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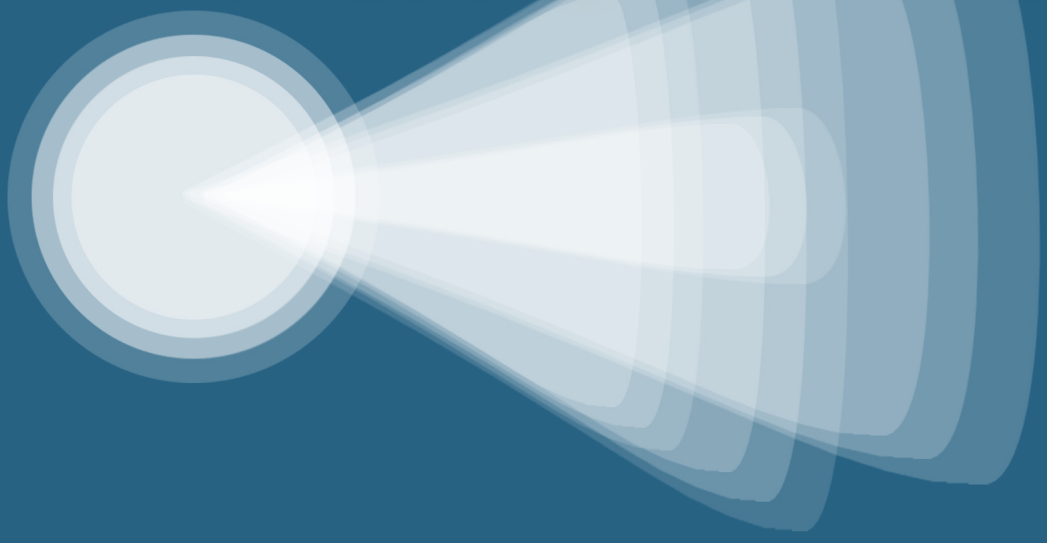
United States
Environmental Protection
Agency

PAG Manual:
Protective Action Guides and Planning Guidance for Radiological Incidents



PAG Manual

Protective Action Guides and Planning Guidance for Radiological Incidents

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FINAL REVISION: SUPERSEDES 1992, 2013 AND 2016 MANUALS

Office of Radiation and Indoor Air
Radiation Protection Division
U.S. Environmental Protection Agency
Washington, DC 20460

LIMITS ON SCOPE

This guidance does not address or impact site cleanups occurring under other statutory authorities such as the United States Environmental Protection Agency's (EPA) Superfund program, the Nuclear Regulatory Commission's (NRC) decommissioning program, or other federal or state cleanup programs.

As indicated by the use of non-mandatory language such as "may," "should" and "can," this Manual only provides recommendations and does not confer any legal rights or impose any legally binding requirements upon any member of the public, state, tribe, locality, or any federal agency.

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CHAPTER 1. OVERVIEW

1.1 PLANNING GUIDANCE AND PROTECTIVE ACTION GUIDES

The U.S. Environmental Protection Agency (EPA) has developed this Manual to assist public officials in planning for emergency response to radiological incidents. For purposes of this document, a radiological incident is an event or a series of events, deliberate or accidental, leading to the release or potential release into the environment of radioactive materials in sufficient quantity to warrant consideration of protective actions. This Manual provides radiological protection criteria for application to all incidents that would require consideration of protective actions.

During an incident with an uncontrolled source of radiation, protection of the public from unnecessary exposure to radiation may require some form of intervention that will disrupt normal living. Such intervention is termed a protective action. Examples of protective actions include:

- Evacuating an area;
- Sheltering-in-place within a building or protective structure;
- Administering potassium iodide (KI) as a supplemental action;
- Relocation;
- Acquiring an alternate source of drinking water; and
- Interdiction of food/milk.

This Manual provides recommended numerical protective action guides (PAGs) for the principal protective actions available to public officials during a radiological incident. A PAG is defined for purposes of this document as the projected dose to an individual from a release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended. (See Section 2.3 for a discussion of projected dose.) PAGs are guides to help officials select protective actions under emergency conditions during which exposures would occur for relatively short time periods. They are not meant to be applied as strict numeric criteria, but rather as guidelines to be considered in the context of incident-specific factors. PAGs do not establish an acceptable level of risk for normal, non-emergency conditions, nor do they represent the boundary between safe and unsafe conditions. The PAGs are not legally binding regulations or standards and do not supersede any environmental laws. For information on roles, responsibilities and authorities during emergency response and recovery, please refer to the National Response Framework: http://www.fema.gov/national-response-framework (FEMA 2008a) and specifically for radiological incidents, the Nuclear Radiological Incident Annex: http://www.fema.gov/pdf/about/divisions/thd/IncidentNucRad.pdf (FEMA 2008b).

