure Pathway	Response Time	Action Available	Public Health Effects
Air - Particulate	Min - Hr	P	D
Gas	Min - Hr	P	F,E,D
Water - Particulate			
Rainout	Hr - Da	P	D
Fallout	Min - Hr	P	D
Immersion	Day	P&R	D,F,E
Food - Milk	Da - Mo	P&R	D
Drinking Water	Hr - Mo	P&R	D
Beverages	Da - Mo	P&R	D
Foodstuffs	Da - Mo	P&R	D
Soil - Resuspension	Da	R	D
Direct	Min - Da	P&R	E,D,F
Direct - Facility	Min	P&R	F,E,D
Air	Min - Hr	P	F,E,D
Water	Hr	P&R	D,F,E

Actions: P - Protective R - Restorative
Effects: F - Rapid Fatality E - Early D - Delayed

1.4 Response Plan Action Times

A typical sequence of events for developing emergency plans and responding to nuclear incidents is shown in figure 1.1. This figure illustrates the general order of events but not relative lengths of time for each event. These will vary according to individual circumstances.

.1 Preparation of Plans

Considerable preparation will be required to ensure the adequacy of emergency response plans. This preparatory time includes the following elements:

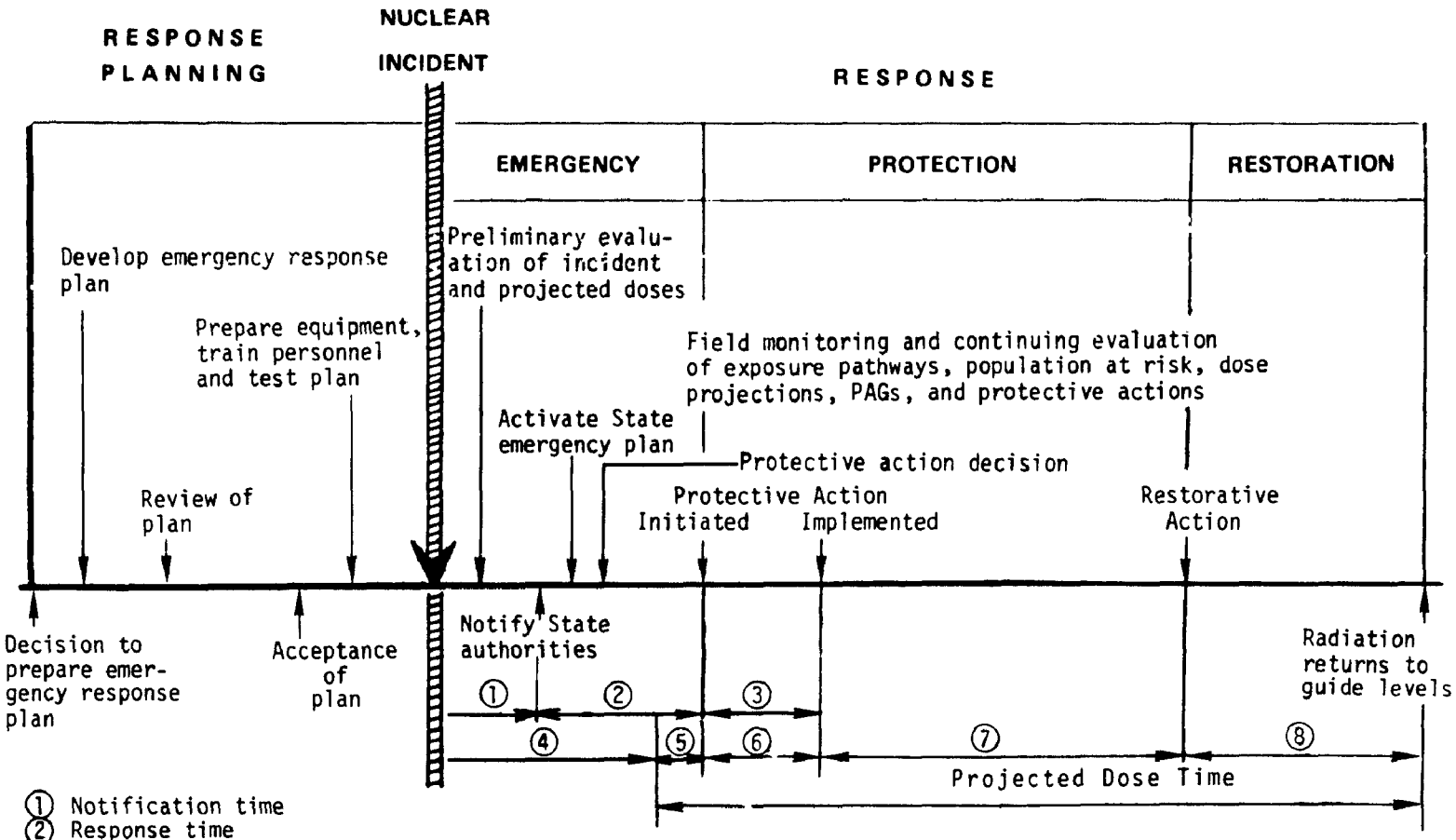
(1) The decision must be made to prepare emergency response plans according to the legislative mandates or needs within a given State.

(2) Then basic plans should be developed using appropriate guidance from this manual and the AEC "Guide and Checklist" (2). These plans should include emergency response actions for coping with nuclear incidents and directions on the use of EPA Protective Action Guides for these situations.

(3) These plans should be approved by responsible persons or agencies.

(4) Scenarios must be developed from the basic plans to cover major contingencies which can be identified.

Methods of implementation must be prepared and tested so that nonviable responses and contingency plans may be identified and discarded. This discarding of nonviable responses may be based in part



① Notification time
② Response time
③ Implementation time
④ Time before population exposure
(Ideally protective actions would be implemented during this time.)
⑤ Possible accumulation of projected dose before initiation of protective action
⑥ Partial accumulation and partial avoidance of projected dose
⑦ Time in which projected dose is avoided by protective action
⑧ Partial accumulation of projected dose during restoration

FIGURE 1.1 SEQUENCE OF EVENTS FOR RESPONSE PLANNING AND RESPONDING TO NUCLEAR INCIDENTS

on evaluation of local constraints. For example, evacuation of prisoners or critically ill persons might not be considered viable while alternative protective actions may be at least partially effective.

Development of the basic emergency response plan may run a course of several months or longer. However, planning should be a continuing activity after the basic plans are developed. Advances in meteorology, development of new protective actions, changing demography, etc., should be used in reevaluation of the original scenarios. And of course, recurrent testing of implementation methods should be carried out.

1.4.2 Implementation of Plans

A sequence of steps to implement a response plan following a nuclear incident is also shown in figure 1.1. The time after an incident may be divided into three phases which are called emergency, protection, and restoration. These phases are not necessarily distinct consecutive time periods, but they do serve to indicate the general nature of activities in a typical response sequence.

The emergency phase includes all those activities leading to initiation of protective actions. This phase involves assessment of the situations and is characterized by urgency in determining the need for protective action and getting the action initiated. In general, this may be considered to be the first few hours following notification of an incident and deals primarily with protection of the population

from exposure to the airborne plume.

The most important step in emergency response is the prompt notification that an incident has occurred that could result in an offsite exposure such that there is a need for initiating protective action. It is the facility operator's responsibility to notify State or local authorities that such an incident has occurred. It is important that agreements be reached during the planning phase on who is to be notified, data to be provided, offsite measurements that will be made, and actions to be initiated at the site so that there will be a minimum time loss in starting implementation of protective action in the offsite area. Proper planning must include incentives to prevent delays in notification. Nuclear facility operators have the initial responsibility for accident assessment. This includes prompt action necessary to evaluate public health and safety both onsite and offsite (2). Ideally, this notification should occur as soon as conditions in the facility are such that an impending accidental release potential exists. While such notification could lead to false alarms on rare occasions, they could also permit more timely protective actions than postponing the notification until a release has occurred.[1]

The sequence of events during the emergency phase includes the notification of responsible authorities, evaluation and recommendations for action, and warning of the public. In this early phase of response, the time available for effective action will probably be quite limited.

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[1]As part of their plans, the State should establish with the facility operator a strict protocol for notification of the State such that early responding of possible impending releases would not involve disincentives to the facility operator.

Immediately upon becoming aware that an incident has occurred that may result in exposure of the offsite population, a preliminary evaluation should be made by the facility operator to determine the nature and potential magnitude of the incident. This evaluation, if possible, should determine potential exposure pathways, population at risk, and projected doses. At this time, projected doses may be estimated from monitoring data at the point of radionuclide release or from releases anticipated for particular types of nuclear incidents. The incident evaluation information should then be presented to the proper authorities. If authorities were notified earlier and have mobilized resources, protective actions can be started immediately in predesignated areas or in the areas indicated by projected dose based on facility operator information. In the absence of detailed information from the facility operator as indicated above, the emergency plans should provide for action in the immediate downwind area of the facility based on notification that a substantial release has occurred or that plant conditions are such that a substantial release potential exists.

The next step is to gather additional information on radiation levels in the environment, meteorology, and environmental conditions. Further actions or modifications to actions already taken should be based on these data and Protective Action Guides considering constraints discussed in section 1.6 of this chapter.

The State should continue to seek information on radionuclide releases and environmental monitoring data. In fact, an evaluation of

such information, as well as exposure pathways, population at risk, dose projections, and PAGs should be a continuing activity in both the emergency and protection phases in order to modify protective actions as needed.

The protection phase begins with the initiation of protective action and continues until that action is terminated. Figure 1.1 indicates that ideally the protective action such as evacuation would be implemented before any population exposure. However, the action may not be initiated in time to avoid all of the projected dose, and some dose may be received during implementation of the action.

The restoration phase includes those actions taken to restore conditions to "normal". Restorative actions include the halting of protective actions, the lifting of restrictions, and possible decontamination procedures.

1.5 Types of Action

The action taken may be, as previously indicated, either protective or restorative. It may also be voluntary or involuntary, or no action at all may be taken.

(1) No action would usually be taken by State authorities if the risk of undesirable radiation effects is anticipated to be much less than the risk of taking action.

(2) Voluntary action may be suggested for the population at risk, or it may be taken by them anyway on the basis of public information provided during an accident situation. Voluntary action may be valid in the gray area where the

risk of exposure to released material and the risk of taking action are not too different. It may also be taken at lower levels of exposure by individuals to alleviate their fears. The negative aspects of possible confusion and possible panic where incomplete knowledge exists must be considered during decisions to implement protective actions.