Some protective actions are not associated with a numerical PAG. For example, the control of access to areas is a protective action implemented in concert with other protective actions; it does not have its own PAG. Any reasonable action to reduce radiation dose is encouraged even if it is not associated with a PAG, such as recommending that individuals use ad hoc respiratory protection with a handkerchief or piece of folded cloth. In areas where PAGs are not exceeded, but airborne radioactivity is present, people might be asked to stay indoors to the extent practicable to reduce their exposures. To further develop radiological emergency plans, brief planning guides have been provided for reentry to relocation areas, the cleanup planning process, and considerations for radioactive waste disposal (see Sections 4.5, 5.1 and 5.2).

1.2 APPLICABILITY

Protective actions may be recommended for a wide range of incidents, but generally apply to incidents involving relatively significant releases of radionuclides. Radiological incidents with potential for significant releases include:

- A fire in a major facility such as a nuclear fuel manufacturing plant;
- An accident at a federal nuclear weapons complex facility;
- An accident at a commercial nuclear power plant (NPP);
- A transportation accident involving radioactive material; and
- A terrorist act involving a radiological dispersal device (RDD) or yield-producing improvised nuclear device (IND).

Each type of incident would pose a unique threat to public health and should be planned for and managed accordingly. Emergency response planning for a given facility or scenario should consider:

- The radionuclides involved;
- The dynamics of the release, including size and magnitude;
- The feasibility of specific protective actions; and
- The timing of notification, response, and protective action implementation.

The decision to advise members of the public to take a protective action during a radiological incident involves a complex judgment in which the radiological risk must be weighed against the action's inherent risks. This decision may have to be made under emergency conditions, with limited information and little time to analyze options. Advance planning reduces the complexity of the decision-making process during an incident. The planning process can identify the viability of responses to various incidents, the courses of action that can be set in motion in advance and the decisions that can only be made during an actual emergency. While many aspects of protective actions can be considered well in advance of an emergency, the situations and conditions that exist at the time of emergency must be considered if the most effective action is to be selected.

The unpredictable locations of certain radiological incidents make advance planning challenging. For example, an RDD could detonate anywhere and spread radiological contaminants over a wide variety of surfaces and terrain. Emergency planners should be prepared to apply PAGs to a wide scope of facilities and circumstances.

1.3 BACKGROUND ON THE UPDATED PAGS

This Manual updates the "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents" (EPA-400-R-92-001, May 1992), published by EPA (EPA 1992b) (hereinafter referred to as the "1992 PAG Manual"). The guidance in this Manual was developed cooperatively with the Federal Radiological Preparedness Coordination Committee (FRPCC), with representation from the EPA; the Department of Energy (DOE); the Department of Defense (DoD); the Department of Homeland Security (DHS) Federal Emergency Management Agency (FEMA); the Nuclear Regulatory Commission (NRC); the Department of Health and Human Services (HHS), including the Centers for Disease Control and Prevention (CDC) and the Food and Drug Administration (FDA); the U.S. Department of Agriculture (USDA); and the Department of Labor (DOL).

1.3.1 Legal Basis

The historical and legal basis of EPA's role in developing this guidance begins with Reorganization Plan No. 3 of 1970, in which the Administrator of EPA assumed all the functions of the Federal Radiation Council (FRC), including the charge to "…advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with states" (Reorg. Plan No. 3 of 1970, sec. 2(a) (7), 6(a) (2); § 274.h of the Atomic Energy Act of 1954, as amended (AEA), codified at 42 U.S.C. § 2021(h)). Recognizing this role, FEMA, in its Radiological Emergency Planning and Preparedness Regulations, directed EPA to "establish Protective Action Guides (PAGs) for all aspects of radiological emergency planning in coordination with appropriate federal agencies" (44 Code of

Federal Regulations (CFR) §351.22(a)). FEMA also tasked EPA with preparing "guidance for state and local governments on implementing PAGs, including recommendations on protective actions which can be taken to mitigate the potential radiation dose to the population" (44 CFR §351.22(b)). All of this information was to "be presented in the EPA Manual of Protective Action Guides and Protective Actions for Nuclear Incidents" (44 CFR §351.22(b)).