(3) Involuntary (mandatory) action by State authorities should be implemented when the risk of undesirable effects exceeds the risk of taking action to such an extent that public well-being can be adversely affected. This is when action must be taken in the public interest.

The types of action which can be taken include:

(1) Protective actions, such as evacuation, taking shelter in homes or civil defense shelters, controlling food and water distribution, prophylaxis (e.g., thyroid protection), or individual protective actions (e.g., gas masks, protective clothing, etc.); and

(2) Restorative action where everything is returned to "normal". This action includes lifting restrictions or halting activities initiated as protective actions. It also includes decontamination where necessary.

The actions to be taken should be evaluated and set in priority or sequence with identification of ranges for appropriate action and of decision points during planning. Based on prior judgment of which

actions may be effective in any given situation, scenarios can be prepared which will indicate which actions or mix of actions are appropriate for various situations.

1.6 Goals of Protective Action

The ideal goal of protective action in an emergency is complete protection of the endangered population. However, various constraints may prevent attaining this ideal, so a more realistic goal is minimization of harmful effects.

In the case of an emergency involving a radiological hazard, efforts are directed towards minimizing:

(1) early somatic effects such as death within days or development of extensive symptoms of radiation sickness;

(2) delayed somatic effects, such as increased probability of death due to radiation related cancer; and

(3) genetic effects such as increased prenatal mortality or increased probability of hereditary defects in future generations.

The minimization of effects implies that the radiation exposure under consideration is an avoidable exposure. However, for purposes of determining whether to take a protective action on the basis of projected dose from an airborne plume, the projected dose should not include unavoidable dose that has been received prior to the time the dose projection is done. If a situation should occur where the unavoidable dose would be very large as compared to the avoidable dose, different protective actions might be warranted.

1.6.1 Balancing Factors to Achieve Protection Goals

The ideal goal is maximum protection of the public with the least cost and disruption. Within the need to protect the public several constraints, including physical, social, and fiscal, will be operating.

The planner should balance the cost of not taking action (risk of radiation exposure) against the cost of taking action from both fiscal and societal aspects. In particular, the fiscal costs of preparing for action, as well as the costs of all actions to be taken, should be balanced against the need for response to protect the public. Also, the societal costs such as panic and disruption of life style should be balanced against the risk to society of not taking action.

This balancing of costs and risks will place constraints on the options available for action. This balancing also implies that in planning, certain cut-off points can be identified, e.g., a marginal increase in protection probably may not justify the required expenditures or extensive disruption of families or daily activities. These costs and constraints should be evaluated in planning by the responsible public officials in determining the responses to be made in a given situation.

Even if the balance of costs indicates that a response or set of actions is reasonable, other constraints may preclude their use. These additional constraints on action are primarily physical in nature (e.g., in the case of a puff release, exposure time may be too short to allow effective protective action).

1.6.2 Constraints on Goal Attainment

The constraints which operate to prevent attaining the ideal goal include those of environmental, demographic, temporal, resource availability, and exposure duration.

Environmental constraints will include meteorologic and geographic considerations. Protective action options may be restricted by severe weather conditions, windstorms, blizzards, tornadoes, large accumulations of snow, etc. Options are also restricted by numbers, types and directions of roads, and obstruction of easy egress from a site by rivers, mountains, or other geologic formations.

Options are further constrained by the density and distribution of population, the total size of the population involved, the age and health status of segments of the population, and other demographic considerations.

Temporal constraints will be present during all phases of protective action and some situations during restorative action. Time available for action may be a real constraint for evacuation of close-in populations, particularly in the case of short term (puff) releases. After an incident, exposures of the population close to the site may occur before control of the situation is established. Even after a decision for action has been made, notification of the population and implementation of the action may require enough time such that substantial exposures occur. The constraint of time in restorative action will probably be more related to reduction of costs rather than to direct protection of the population. Rapid decontamination to allow

access to utilities, food stores, crops, etc., will reduce the total cost due to the accident.

Resources will be one of the largest constraints on viable options for action. The best planning will fail if the resources to implement actions are not available. Resources needed are fiscal, manpower, and property, although fiscal will probably be the limiting factor. Given sufficient fiscal investment, then manpower, equipment, and training, all will be available in adequate quantities. However, since only limited amounts of fiscal support may be available, the lack of equipment and manpower with sufficient training and practice in implementation of protective actions will limit the number of viable options for protecting the public.

In general, as the population to be protected increases, less protection is available for the same total cost (equal levels of protection require greater fiscal investment in large populations than in small populations). Likewise, as the level of preparedness increases, the cost of obtaining and maintaining this preparedness increases. The cost of protective action, however, will probably be a step function. Each decision to take an action or extend an action will cause an incremental step increase in the cost. All of these constraints must be considered in planning operations so that the optimum protection of the public can be obtained with the least expenditure, both social and fiscal, commensurate with the goal of protective action.

1.6.3 Evaluation of Constraints

Local officials involved in developing emergency response plans must be thoroughly informed on what protective actions are available for limiting the radiation exposure of the general public during a nuclear incident. These actions are a vital part of the emergency response plan and should be specified during the planning phase rather than at the time of the incident. There are, however, local constraints associated with each protective action which will influence the decision to implement a given protective action. The local planner must also be familiar with and apply these constraints to any emergency situation. Ideally, it should be possible to balance these constraints in some analytical fashion which would place each constraint in its proper perspective on a common scale. Since many of the constraints cannot be quantified, local planners must use rational, subjective judgment in evaluating them.

Tables 1.3 and 1.4 list protective actions that are available for various types of reactor incidents as a function of approximate time periods following the incident, and the following discussion attempts to evaluate constraints such as costs, time, societal considerations, etc., that relate to each protective action. This information should be valuable to the local planner in making the value judgments that are necessary to plan actions during an emergency.

1.6.3.1 Constraints on Evacuation

While evacuation may seem to be the protective action of choice following a nuclear incident at a fixed nuclear facility, constraints

Table 1.3 Protective and Restorative Actions for Nuclear Incidents Resulting in Airborne Releases

Nuclear Incident	Protection Phase			Restoration Phase[c]
	Approximate Time of Initation			
	0-4 hr.	4-8 hr.	> 8 hr.	
Puff Release[a]--Gaseous or Gaseous and Particulate	1,2,3,4,5	3,4,5	3,4,5,6, 7,8	9,10,11
Continuous Release[b]- Gaseous or Gaseous and Particulate	1,2,3,4,5	1,2,3,4,5	1,2,3,4, 5,6,7,8	9,10,11

1 Evacuation

2 Shelter

3 Access control

4 Respiratory protection for emergency workers

5 Thyroid protection for emergency workers

6 Pasture control

7 Milk control

8 Food and water control

9 Lift protection controls

10 Reentry

11 Decontamination

[a] Puff release - less than 2 hours

[b] Continuous release - 2 hours or more

[c] Restoration phase may begin at any time as appropriate

Table 1.4 Initiation Times for Protective Actions

Approximate Initiation Time	Exposure Pathway	Action to be Initiated
0-4 hours	inhalation of gases or particulates	evacuation, shelter, access control, respiratory protection, prophylaxis (thyroid protection)
	direct radiation	evacuation, shelter, access control
4-48 hours	milk	take cows off pasture, prevent cows from drinking surface water, quarantine contaminated milk
	harvested fruits and vegetable	wash all produce, or impound produce
	drinking water	cut off contaminated supplies, substitute from other sources
	unharvested produce	delay harvest until approved
2-14 days	harvested produce	substitute uncontaminated produce
	milk	discard or divert to stored products, such as cheese
	drinking water	filter, demineralize

associated with a specific site could render the evacuation ineffective or undesirable. Other optional protective actions such as taking shelter should be considered. The planner must take into consideration all local constraints to determine whether or not evacuation is a viable protective action for the given situation. Examples of the effects of constraints could be provided on a general basis. However, it remains the responsibility of the planner to determine the most reasonable protective actions for each site.

A. Effectiveness of Evacuation

The effectiveness of evacuation in limiting radiation dose is a function of the time required to evacuate. If a radioactive cloud is present, the dose will increase with the time of exposure; if the evacuation is completed before the cloud arrives, then evacuation is obviously 100 percent effective. Anything that delays an evacuation is therefore a constraint, and such constraints are likely to be very much a function of local site conditions and planning. The planner should be aware of these constraints in order to minimize their impact, thus maximizing the effectiveness of the evacuation.

The evacuation time, T(EV), at a particular site is defined as the time from the start of the nuclear incident to the time when evacuees have cleared the affected areas. It may be expressed as:

$$T(EV) = T_D + T_N + T_M + T_T$$

where:

T_D = time delay after occurrence of the incident associated with

notification of responsible officials, interpretation of data, and the decision to evacuate as a protective action.

T_N = time required by officials to notify people to evacuate.

T_M = time required for people to mobilize and get underway.

T_T = travel time required to leave the affected areas.

T_D includes several separate time elements as defined above, and all of them can be reduced by effective planning. Nominal values for T_D may range from 0.5 hours up to 1.5 hours and possibly longer depending on the adequacy of planning and whether the decision is to be based on onsite information or offsite environmental measurements.

The least well defined time constraint is T_N, which is strongly influenced by local population, geographic conditions, and planning. T_N has been postulated to be inversely proportional to population density; the closer people are together, the quicker it is to notify them to evacuate. For fast developing incidents, news media warnings must be augmented by telephone, pulic address, and door knocking, the effectiveness of which is a function of local planning and resources. There are new innovations such as computer telephoning, planes with loud speakers, etc., which the local planner may find worthwhile to explore. The value of T_N under the best conditions of local planning is estimated to range from 15 minutes to 1 hour or more.

T_M, the time required for people to prepare to leave, depends on such parameters as:

(1) Is the family together?

(2) Rural or urban community? Some farms or industries require more shutdown time than others.

(3) Special evacuations - special planning effort is required to evacuate schools, hospitals, nursing homes, penal institutions, and the like.

(4) There will be some people who will refuse to evacuate.

The best time for T_M for an urban family together might be 0.2 to 0.5 hours, while to shut down a farm or factory might take hours.

The evacuation travel time, T_T, is related to:

(1) Total number of people to be evacuated.

(2) The capacity of a lane of traffic.

(3) The number of lanes of highway available.

(4) Distance of travel.

(5) Roadway obstructions such as uncontrolled merging of traffic or accidents.

The total number of people to be evacuated depends on the population density and affected area. It is an advantage if good planning can keep the area and thus the number of people to as small a value as possible, or possibly to evacuate one area at a time so that the number of people on the move at one time is within the capacity of the roads.

The capacity of a lane of traffic depends on the number of vehicles per hour and the capacity of each. Surveys during evacuations found

4 persons/car on the average indicating that at 2,500 cars/hr at 35 mph, the capacity of a lane is 10,000 persons/hr. Commuter traffic, however, contains about 1.2 persons/car, lowering the capacity to about 3,000 persons/hr-lane. Use of buses exclusively, if this is practical, increases the lane capacity by a factor of about 10 such that 100,000 persons/hr-lane could be moved. However, if buses are used, the increase in time caused by getting the buses to the evacuation area and by return trips must be considered. If the average speed of traffic is less than 35 mph, capacity/lane-hr is lowered in proportion.

The number of lanes of traffic is ordinarily sufficient for evacuation from the low population zone around fixed nuclear facilities. Lanes may be increased by using lanes that ordinarily carry traffic into the area. All these lanes cannot be used, however, since some, at the option of the planner, must be held open for emergency vehicles coming into the area.

Traffic control will be effective in reducing the evacuation travel time. If lanes ordinarily inbound are used for outbound traffic, traffic officers will be required to direct vehicles to them; otherwise they will not be used. Traffic barriers, signs, traffic light overrides, disabled vehicle removals, etc., will be required to keep traffic speeds high. Traffic control at bottlenecks will be of particular importance. Allowing single lanes to run alternately rather than having cars dovetail through an intersection will significantly

increase traffic flow. Access controls to keep unauthorized vehicles and persons out of the evacuated areas will be needed also.

Examination of specific sectors around four different light-water power reactors indicates that T_T may range from 0.2 to as much as 1.5 hours under exceptional conditions where the road system is inadequate compared to the population to be evacuated. An average traffic speed of 35 mph was assumed if road capacity was great enough to preclude traffic jams.

Table 1.5 summarizes the various time segments that act as constraints on evacuation. These values are rough estimates that should be improved upon by the local planner for each site. An example of a one-hour evacuation might be the evacuation late in the evening of a rural area including a small town (250 persons). In such a case the population is small, concentrated, and at that time the families would be united. An example of an evacuation in the longer time range might be evacuation during the daytime of a rural, low population zone containing farms. Warning would be time consuming, and the preparation for farm shutdown might be lengthy. The road system is adequate, but families may be separated during the day, requiring longer evacuation travel distances. Emergency plans for areas located near State boundaries would require interstate cooperation and planning. High population, high density areas such as those around Indian Point present a different situation, and evacuation times are more complex, probably longer, and must be analyzed on a case by case basis. In these areas, notification time may be short but access

Table 1.5 Approximate Range of Time Segments Making Up the Evacuation Time[a]

Time Segment	Approximate Range Hours
T_D	0.5 - 1.5[b]
T_N	0.2 - 1.0[c]
T_M	0.2 - 2.0[d]
T_T	0.2 - 1.5[e] / 1.1 - 6.0

[a] High population, high density areas such as those around Indian Point, present a different situation, and evacuation times are more complex, probably longer, and must be analyzed on a case by case basis.

[b] Maximum time may occur when offsite radiation measurements and dose projections are required before protective action is taken.

[c] Maximum time may occur when population density is low and evacuation area is large.

[d] Maximum time may occur when families are separated, a large number of farms or industries must be shut down, and special evacuations are required.

[e] Maximum time may occur when road system is inadequate for the large population to be evacuated and there are bottlenecks.

limited. Appendix B provides techniques for evaluating the various time periods involved in evacuation.

B. Risk of Death or Injury

If evacuation were likely to greatly increase an individual's risk of death or injury, this would act as a significant constraint on the use of evacuation as a protective action for a nuclear incident. Fortunately, examination of numerous evacuations indicate that risk of death or injury is not likely to be increased when evacuation is made by motor vehicle (3). Premature childbirth is routinely encountered in emergencies and subsequent evacuations, and in at least one State emergency plan, prior arrangements are made for this problem.

C. Evacuation Costs

For evacuations caused by storms or floods, cost is not usually a constraint because hazard to life and limb is obvious and because the evacuation cost is judged to be small compared to the damage caused by the disaster. However, in the event of a nuclear incident where there may be the strong inclination to evacuate even though the radiation dose to be saved is vanishingly small, the economic cost of the evacuation may act as a constraint. Therefore, the planner may wish to estimate this cost for various kinds of evacuation.

Evacuation costs may be broken into four categories:

(1) costs involving evacuees,

(2) costs involving evacuators,

(3) financial losses of farm areas, and

(4) financial losses of urban and industrial areas.

Limited information on estimated costs is given in reference (3). For a specific site, the various costs probably can be ascertained with more accuracy. Parameters that would affect the costs of an evacuation around a specific site are listed in table 1.6. Consideration of these parameters and how they affect cost should allow the planner to calculate the approximate monetary cost of an evacuation and thus estimate and evaluate this constraint.

1.6.3.2 Seeking Shelter

The local constraints on seeking shelter as a protective action, such as time to take action, cost of taking the action, and societal considerations, intuitively tend to support taking such action since the cost in each case is relatively small. However, if one compares the effect of seeking shelter with some other action such as evacuation on the basis of dose savings, it may be concluded that evacuation will save a far greater dose than seeking shelter. Generally, shelter provided by dwellings with windows and doors closed and ventilation turned off would provide good protection from inhalation of gases and vapors for a short period (i.e., one hour or less) but would be generally ineffective after about two hours due to natural ventilation of the shelter.

Not every constraint can be evaluated using established techniques; therefore, a certain amount of subjective judgment must be made on the part of the local planner. The important thing is that the local planner be aware of the constraints associated with each action and that these constraints be balanced on whatever basis possible in order

Table 1.6 Parameters Affecting the Cost of Evacuation

Area

- Size of area affected
- Location

Population

- Number
- Distribution
- Makeup

Institutions

- Type
- Population in
- Care required

Farms

- Size
- Type
- Product values

Business and Industry

- Type
- Size
- Work force
- Product value

Mode of Travel

Number of Evacuators Required

Shelters Needed

Duration of the Evacuation

Anti-looting Efforts

to arrive at a decision.

1.6.3.3 Access Control

Access control can be a very effective protective action to avoid exposure of personnel who might otherwise enter high exposure areas unnecessarily. Whether or not it can be applied effectively at all sites will depend upon several considerations which are site specific. For example, the time required to establish the necessary roadblocks may be longer than the exposure time. The cost of maintaining the capability for roadblocks and control of access points may be prohibitive. Furthermore, personnel that would be used in maintaining roadblocks might be more effectively used for other emergency functions. All of these factors must be considered in deciding whether to plan for full or partial access control during the early phases of an incident.

1.6.3.4 Respiratory Protection

Radiation exposure from inhalation of gaseous or particulate radionuclides may be reduced by the use of respirators. These devices protect the wearer by removing radioiodines (the primary gaseous nuclide of concern) on activiated charcoal and by removing particulate material by filtration. Several types of respirators are commercially available for use by adult male workers in contaminated atmospheres. However, respirators designed for women and children, i.e., the most radiation sensitive part of the population, may not be readily available. The first constraint on the use of respirators, therefore, is whether suitable devices are available. Secondly, for respirators to be

effective for the general population, they should be kept on hand by each person for immediate use upon notification and they must have been individually fitted. This means they should be distributed to the population at risk prior to a nuclear incident, and training should be provided for their use. The logistics of distributing such devices after an incident would greatly reduce their effectiveness by limiting their time of use. The cost of providing respirators for the entire population at risk is also a constraint, especially for large populations. Additional constraints include upsetting the population by acknowledging the danger with visible means and the failure of individuals to have their respirators personally available over long periods (years) Even if funding is available to provide the necessary respirators, it should be noted that use of such devices can only be a short term action of 2 to 3 hours. Therefore, they might best be used in conjunction with other protective actions such as seeking shelter or evacuation. It should also be kept in mind that respirators would not be of value where the exposure of concern was from direct radiation and not from inhalation of iodines or particulate material. Respirators may be most effective for emergency workers or other persons required to remain in evacuation zones.

1.6.3.5 Prophylaxis (Thyroid Protection)

The uptake of inhaled or ingested radioiodine by the thyroid gland may be reduced by the ingestion of stable iodine. The oral administration of about 100 milligrams of potassium iodide will result

in sufficient accumulation of stable iodine in the thyroid to prevent significant uptake of radioiodine. The main constraint in the use of this means of thyroid protection is that potassium iodide is normally administered only by prescription and would have to be distributed in accordance with State health laws. Potassium iodide as a prophylaxis is only effective if the exposure of concern is from radioiodine and only if the stable iodine is administered before or shortly after the start of intake of radioiodine. All emergency workers for areas possibly involving radioiodine contamination should receive this kind of thyroid protection, especially if appropirate respirators are not available. The cost constraint would not be significant for potassium iodide itself, but the cost for administering this material should be considered, including the cost of testing emergency workers for sensitivity to iodine prior to issue or use.

The use of stable iodine as a protective action for emergency workers has been recommended by EPA, but only in accordance with State health laws and under the direction of State medical officials as indicated above. However, the efficacy of administering stable iodine as a protective action for the general population is still under consideration by government agencies and should not be construed to be the policy of EPA at this time.

1.6.3.6 Milk Control

In order to protect the population from exposure to ingestion of contaminated milk, the planner has two basic alternative actions, which are:

(1) Cow-feed or pasture control to prevent the ingestion of radioactive materials by dairy cattle, or

(2) Milk control either by diverting the milk to other uses that allow the radioactivity to decay before ingestion or by destroying the milk and substituting uncontaminated milk from other areas.

The optimum action would be to prevent, through pasture and feed control, contamination of the milk. This would be followed up by milk control only in contaminated areas where pasture and feed control were not carried out or were not adequate. Local constraints may reduce the acceptability or effectiveness of these two protective actions. The alternatives to taking these actions include:

(1) Permitting the population to receive higher dosage. (Thyroid cancer is generally not fatal.)

(2) Suggest voluntary avoidance of the use of contaminated milk by children and pregnant women. (Children are more sensitive than adults because of greater intake of milk and greater concentration within the thyroid.)

(3) Administer stable iodine as discussed earlier under thyroid protection (section 1.6.3.5).

The local constraints on the control of dairy cow feed or pasture may include the following:

(1) A shortage of uncontaminated feed.

(2) A shortage of personnel to carry out feed and pasture controls in evacuated areas.

(3) The short time available to implement feed and pasture controls over a large area (possibly hundreds of square miles) may create communication problems and uncertainties as to the areas where pasture and feed control should be implemented.