Additionally, section 2021(h) charged the Administrator with performing "such other functions as the President may assign to him [or her] by Executive Order." Executive Order 12656 states that the Administrator shall "develop, for national security emergencies, guidance on acceptable emergency levels of nuclear radiation…." (Executive Order No. 12656, sec. 1601(2)). EPA's role in the development of PAGs was also recognized in the "Nuclear Radiological Incident Annex of the National Response Framework" of June 2008 (FEMA 2008b).

1.3.2 Interaction with Federal Radiation Council (FRC) Reports No. 5 and 7

In the 1960s, the Federal Radiation Council (FRC) defined PAGs and established limiting guides for ingestion of strontium-89, strontium-90, cesium-137, and iodine-131 (FRC 1964; FRC 1965). That guidance applied to restricting the use of food products that had become contaminated as the result of release of radioactivity to the stratosphere from weapons testing. Since the 1960s, experience with other exposure scenarios such as accidents and terrorism made more guidance necessary. During the period immediately following an incident at any domestic nuclear facility, when the critical source of exposure is expected to be a nearby airborne plume, the principal protective actions are evacuation or sheltering. The PAGs developed here thus do not supersede previous guidance, but provide additional guidance for promptly addressing exposure pathways specific to a domestic nuclear incident.

1.3.3 Technical Basis

The FRC introduced the concept of a PAG in a series of recommendations issued in the 1960s. A key concept about PAGs is that the decision to implement protective actions should be based on the projected dose that would be avoided if the protective actions were implemented. Developers of the EPA PAGs considered the following three principles in establishing exposure levels for the PAGs—

1. Prevent acute effects.
2. Balance protection with other important factors and ensure that actions result in more benefit than harm.
3. Reduce risk of chronic effects.

These principles apply to the determination of any PAG. Principles 1 and 2 have been proposed for use by the international community as essential bases for decisions to intervene during an incident. Principle 3 has been recognized as an appropriate additional consideration (IAEA 2002). Although it is important during emergency planning to consider a range of source terms to assess the costs associated with their implementation, the PAGs are pre-determined for use in emergencies without regard to the magnitude or type of radiological release.

1.3.4 Changes in Scenarios since the Issuance of the 1992 PAG Manual

EPA's 1992 PAG Manual provided emergency management officials at the federal, state, tribal and local levels with the technical basis to plan responses to radiological emergencies. The 1992 PAG Manual was written to accommodate the worst release scenario deemed likely at the time – a major accident at a commercial NPP that would result in a significant off-site release of radioactive material. ("Site" and "off-site" in this Manual refer to locations where the radiological incident occurs and are not limited to facility-type incidents.) Certain characteristics typify NPPs, including: fixed locations at which an accident might occur; a known suite of radionuclides on site, the dose from which is dominated by short-lived radioisotopes; tight regulatory controls and requirements; skilled operational personnel who plan for

and exercise emergency responses; state and local involvement in emergency planning; well-developed and zoned emergency evacuation plans and routes; and advance notice (generally hours to days) from deteriorating plant conditions prior to accidental release of radioactive material into the environment. Therefore, the 1992 PAG Manual provided decision-makers with radiation dose-based PAG values for various exposure pathways (such as whole body, skin dose, and food ingestion) and associated protective actions that were adapted to the mix of radionuclides and operational environments associated with commercial NPPs.

In late 1991, EPA conducted a symposium titled "Implementing Protective Actions for Radiological Incidents at Other Than Nuclear Power Reactors," to evaluate PAGs for incidents other than accidents at NPPs and concluded that the PAGs could be applied to all radiological incidents (EPA 1992a). Since then, new radiological and nuclear scenarios involving terrorist use of radioactive materials have gained status in radiological emergency response planning.