(4) The cost of the stored feed and the cost of transporting it to needed areas might be prohibitive.

Local constraints on the control of milk may include:

(1) The shortage of nearby processing plants.

(2) Inadequate storage capacity to wait for radioactive decay.

(3) Objections to shipment of contaminated milk to other jurisdictions for processing.

(4) Pollution from disposal of large volumes of milk.

(5) Shortage of monitoring personnel and equipment for all milk producers.

(6) Shortage of milk for critical users.

(7) Costs associated with transporting, storage, or disposal of milk.

The dose to the thyroid of a child from drinking milk contaminated with radioiodine through the atmosphere-pasture-cow-milk exposure pathway may be hundreds of times the thyroid dose that would be received by the same child from breathing the air that caused the contamination of the pasture. Therefore, the size of the area over which milk might

have to be controlled could be much larger than the size of the area that would be evacuated to prevent inhalation of the iodine.

To avoid the problems and constraints assoicated with milk storage, transport, or disposal, the planner should prepare for pasture or feed control in all directions from the plant out to five times the distance planned for evacuation and in predominantly downwind directions out to about 50 to 100 miles. Controls over greater distances could be needed if the wind persisted in a single direction for an extended period. If pasture and feed control actions have been implemented (even if only partially implemented), noncontaminated milk supplies may be available at least for critical users.

All milk producers in the affected area should be restricted from using or distributing milk until monitored. If monitoring of all milk supplies is a constraint, monitoring efforts could be concentrated on milk supplies where pasture and feed control had been implemented and on the fringes of the contaminated area.

The planner can reduce the effect of constraints related to uncontaminated feed supplies and processing plants by identifying their locations and procedure for access.

Resistance by milk producers to protective actions for milk may be reduced by the planner having answers to questions regarding reimbursements of costs incurred by the producer.

1.6.3.7 Food Control

Food exposed to airborne radioactive materials may become contaminated by deposition of radioiodine and particulate material. To avoid population exposure from ingestion of these materials, the response planner should consider the following protective actions for short term protection.

(1) Prohibition on use of potentially contaminated food such as field and orchard crops and substitution from uncontaminated supplies.

(2) Decontamination.

The primary constraint on the use of these controls will be the availability of adequate substitute supplies at a reasonable cost. If other supplies are not available or the cost is high, then it may be necessary to implement decontamination procedures. For protection beyond a few days where availability and cost constraints would be more critical, then decontamination may be even more cost effective. The primary means of decontamination would be through washing and peeling (where appropriate) of fresh fruits and vegetables. The constraints on such procedures would be the ability to monitor the decontaminated items to assure adequate decontamination. Monitoring of food will likely be a much demanded service both by the individual farmer-consumer and by the distributor.

Other alternative controls would be to impound food stocks and store them to allow decay of radiation levels or destroy them to prevent consumption. The main constraint on these alternatives would be spoilage

and the value of the food stocks in relation to the costs of storage or destruction.

1.6.3.8 Water Control

Water may be contaminated either by direct release of radionuclides to surface waters or by deposition from an atmospheric release. Water reservoirs supplied by land surface run-off or cisterns supplied by roof run-off would be most severely affected by atmospheric deposition, whereas reservoirs supplied from streams and lakes would be most affected by contaminated liquid effluents. Spring and well water should not be affected by an accidental release of radioactive material to the atmosphere or to waterways. However, springs or wells that appear muddy after a rain might be suspect and should be monitored after a rain if they are in the area receiving heavy deposition. Some accident scenarios involve fuel melting its way into the soil, and such a condition could contaminate underground water supplies.

The protective actions for water can be either to prevent contamination or decontamination of the water supply or to condemn the use of the water for consumption.

In the case of reservoirs supplied from surface or roof run-off, prevention of reservoir contamination would not be possible unless methods existed for diverting the run-off. Reservoirs receiving their supply from a stream or lake normally are filled through pumping and filtration stations which are controlled by operators. These stations could be shut off if the source of the water supply became contaminated.

This may also be true for food processors using a stream or lake directly for their water supply. Many reservoirs supply water to municipal systems through a filtration plant. Such a plant would tend to decontaminate the water supply, and monitoring of water after filtration would provide data that should be taken into consideration in the process of deciding whether or not to condemn the supply.

The constraints associated with restrictions on supplies to reservoirs or condemnation of water systems are related to the difficulties, hardships, and costs associated with the resulting shortage of water supplies. If the planner determines that these protective actions may be appropriate for particular water systems, he should also identify the hardships that may result and plan methods for alternative supplies. These may include rationing of uncontaminated supplies, substitution of other beverages, importing water from other uncontaminated areas, and the designation of certain critical users that could be allowed to use contaminated supplies. These might be fire-water systems and process cooling systems.

1.6.3.9 Restorative Actions

A. Lifting Protection Controls

The lifting of controls for protective actions may be justified on the basis of cost savings when the corresponding health risks have been adequately reduced. For example, the costs to the public and the State in maintaining access control, pasture control, milk control, or food and water control will exceed the risk reduction value of

these controls after some period, and then the controls should be lifted. The costs for maintaining these controls will be relatively constant with respect to time while their significance in reducing risk will decrease as the source of radionuclides is halted and the released nuclides disperse or decay away. Therefore, it may be desirable to lift controls even though some additional dose may be accrued.

B. Reentry

After evacuation, persons will be allowed to reenter the zone when the potential radiation risk has been averted or reduced to guide levels for members of the general population. However, it may be necessary for certain essential personnel to return even before the dose is reduced to these guide levels. In addition, reentry may be allowed earlier for less radiosensitive persons such as adult males who may need to return to their homes or jobs. The criteria for reentry will require a balancing of remaining radiation risk such as from ground contamination and the cost of disrupted services, lost income, etc. resulting from the evacuation. Time is not a constraint on reentry except as a factor in the cost of remaining out of the evacuated area.

C. Decontamination

The movement of radionuclides along several pathways involving milk, food, and water may result in prolonged contamination. Each of these elements may require processing to remove radioactive contaminants

prior to consumption. In each case, the radionuclide concentrations would be r duced to levels "as low as practicable" commensurate with treatment costs.

CHAPTER 2

Protective Action Guides for Exposure to Airborne Radioactive Materials

2.0 Introduction

Following an incident involving a release of radioactive material to the atmosphere, there may be a need for rapid action to protect the public from radiation exposure from inhalation and/or from whole body external radiation. This chapter provides Protective Action Guides (PAGs) for whole body external gamma radiation and for inhalation of radioactive material in an airborne plume. A person who is exposed to the plume of airborne radioactive materials may also be exposed at a later date from contaminated food, water, or other pathways. However, the PAGs in this chapter refer only to the exposure received directly from the airborne plume. The emergency response situation addressed in this chapter is the period from initiation of an atmospheric release until perhaps two to four days after the event occurs. During this period, the principal effort would be directed toward protection of the public from direct exposure to the plume or from inhalation of radioactive material in the plume.

It is important to recognize that the PAGs are defined in terms of projected dose. Projected dose is the dose that would be received by the population if no protective action were taken. For

these PAGs, the projected dose does not include dose that may have been received prior to the time of estimating the projected dose. For protective actions to be most effective, they must be instituted before exposure to the plume begins. PAGs should be considered mandatory values for purposes of planning, but under accident conditions, the values are guidance subject to unanticipated conditions and constraints such that considerable judgment may be required for their application.

2.1 Whole Body External Exposure

A radioactive plume will consist of gaseous and/or particulate material. Either of these can result in whole body external exposure. Measurements or calculations of environmental levels of radioactivity are usually in terms of exposure. To translate from whole body gamma exposure to whole body dose requires a correction factor of approximately 0.67. However, due to the many uncertainties in projecting dose from exposure to a plume, it is generally conservatively assumed that gamma exposure and whole body gamma dose are equivalent.

Recommended PAGs for emergency response in the case of whole body external exposure to radionuclides in the atmosphere are summarized in table 2.1. These guidelines represent numerical values as to when, under the conditions most likely to occur, intervention is indicated to avoid radiation exposure that would otherwise result from the incident. When ranges are shown, the

Table 2.1 Protective Action Guides for Whole Body Exposure to Airborne Radioactive Materials

Population at Risk	Projected Whole Body Gamma Dose (Rem)
General population	1 to 5[a]
Emergency workers	25
Lifesaving activities	75

[a]When ranges are shown, the lowest value should be used if there are no major local constraints in providing protection at that level, especially to sensitive populations. Local constraints may make lower values impractical to use, but in no case should the higher value be exceeded in determining the need for protective action.

lowest value should be used if there are no major local constraints in providing protection at that level, especially to sensitive populations. Local constraints may make lower values impractical to use, but in no case should the higher value be exceeded in determining the need for protective action. The rationale and technical bases for the numerical guides and their ranges are described in greater detail in Reference (4) and are summarized in Appendix C. It is recommended that anyone responsible for applying these guides in a nuclear emergency become familiar with the rationale on which the guidance was based.

2.2 Inhalation Dose

The gaseous portion of a radioactive plume may consist of noble gases and/or vapors such as radioiodines. The noble gases will not cause as much dose from inhalation as from whole body external exposure and therefore need not be considered as a separate contributor to inhalation exposure. The principal inhalation dose will be from the iodines and particulate material in the plume.

2.2.1 Exposure to Radioiodines in a Plume

Due to the ability of the thyroid to concentrate iodines, the thyroid dose due to inhaling radioiodines may be hundreds of times greater than the corresponding whole body external gamma dose that would be received. The PAGs for thyroid dose due to inhalation from a passing plume are shown in table 2.2. The technical support for their development is provided in reference (4) and is summarized in Appendix C.

Table 2.2 Protective Action Guides for Thryoid Dose Due to Inhalation from a Passing Plume

Population at Risk	Projected Thyroid Dose rem
General population	5-25[a]
Emergency workers	125
Lifesaving activities	(b)

[a] When ranges are shown, the lowest value should be used if there are no major local constraints in providing protection at that level, especially to sensitive populations. Local constraints may make lower values impractical to use, but in no case should the higher value be exceeded in determining the need for protective action.

[b] No specific upper limit is given for thyroid exposure since in the extreme case complete thyroid loss might be an acceptable penalty for a life saved. However, this should not be necessary if respirators and/or thyroid protection for rescue personnel are available as the result of adequate planning.

2.2.2 Exposure to Particulate Material in a Plume

This section is being developed.

2.3 Interpretation of PAGs

The guides for the general population listed in tables 2.1 and 2.2 were arrived at in consideration of protection of the public from early effects of radiation and maintaining the delayed biological effects at a low probability. Consideration has been made of the higher sensitivity of children and pregnant women and the need to protect all members of the public. Consideration has also been made that personnel may continue to be exposed via some pathways after the plume passes, and that additional PAGs may have to be applied to these exposure pathways.

Where a range of values is presented, the lower guide is a suggested level at which the responsible officials should consider initiating protective action particularly for the more sensitive populations indicated above. The higher guide is a mandatory level at which the respective governmental agency should plan to take effective action to protect the general public unless the action would have greater risk than the projected dose.

At projected doses below the lower guide, responsible officials may suggest voluntary action available to the public at risk. This should be done with the philosophy that population doses be kept as low as possible as long as the effects of

action are not more hazardous than the projected dose. The concept of voluntary action and the types of action that may be considered were discussed in Chapter 1.

The need for selected populations, such as emergency response team members and persons involved in lifesaving activities, to be allowed higher exposures than the general public is in line with policies wherein these categories of individuals normally accept greater risk. Public safety and nuclear plant personnel will be essential to provide services for the public even though they may receive a greater radiation exposure.

In the event greater exposures to selected populations are required to save lives, these should be taken. However, if the radiation injury in these lifesaving activities is excessive, the harm may exceed the good, so some restrictions must be made.

Because of the variations in sensitivity of the population to radiation effects and in local conditions (weather, etc.), a range of values is recommended for the general population. Where selective protective actions (i.e. evacuation) for the general population is possible, children and women of childbearing age should be protected at the lower levels of the range. A further interpretation of the range is that plans should be made to consider organized protective action at the lower end of the range whereas it is mandatory that plans be made to implement protective action at the upper end. However, if no constraints existed, the lower range should

always be used. Since constraints exist on a local basis under different conditions, the range allows adjustment by local officials during the planning stage for special local problems as discussed in Chapter 1.

The values given for emergency workers recognize the need for some civil functions to continue in the event of an evacuation of the general population. The risks are considered to be warranted when necessary on the basis of the individual exposure and the benefits derived. In such cases, precautions should be taken to minimize exposures to emergency workers.

PAGs for lifesaving missions are given for those persons whose normal duties might involve such missions, i.e., police, firemen, radiation workers, etc. These guides would normally be limited to healthy males. No specific upper limits are given for thyroid exposure since in the extreme case, complete thyroid loss might be an acceptable penalty for a life saved. However, this should not be necessary if appropriate protective measures for rescue personnel are available as the result of adequate planning. For example, respiratory protection and/or stable iodine for blocking thyroid uptake of radioiodine should be available to the extent possible for personnel involved in lifesaving missions and other emergency actions. The issuance of stable iodine must be in accordance with state medical procedures.

CHAPTER 3

Protective Action Guides for Exposure from Foodstuffs or Water

3.1 Whole Body External Exposure

3.2 Ingestion

3.2.1 Milk

3.2.2 Food

3.2.3 Water

(Guidance to be Developed)

CHAPTER 4

Protective Action Guides for Exposure from Material Deposited on Property or Equipment

4.1 Reentry and Release

4.2 Decontamination

4.3 Land Use

(Guidance to be Developed)

CHAPTER 5

Application of Protective Action Guides for Exposure to Airborne Radioactive Materials

5.0 Introduction

Following notification that a radiological incident has occurred involving an atmospheric release that may require protection of the public, the State authorities will need information for decisions on what protective actions to implement. The types of information needed are (1) Protective Action Guides (dose limits) adjusted for local situations and (2) projected doses in specific areas for comparison to the Guides. Projected doses must be determined on the basis of data available following the incident. These data may come from either onsite measurements and conditions or offsite environmental measurements. This chapter deals with methods for estimating population dose from exposure to a radioactive cloud or plume and comparison of the projected dose with PAGs for decisions on protective actions. These methods are recommended for use by State and local officials for development of operational plans for responding to incidents at nuclear facilities. The guidance in this chapter is directly related to releases to the atmosphere that have been postulated for nuclear power facilities.

5.1 Release Assumptions

The types of protective actions that should be planned to reduce population exposure are related to the characteristics of the release that might occur. A recent publication of the NRC, WASH-1400 (1), indicates that should there be an accident at a nuclear power station, there is an extremely wide spectrum of different kinds of possible releases to the atmosphere depending on the severity and the exact sequence of the failure modes. Significant releases of radioactivity may occur within 1-1/2 to 2-1/2 hours of the initiating cause of the incident; therefore, if protective actions are to be effective, they must be taken promptly.

Incidences of relatively small environmental impact may involve a loss of coolant for the reactor but without a meltdown of the reactor core. For this class of accidents, the release to the atmosphere should be restricted to mostly radioactive noble gases and iodines.

Accidents of increasingly larger environmental impact would involve a meltdown of the reactor core and eventual loss of containment integrity. This class of accident will release quantities of radioactive particulate matter as well as the radioactive noble gases and iodines.

5.1.1 Noble Gases and Radioiodine Releases

For an atmospheric release at a nuclear power facility that involves only noble gases and radioiodines, it is usually conservative to assume that 100 percent of the equilibrium noble gases inventory and 25 percent of the equilibrium radioiodine inventory[1] would be available for release from containment. In the absence of more accurate information from the facility operator regarding the release composition, it would be conservative to assume that this composition is released to the environment at the design leakrate. The relative abundance of radioiodines and noble gases in an actual release from containment would be a function of the effectiveness of engineered safeguards (e.g., filters, spray systems, and scrubbing systems) in removing each component.

Table 5.1 summarizes the total quantities of radiologically significant gaseous radionuclides that are available to be released to the containment vessel following a loss of coolant accident at a 1,000 megawatt-electrical nuclear power reactor assuming 100 percent of the noble gases and 25 percent of the radioiodines escape from the core. These values may be adjusted linearly for reactors of other sizes.

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[1]This assumption is in agreement with NRC guidance (2,5,6) on assumptions that may be used in evaluating the radiological consequences of an accident at a light water cooled nuclear power facility.

Table 5.1 Initial inventory of the radiologically significant noble gases and iodines

Nuclide	Megacuries[a] available for release from containment	Half life
Krypton-85m	33.5	4.4 hr.
Krypton-85	0.66	10 yr.
Krypton-87	64.4	76 min.
Krypton-88	93.0	2.8 hr.
Iodine-131	18.7	8.1 day
Iodine-132	28.5	1.3 hr.
Iodine-133	45.9	20 hr.
Xenon-133m	4.0	2.3 day
Xenon-133	164.3	5.3 day
Iodine-134	51.5	52 min.
Iodine-135	39.5	6.7 hr.
Xenon-135m	19.0	16 min.
Xenon-135	46.4	9.1 hr.

Sum of kryptons 192 MCi

Sum of xenons 258 MCi

Sum of noble gases = 425 MCi

Sum of iodines = 184 MCi

$$\text{Ratio of } \frac{\text{iodines}}{\text{noble gases}} = \frac{184}{425} = 0.4$$

[a] Based on equilibrium inventory developed from maximum full power operation of a 1000 megawatt electrical light-water-cooled nuclear power reactor. This includes 100 percent of the noble gases and 25 percent of the iodines.

Calculations of the projected population dose based on the relative quantities shown in table 5.1 indicate that the thyroid dose from inhalation of radioiodine ranges up to 1,000 times greater than the whole body gamma dose from noble gases and radioiodines. If the engineered safeguards function as designed, they should reduce the iodine concentration such that the whole body gamma radiation exposure to noble gases will be the controlling pathway.

5.1.2 Radioactive Particulate Material Releases

This section is being developed.

Initial studies indicate that except for the most severe and improbable accidents postulated by WASH-1400, protective actions (prophylaxis iodine excepted) chosen on the basis of assuming that the iodine exposure pathway is critical (figure 5.2) will be sufficient to provide protection from radioactive particulate material. This particulate material will deliver an additional dose to the lung and to the whole body from material located in the lung, but these doses are not likely to be greater than the thyroid dose.

5.2 Application of Protective Actions

Following an incident at a nuclear power facility involving a release to the atmosphere, the most urgent actions in terms of response time will be those to protect the population from inhalation of radioactive materials in the plume

and from direct whole body exposure to gamma radiation from the plume. The time of exposure to the plume can be conveniently divided into two periods; (1) the period immediately following the incident when little or no environmental data are available to confirm the seriousness of population exposures, and (2) a period when environmental levels and/or concentrations are known During the first period, speed for completing such actions as evacuation, seeking shelter, and access control may be critical to minimize exposure in areas where PAGs may be exceeded. Furthermore, environmental measurements made during this period may have little meaning because of uncertainties concerning plume location when measurements are made or changes in release rate due to changes in pressure and radionuclide concentrations within containment. Therefore, it may be necessary to initiate early protective actions on the basis of dose projections provided by the facility operator followed by adjustments to these actions based on more detailed environmental measurements.

For accidents involving a release to the atmosphere at a nuclear power facility, the following sequence of events is suggested to minimize population exposure.

(1) Notification by the facility operator that an incident has occurred that is expected to cause offsite projected doses that exceed the PAGs. This notification should be provided as soon as possible following

the incident and prior to the release if possible.

(2) Immediate evacuation of a predesignated area.

(3) Monitor gamma exposure rates in the environment.

(4) Calculate plume centerline exposure rate as inversely proportional to distance from release point, or use prepared isopleths to estimate exposure rate in downwind area.

(5) Use exposure rate and estimated exposure duration to convert to projected dose.

(6) Compare projected dose to PAGs and adjust areas for protective actions as indicated. Table 5.2 summarizes recommended actions as a function of PAG levels for exposure to a gaseous plume.

(7) Continue to make adjustments as more data become available.

5.2.1 Actions Based on Licensee Notification

The AEC Guide and Checklist (2) indicates that the notification from a nuclear power facility to the State and local response organizations should include an estimate of the projected dose to the population at the site boundary and in the low population zone following an accidental release. The State emergency response planners should make arrangements with the facility operator to assure this information will be made available on a timely basis (within 1/2 to 1 hour following)

Table 5.2 Recommended protective actions to avoid whole body and thyroid dose from exposure to a gaseous plume.