In 2008, DHS published "Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents" (DHS 2008). An RDD is a device or mechanism that is intended to spread radioactive material from the detonation of conventional explosives or other means. An IND is a crude, yield-producing nuclear weapon fabricated from diverted fissile material. Incidents like these may occur anywhere with little or no warning. The DHS guidance, developed cooperatively with EPA, DOE, DoD, DOL, HHS, Department of Commerce, and the NRC, affirms the applicability of existing 1992 EPA PAGs to terrorist acts, while acknowledging that the PAGs were inadequate for early response planning needs specific to an IND. To address this gap, "Planning Guidance for Response to a Nuclear Detonation" (NSS 2010) was subsequently published.

This Manual substantively incorporates late phase cleanup guidance provided in the 2008 DHS document and refers readers to additional planning resources.

1.3.5 Key Changes to PAGs in this Updated Manual

This updated Manual applies PAGs and protective actions to an expanded range of sources of potential radiological releases, including commercial nuclear power facilities, uranium fuel cycle facilities, nuclear weapons facilities, transportation accidents, radiopharmaceutical manufacturers and users, space vehicle launch and reentry, RDDs and INDs.

Dosimetry for all the PAGs was updated using the International Commission on Radiological Protection (ICRP) Publication 60 series (ICRP 1991). The PAGs in this Manual may be implemented using calculated, measurable values contained in the Federal Radiological Monitoring and Assessment Center (FRMAC) Assessment Manuals,[1] though using other incident-specific dose assessment methodologies is encouraged, where appropriate. EPA anticipates that radiological assessment methods will be periodically updated as improved models and methods become available. Therefore, readers are encouraged to review the current version of the FRMAC Assessment Manual to understand the most current, default radiological assessment methods. For simplicity, specific organ dose thresholds for evacuation and sheltering were removed from the Manual.

While most of the PAGs and corresponding protective actions from the 1992 PAG Manual remain unchanged, this Manual incorporates several related guidance documents published subsequent to the 1992 guidance, including FDA's 1998 update of the PAGs for interdiction of food. This Manual also incorporates FDA's 2001 guidance to lower the PAG for administration of potassium iodide (KI) to 5 rem (50 millisieverts (mSv)) projected child thyroid dose. In addition to guidance on KI, this updated Manual includes references to other FDA-approved medical countermeasures potentially useful in mitigating effects associated with radiation emergencies. Such countermeasures include the radioisotope

[1] See FRMAC Assessment Manuals at http://nnss.gov/pages/programs/FRMAC/FRMAC_DocumentsManuals.html.

decorporation agents calcium-DTPA, zinc-DTPA, and Prussian blue, and the leukocyte growth factors filgrastim and pegfilgrastim. This update removes the intermediate phase relocation PAG of 5 rem (50 mSv) over 50 years to avoid confusion with long-term cleanup.

Recommended limits of exposure for emergency workers also remain unchanged from the 1992 PAG Manual. The emergency worker guidelines in this manual are consistent with federal and state regulations. To further develop radiological emergency plans, brief planning guides have been provided for reentry to relocation areas, a cleanup planning process, and considerations for radioactive waste disposal. In this Manual, the term reentry is used for emergency workers and members of the public going into relocation areas temporarily, under controlled conditions. Table 1-1 (see below) presents PAGs with their principal associated protective actions and also presents related guidelines, and planning guidance.

1.4 RADIOLOGICAL INCIDENT PHASES AND APPLICABILITY OF PROTECTIVE ACTIONS

Emergency planners divide responses to radiological incidents into three phases of activity—

- **Early Phase** — The beginning of a radiological incident for which immediate decisions for effective use of protective actions are required and must therefore be based primarily on the status of the radiological incident and the prognosis for worsening conditions. When available, predictions of radiological conditions in the environment based on the condition of the source or actual environmental measurements may be used. Protective actions based on the PAGs may be preceded by precautionary actions during the period. This phase may last from hours to days.
- **Intermediate Phase** — The period beginning after the source and releases have been brought under control (has not necessarily stopped but is no longer growing) and reliable environmental measurements are available for use as a basis for decisions on protective actions and extending until these additional protective actions are no longer needed. This phase may overlap the early phase and late phase and may last from weeks to months.
- **Late Phase** — The period beginning when recovery actions designed to reduce radiation levels in the environment to acceptable levels are commenced and ending when all recovery actions have been completed. This phase may extend from months to years. A PAG level, or dose to avoid, is not appropriate for long-term cleanup.