Projected Dose (Rem) to the Population	Recommended Actions[a]	Comments
Whole body <1 Thyroid <5	·No protective action required. ·State may issue an advisory to seek shelter and await further instructions or to voluntarily evacuate. ·Monitor environmental radiation levels.	Previously recommended protective actions may be reconsidered or terminated.
Whole body 1 to <5 Thyroid 5 to <25	·Seek shelter and wait further instructions. ·Consider evacuation particularly for children and pregnant women. ·Monitor environmental radiation levels. ·Control access.	
Whole body 5 and above Thyroid 25 and above	·Conduct mandatory evacuation of populations in the predetermined area. ·Monitor environmental radiation levels and adjust area for mandatory evacuation based on these levels. ·Control access.	Seeking shelter would be an alternative if evacuation were not immediately possible.
Projected Dose (Rem) to Emergency Team Workers		
Whole body 25 Thyroid 125	·Control exposure of emergency team members to these levels except for lifesaving missions. (Appropriate controls for emergency workers, include time limitations, respirators, and stable iodine.)	Although respirators and stable iodine should be used where effective to control dose to emergency team workers, thyroid dose may not be a limiting factor for lifesaving missions.
Whole body 75	·Control exposure of emergency team members performing lifesaving missions to this level. (Control of time of exposure will be most effective.)	

[a]These actions are recommended for planning purposes. Protective action decisions at the time of the incident must take into consideration the impact of existing constraints.

the incident and prior to the start of the release if possible), and that it will be provided in units that can be compared to PAGs (i.e., projected dose to the whole body or thyroid).

The first indication that an incident has occurred with potential for population dose in excess of PAGs should come to State authorities from the facility operator. Although plans may include provisions for the facility operator to include information in the notification regarding projected dose to the population, such information may not be available. Furthermore, if dose projections are available, there may be reason to suspect their accuracy. Therefore, the State should have planned a designated area for immediate evacuation (or other suitable action). Immediate actions would be taken in this area if the facility operator's estimate of projected dose was not available or was not considered to be on a sound basis. If the facility operator provides projections of population dose, then these projections should be used by the State to determine the area for immediate action in lieu of the predesignated area.

The recommended area to be designated for immediate action is the downwind sector (one sector covers 22-1/2 degrees) and the two adjacent sectors. The radial distance for action should be to the outer edge of the low population zone. Other planned downwind distances or widths for immediate action may be justifiable for particular sites.

A transparency should be prepared which shows the downwind area for immediate action. The scale of the transparency should be the same as the map of the environs around the facility so that the action area can be quickly identified.

5.2.2 Actions Based on Environmental Measurements

During or following initial actions to protect the close-in population, environmental exposure rate measurements should be made to provide a data base for projecting dose and for re-evaluating the need for additional protective actions or termination of those actions already taken.

5.2.2.1 Dose Projection for Noble Gas and Iodine Releases

A gaseous release from a light water reactor is assumed to include radioactive noble gases, and iodines as shown in table 5.1. Unless engineered safeguards were successful in significantly reducing the quantity of radioiodines available for release relative to the quantity of noble gases, the dose from the inhalation of radioiodine would be the controlling pathway.

Since field measurements of environmental radioiodine concentrations would be difficult and time-consuming, it is recommended that the State plan to measure gamma exposure rate and estimate thyroid dose from inhalation by converting from gamma exposure rate to projected thyroid dose. The method for this conversion is discussed later in this section.

The projection of either whole body dose or thyroid dose requires a knowledge of the exposure rate and the time period of exposure. The time period of exposure may be difficult to predict. Exposure would start at a particular site when the plume arrived and would be ended by a shift in wind direction or by an end to the release. Arrangements should be made for the State or local weather forecast center to provide information on predicted wind direction persistence during the incident. If neither wind change nor the time until the end of the release can be predicted, the period of exposure could be assumed to be equal to the maximum (or 99% probable maximum) duration of wind direction for that site as determined from previous meteorological history.

Having obtained information regarding gamma exposure rate at selected locations in the environment, one must then estimate exposure rate in additional locations in order to identify the pattern of the exposed area. Estimation of exposure rate patterns based on a few downwind measurements can be conducted in a variety of ways. One simple way is to determine a plume centerline exposure rate at ground level at some known distance from the release point and use these data to calculate exposure rates at other designated distances downwind by conservatively assuming that the cloud centerline exposure rate is inversely proportional to the distance from

the release point.[2] The following relationship can be used for this calculation:

$$D_2 = \frac{D_1 R_1}{R_2}$$

Where:

D_1 = exposure rate measured at distance R_1

D_2 = exposure rate at distance R_2

One could then develop a crude and very conservative pattern of estimated exposure rates by assuming that the exposure rate calculated for the plume centerline would also exist at points equidistant from the source in the downwind sector (22½ degrees) and in the two adjacent sectors. This 67½ degree sector allows for wind meander and some uncertainty in wind direction. The use of this method would likely result in an overestimate of the exposure rate in all areas downwind of the measurement point. In addition, one must be sure that the exposure rate measurement is taken at or near the plume centerline.

A second and more accurate method for estimating exposure rate patterns is to use a series of prepared exposure isopleths (maps with lines connecting points of equal exposure rates)

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[2]The centerline exposure rate can be determined by traversing the plume at a point sufficiently far downwind (usually greater than one mile from the site) while taking continuous exposure rate measurements. The highest rating should be at the centerline of the plume.

plotted on transparencies. These isopleth plots are frequently available from the licensee thus eliminating the need for the State to develop them. Since both the meteorological stability and the wind speed existing at the time of the release affect the shape of the exposure isopleth curves, several sets of curves would be needed to represent the variety of stability conditions and wind speeds likely to exist at that site. The appropriate transparency can be selected on the basis of wind speed and meteorological conditions at the time of the incident. The transparency can then be placed over a map of the area such that the curves are properly oriented with regard to wind direction. The isopleth curves are used to estimate exposure rate by plotting the exposure rates known at specific locations on the curves. Exposure rates at other locations are simple multiples of the known exposure rates as indicated by the multipliers associated with each curve.

A third alternative for determining exposure rate patterns is to obtain gamma exposure rate measurements at a large number of locations and plot these data on a map of the area. This method would provide the most accurate data but would require a large number of radiation instruments and trained persons to make the measurements as well as a method for communicating the data to the control center on a continuing basis.

Having established gamma exposure rate patterns in the environment and having determined (or estimated) the time period of exposure, the next task is to estimate the projected whole body and thyroid dose to members of the population so that the projected dose can be compared with appropriate PAGs. If engineered safeguards operate as designed. they may reduce iodine concentrations to levels such that the whole body gamma radiation exposure from noble gases will be the controlling pathway. Otherwise, the controlling exposure pathway will be inhalation of radioiodines resulting in thyroid dose ranging up to hundreds of times the whole body gamma dose depending on the effectiveness of the engineered safeguards.

To avoid the necessity for calculating projected dose at the time of the incident, it is recommended that dose projection nomograms be developed. Figures 5.1 and 5.2 are examples of such nomograms. Appendix D provides details regarding their development.

The projected whole body gamma dose can be estimated by simply multiplying the gamma exposure rate at a particular location by the time period of exposure. Figure 5.1 provides this multiplication. It also provides a relationship between exposure rate in mr/hr and the noble gas concentration based on the mixture of radioactive noble gases shown in table 5.1.

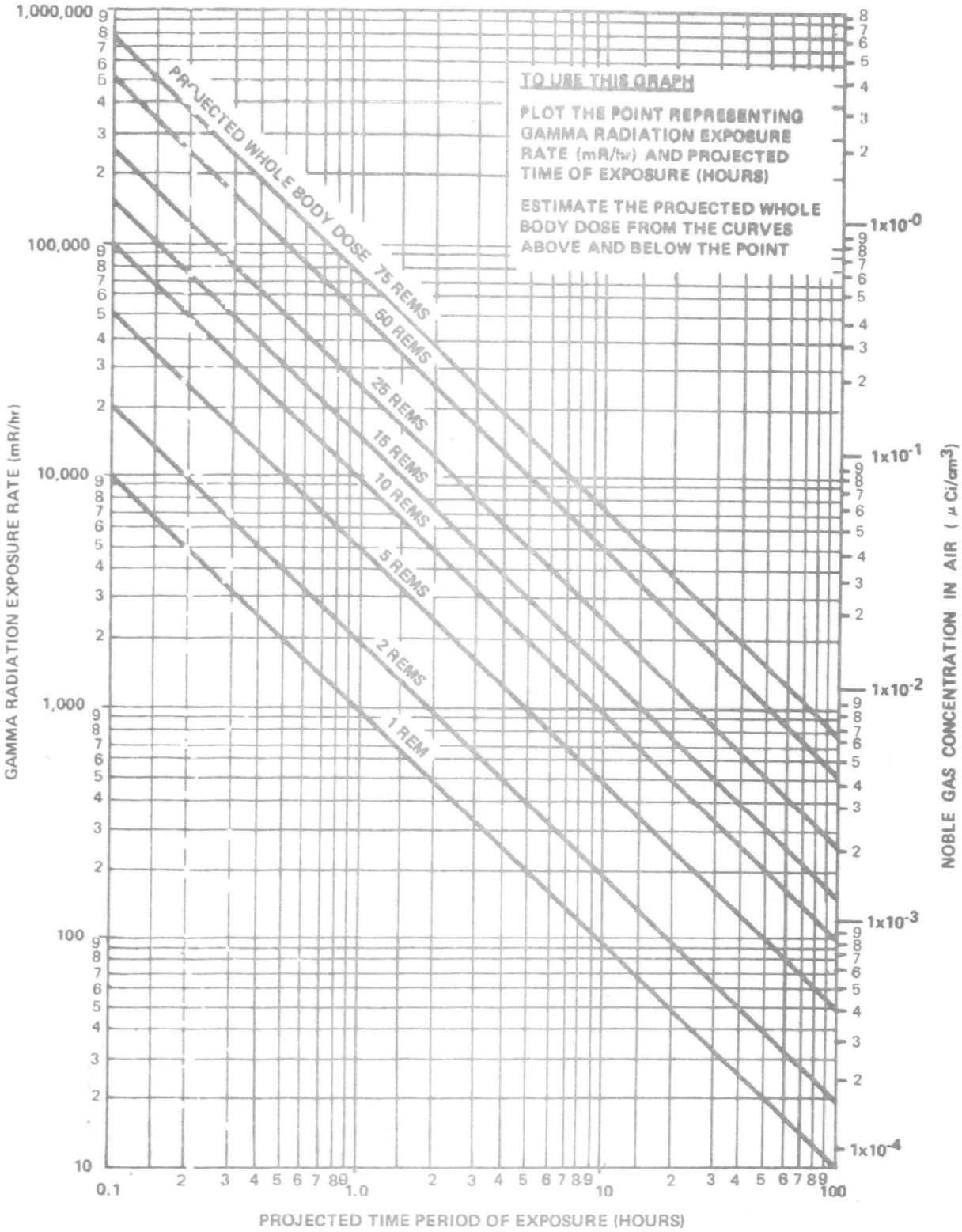

FIGURE 5.1–PROJECTED WHOLE BODY GAMMA DOSE AS A FUNCTION OF GAMMA RADIATION EXPOSURE RATE AND PROJECTED TIME PERIOD OF EXPOSURE

[redacted]

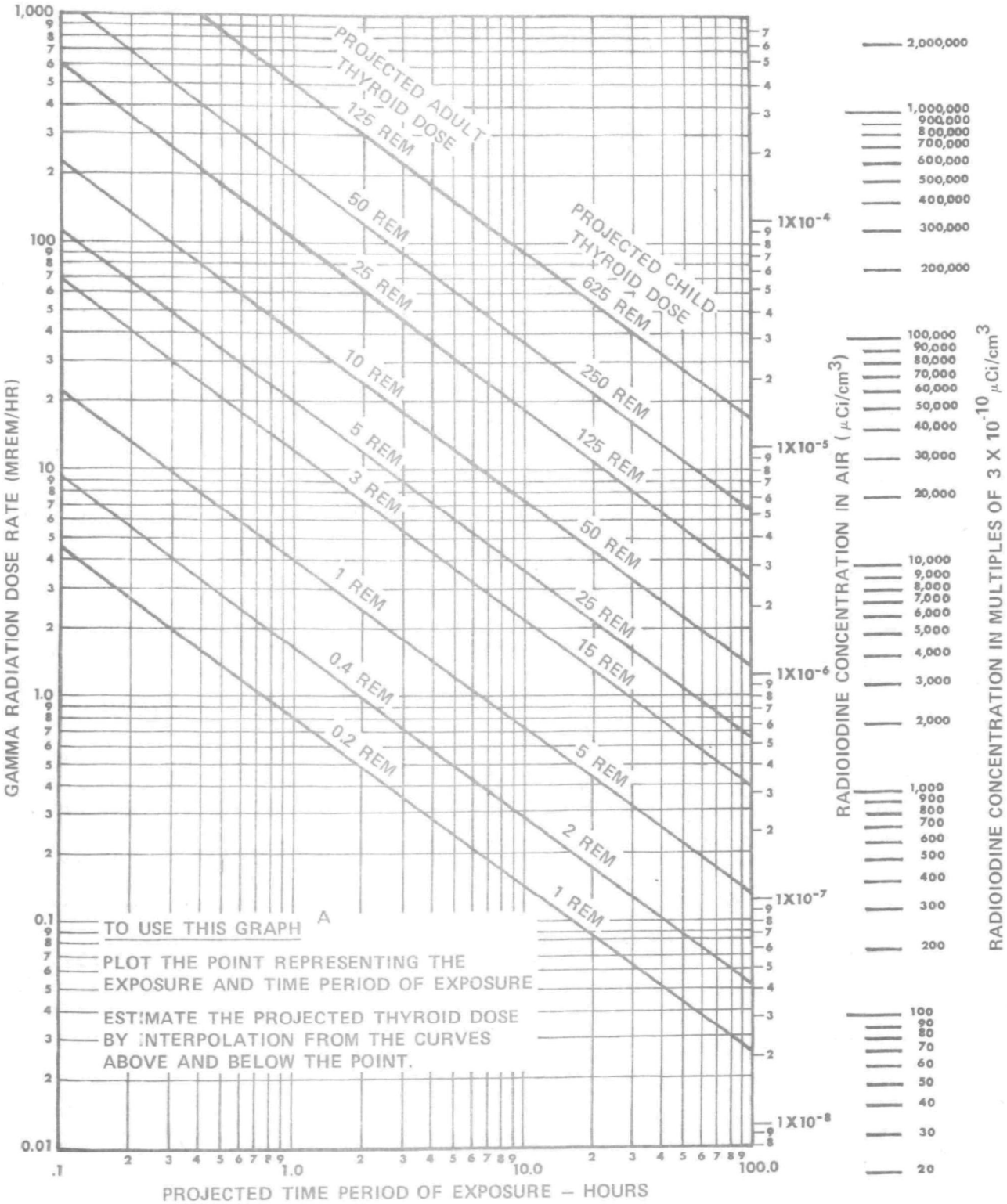

FIGURE 5.2 PROJECTED THYROID DOSE AS A FUNCTION OF GAMMA RADIATION EXPOSURE RATE AND PROJECTED TIME PERIOD OF EXPOSURE

A. USE OF THIS FIGURE ASSUMES THAT THE RADIOIODINE/NOBLE GAS ACTIVITY RATIO IS 0.3. IF IT IS KNOWN THAT THE RATIO HAS A LOWER VALUE, THE CORRECTION FACTOR GIVEN IN FIGURE 5.3 SHOULD BE USED.

The estimation of projected thyroid dose on the basis of gamma exposure rates and duration of exposure is more complex because the projected dose is also a function of the composition of the release which is a function of the type of incident, the time after shutdown, and the operation of engineered safeguards.

In the most probable event, radioiodines will be present in a release but neither the ratio of radioiodines to the noble gases nor concentrations of radioiodines in the environment will be known. If this is the case, the conservative assumption can be made that the radioiodine is the most critical and that the radioiodine/noble gas activity ratio is 0.3. (Although the initial ratio in containment is assumed to be 0.4 as shown in table 5.1, this value rapidly decreases with time and 0.3 would be more representative by the time the plume reached the population). This assumption allows the direct use of figure 5.2 to estimate projected thyroid dose as a function of gamma exposure rates and time period of exposure. If the actual radioiodine/noble gas activity ratio has been determined and is less than 0.3, figure 5.3 may be used to derive the appropriate correction factor for gamma dose rate values before applying them in figure 5.2 If radioiodines are known to be absent or reduced to 0.005 or less of the original concentration, the critical exposure pathway becomes that of whole body gamma exposure, and figure 5.1 applies instead of figure 5.2.

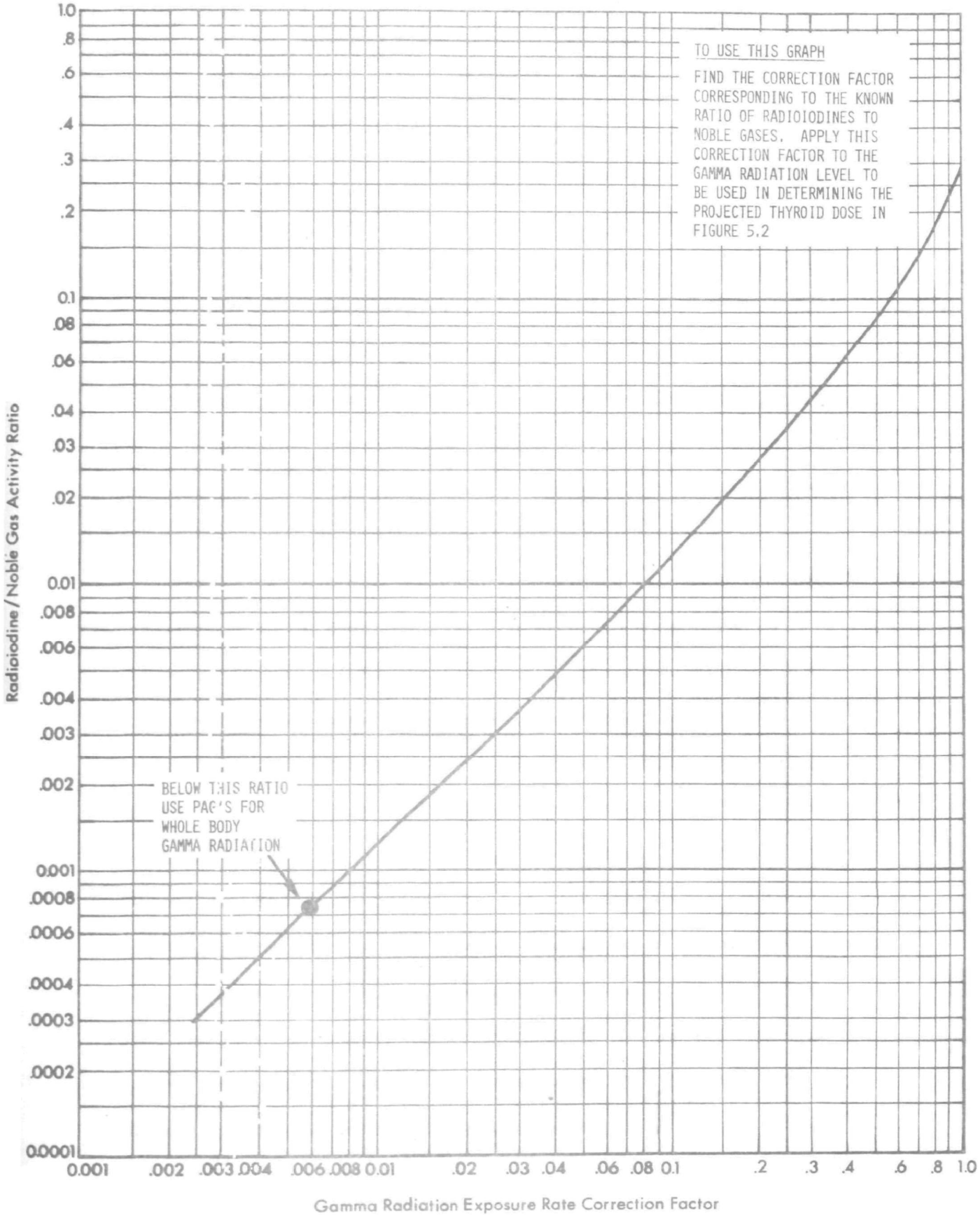

FIGURE 5.3 GAMMA RADIATION EXPOSURE RATE CORRECTION FACTOR

A better method for correcting the gamma exposure rate for use in figure 5.2 to estimate the projected thyroid dose would be to take one or more iodine concentration measurements at some locations where gamma exposure rate measurements were taken. Compare the gamma exposure rates to the corresponding iodine concentration measurements on figure 5.2 and determine the ratio of measured concentration to the observed "corresponding" concentration. This ratio can be used to correct other gamma measurements prior to their use in figure 5.2 to project thyroid dose.

Figure 5.2 can also be used to estimate projected thyroid dose if one knows environmental concentrations in terms of $\mu Ci/cm^3$. To use figure 5.2 to estimate projected thyroid dose, one needs the projected time period of exposure and the environmental radioactivity level. The time period of exposure may be estimated on the basis of (1) history of maximum wind direction persistence for that area, (2) forecasts of wind change at the time of the incident, or (3) the facility operator's prediction of the expected duration of the release based on plant conditions.