The phases cannot be represented by precise periods of time – and may even overlap – but to view them in terms of activities, rather than time spans, can provide a useful framework for emergency response planning.

In the early phase, sheltering-in-place and evacuation are the principal protective actions. These actions are meant to avoid inhalation of gases or particulates in an atmospheric plume and to minimize external radiation exposures. Administration of prophylactic drugs may be employed depending on the specific radionuclides released; in particular, KI, also called “stable iodine,” may be administered as a supplementary protective action in incidents involving the release of significant quantities of radioactive iodine, such as NPP incidents. Some protective actions may begin prior to the release of radioactive material when there is advance notice.

Planning considerations for reentry and relocation are suggested and basic planning guidance for late phase cleanup is provided in Chapters 4 and 5.

Table 1-1. Summary Table for PAGs, Guidelines, and Planning Guidance for Radiological Incidents[a]

Phase	Protective Action Recommendation	PAG, Guideline, or Planning Guidance
Early Phase	Sheltering-in-place or evacuation of the public[b]	**PAG**: 1 to 5 rem (10 to 50 mSv) projected dose over four days[c]
	Supplementary administration of prophylactic drugs – KI[d]	**PAG**: 5 rem (50 mSv) projected child thyroid dose[e] from exposure to radioactive iodine
	Limit emergency worker exposure (total dose incurred over entire response)	**Guideline**: 5 rem (50 mSv)/year (or greater under exceptional circumstances)[f]
Intermediate Phase	Relocation of the public	**PAG**: $\geq$ 2 rem (20 mSv) projected dose[c] in the first year 0.5 rem (5 mSv)/year projected dose in the second and subsequent years
	Apply simple dose reduction techniques	**Guideline**: < 2 rem (20 mSv) projected dose[c] in the first year
	Food interdiction[g]	**PAG**: 0.5 rem (5 mSv)/year projected whole body dose, or 5 rem (50 mSv)/year to any individual organ or tissue, whichever is limiting
	Drinking water	**PAG:** 100 mrem (1 mSv or 0.1 rem) projected dose, for one year, to the most sensitive populations (e.g., infants, children, pregnant women and nursing women); 500 mrem (5 mSv or 0.5 rem) projected dose, for one year, to the general population
	Limit emergency worker exposure (total dose incurred over entire response)	**Guideline**: 5 rem (50 mSv)/year
	Reentry	**Guideline**: Operational Guidelines[h] (stay times and concentrations) for specific reentry activities (see Section 4.5)
Late Phase	Cleanup[i]	**Planning Guidance**: Brief description of planning process (see Section 5.1)
	Waste Disposal	**Planning Guidance**: Brief description of planning process (see Section 5.2)

[a] This guidance does not address or impact site cleanups occurring under other statutory authorities such as the United States Environmental Protection Agency's (EPA) Superfund program, the Nuclear Regulatory Commission's (NRC) decommissioning program, or other federal or state cleanup programs.

[b] Should begin at 1 rem (10 mSv); take whichever action (or combination of actions) that results in the lowest exposure for the majority of the population. Sheltering may begin at lower levels if advantageous.

[c] Projected dose is the sum of the effective dose from external radiation exposure (e.g., groundshine and plume submersion) and the committed effective dose from inhaled radioactive material.

Note: Footnotes continued on next page

Table 1-1. Summary Table for PAGs, Guidelines, and Planning Guidance for Radiological Incidents (continued)

[d] Provides thyroid protection from radioactive iodines only. See the complete 2001 FDA guidance, "Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies" (FDA 2001). Further information is also available in "KI in Radiation Emergencies – Questions and Answers" (FDA 2002), and "Frequently Asked Questions on Potassium Iodide (KI)." For information on radiological prophylactics and treatment other than KI, refer to http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness/ucm063807.htm, https://www.emergency.cdc.gov/radiation, and www.orau.gov/reacts.

[e] Thyroid dose. See Section 1.4.2. The one-year old age group is expected to receive the largest dose to the thyroid from exposure to radioactive iodine. Therefore, it is recommended that the one-year old age group is considered when considering the administration of prophylactic KI.