To estimate projected thyroid dose for a particular site, plot the point of figure 5.2 corresponding to the exposure rate (gamma exposure rate in mr/hr, or radioiodine concentrations in $\mu Ci/cc$) and the expected time period of exposure for persons at that location. Estimate the projected thyroid dose from the dose

values on the curves below and above the point.[3] For example, if the gamma radiation level is reported to be 100 mR/hr and is expected to last three hours, then the projected adult thyroid dose is approximately 60 rems, and the child thyroid dose would be approximately 300 rems. (Refer to table 5.2 for recommended protective actions associated with each projected dose).

Figure 5.3 is used only in the event that the radioiodine/noble gas activity ratio is known and is less than the assumed value of 0.3 and only for correcting the gamma exposure rate for use in figure 5.2. No correction factor is needed if the environmental radioactivity level is expressed as iodine concentration. The measured gamma exposure rate may be multiplied by the factor obtained from figure 5.3 to give a "corrected" gamma exposure rate for use with figure 5.2 to determine projected thyroid dose.

For example, if the radioiodine/noble gas radioactivity ratio is measured and found to be 0.01, the gamma radiation level correction factor from figure 5.3 is 0.08. The "corrected" gamma radiation level is then 8 mR/hr for a measured gamma radiation level of 100 mR/hr. For a projected time period of exposure

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[3]Note that the child thyroid dose is five times the adult thyroid dose. The child dose would apply to general populations for deciding whether or not to evacuate, while the adult dose would apply to emergency teams or other adults.

of three hours, the actual projected child thyroid dose would be approximately 25 rem as compared to approximately 300 rem without use of the correction factor.

For a puff or continuous release to the atmosphere where the report of release includes the number of curies released or that could potentially be released or where the release rate and the expected duration of the release is reported, the immediate question becomes; how far downwind should actions be taken to protect the population from the airborne plume? Although dose projections based on release information would normally be done by facility operators, it is advisable for State radiological personnel to understand the techniques involved. The dose projections can be accomplished by using nomograms such as those in figures 5.1 and 5.2 to identify the time-concentration that would produce a projected dose equal to the PAG and a plot of $\chi\bar{U}/Q$ versus downwind distance such as figure 5.4 to determine the distance where that time-concentration would exist.

To make this determination, one must have information regarding the principal exposure pathway, the curies released of the radionuclides contributing to that exposure pathway, the windspeed, and atmospheric stability class. In the absence of any of these bits of information, one must be prepared to substitute assumed values and conditions based on a knowledge of the facility and the environment.

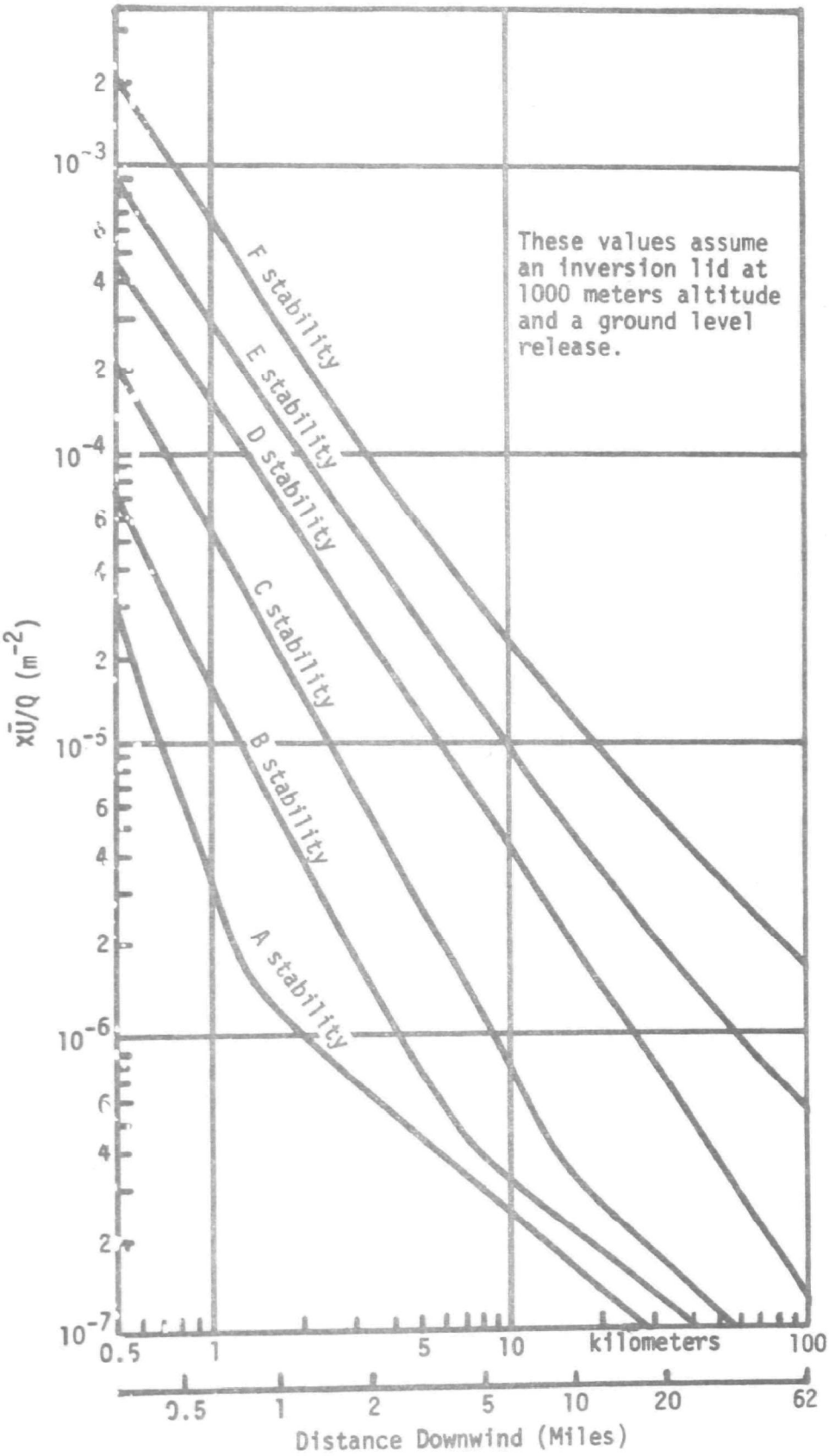

Figure 5.4 Typical values for $\bar{x}\bar{U}/Q$ as a function of atmospheric stability class and downwind distance

The methods for determining the downwind distance to where protective action should be taken for a puff release are similar to the methods for a longer term release. However, for purposes of using the nomograms in figures 5.1 and 5.2, it is convenient to assign a release time of one hour for the puff release. The distance downwind for protective action can be read from a plot of $\chi\bar{U}/Q$ versus distance for various atmospheric stability classes as shown in figure 5.4. The term $\chi\bar{U}/Q$ can be calculated using the relationship

$$C\bar{U} = Q \times \chi\bar{U}/Q \qquad (1)$$

Where:

C = environmental concentration of concern in Ci/m^3 or $\bar{U}Ci/cm^3$

$\bar{U}$ = average windspeed in m/sec. Multiply MPH by .5 to obtain m/sec (approximately)

Q = release rate in curies/sec

χ/Q = environmental concentration at a particular location per curie per second being released at the source (sec/m^3)

Then:

$$\chi\bar{U}/Q = C\bar{U}/Q \qquad (2)$$

For example:

If the accident involves a puff release of 20,000 curies of iodines and the PAG is 5 rem to the thyroid, then from figure

5.2 one can observe that the concentration of concern over a period of one hour would be 3.3×10^{-6} uci/cm^3. The release rate averaged over one hour would be $\frac{20,000 \text{ ci}}{3600 \text{ sec}} = 5.5$ ci/sec.

Therefore:

$$\chi\bar{U}/Q = \frac{3.3 \times 10^{-6} \ (\bar{U}\text{Ci/cm}^3) \times \bar{U}(\text{m/sec})}{5.5 \text{ ci/sec}}$$

$$= 6.7 \times 10^{-7} \ \bar{U}$$

If:

$$\bar{U} = 10 \text{ mph} \approx 5 \text{ m/sec}$$

Then:

$$\chi\bar{U}/Q = 3 \times 10^{-6}$$

From figure 5.4 one can observe that a $\chi\bar{U}/Q$ value of 3×10^{-6} would occur at about 0.6 miles downwind under atmospheric stability condition A and about 35 miles downwind under condition F.

For the puff release, PAGs could be identified (i.e. 5 rem to the thyroid) and a specific time period for the release could be assumed (i.e., 1 hour = 3,600 sec) so that equation 2 could be simplified to:

$$\chi\bar{U}/Q = \frac{3.3 \times 10^{-6} \ \bar{U}\text{Ci/cc} \times \bar{U}}{\text{ci/3600 sec}} = \frac{.012\bar{U}}{\text{curies released}}$$

or:

$$\chi\bar{U}/Q = \frac{0.012\bar{U}}{\text{Ci}} \qquad (3)$$

The methods presented in this Chapter for relating data at the time of the incident to projected dose are recommended for

use in development of operational response plans for gaseous releases. However, planners are encouraged to improve on these methods where possible and to alter them as necessary to respond to special circumstances.

5.2.2.2 Dose Projection for Particulate Material Releases

This section to be developed.

CHAPTER 6

Application of PAGs for Foodstuffs and Water Contamination

6.1 Relocation

6.1.1 Whole Body

6.1.2 Organ Exposure

6.2 Shelter

6.2.1 Whole Body

6.3 Access Control

6.4 Milk Control

6.5 Food Control

6.6 Water Control

(Guidance to be Developed)

CHAPTER 7

Application of PAGs for Contaminated Property or Equipment

7.1 Release and Reentry

7.2 Decontamination

7.3 Land Use

(Guidance to be Developed)

CHAPTER 8

Application of PAGs for Transportation Incidents

(Guidance to be Developed)

APPENDIX A

Summary of Interim Guidance on Offsite Emergency Radiation Measurement Systems

(to be developed)

APPENDIX B

Planner's Evaluation Guide for Protective Actions

(to be developed)

APPENDIX C

Summary of Technical Bases for Protective Action Guides

(to be developed)

APPENDIX D

Technical Bases for Dose Projection Methods

(to be developed)

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