[f] When radiation control options are not available, or, due to the magnitude of the incident, are not sufficient, doses to emergency workers above 5 rem (50 mSv) may be unavoidable and are generally approved by competent authority. For further discussion see Chapter 3, Section 3.1.2. Each emergency worker should be fully informed of the risks of exposure they may experience and trained, to the extent feasible, on actions to be taken. Each emergency worker should make an informed decision as to how much radiation risk they are willing to accept to save lives.

g For more information on food and animal feeds guidance, the complete FDA guidance (FDA 1998) may be found at http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM094513.pdf.

[h] For extensive technical and practical implementation information please see "Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident" (DOE 2009).

[i] This cleanup process does not rely on and does not affect any authority, including the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 42 U.S.C. 9601 et seq. and the National Contingency Plan (NCP), 40 CFR Part 300. This document expresses no view as to the availability of legal authority to implement this process in any particular situation.

1.4.1 Implementation of Protective Action Guides and Protective Actions

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

During the early phase, the sequence of events includes evaluation of conditions at the location of the incident, notification of responsible authorities, prediction or evaluation of potential consequences to the general public, recommendations for action and implementation of actions for the protection of the public.

In the intermediate phase, dose projections used to support decisions about protective actions may be based on measurements of actual levels of environmental radioactivity and refined dose models, reducing the need for worst-case scenarios. When conditions warrant relocation of populations, the collection of extensive radiological and cost-of-cleanup data will be necessary to form the decision basis for cleanup and recovery of the affected areas.

1.4.2 Early Phase Protective Action Guides and Protective Actions

In the early phase, there may be little or no data on actual releases to the environment and responders may have to rely on crude estimates of airborne releases. Decision time frames are short and preparation is critical to make prudent decisions when data are lacking or insufficient.

The principal protective actions for the early phase are evacuation and sheltering-in-place. These protective actions would be taken if whole body doses are projected to exceed 1 to 5 rem (10 to 50 mSv)

over four days. The decision to evacuate must weigh the anticipated radiation dose to individuals in the affected population against the feasibility of evacuating within a determined time frame and the risks associated with the evacuation itself. For example, evacuating a population of 50,000 carries with it a statistical risk of injury or death from transportation hazards or increased exposure. Evacuation also takes time. In the case of an accident at an NPP, there will likely be time for an orderly and relatively safe evacuation. In the case of a fire or explosion of an RDD in an urban area, evacuating a large group of people could leave them exposed to the plume and actually increase radiation dose. Sheltering-in-place may be warranted in situations where evacuation poses a greater risk of exposure or physical harm.

In addition, there are actions that are advisable, but not associated with a numerical PAG. For example, individuals should be instructed to cover airways (nose and mouth) with available filtering material when airborne radionuclides may be present. Decontamination is another protective action that may be utilized in the early phase and may include washing of contaminated individuals, removing contaminated clothing, and decontaminating surfaces of critical areas and objects. Further, in areas where airborne radioactivity is present but PAGs are not exceeded, officials can consider asking people to stay indoors to the extent practicable. In such cases, individuals are not prevented from carrying out necessary tasks (e.g., seeking medical care, purchasing food). Similar to actions used in major cities on high pollution days, these measures can be effective to reduce radiation doses when prolonged releases occur, as was the case for the Fukushima accident in Japan.

In cases where significant quantities of radioiodine may have been released, administration of the radioprotectant KI should be considered as a supplementary protective action if the projected child thyroid dose exceeds 5 rem (50 mSv). This PAG is lower than the 1992 guidance. The lower dose, which FDA adopted in 2001, is for protection of children based on early studies of Chernobyl exposure data. Of the age groups in ICRP 60 series (ICRP 1991), the one-year old age group is expected to be limiting for thyroid dose projections. Therefore, it is recommended that the one-year old age group thyroid dose be projected when considering the administration of prophylactic KI.

The choice of protective action will be based on the status of the incident site and the prognosis for worsening conditions. In the early phase, precautionary actions based on worst-case scenarios may be used before implementation of protective actions based on PAGs. For example, in the case of RDD detonation, governments may instruct affected populations to shelter-in-place as a precautionary action while radiation levels are being measured to determine appropriate PAG-based protective actions. Officials should plan for rapid broadcast and dissemination of protective action orders to the public.

When available, predictions of radiological conditions in the environment based on an estimate of the source or actual environmental measurements may be used. Nuclear facilities, for example, have continuous, real-time radioactive effluent monitoring capabilities to monitor radioactive material released to the environment and may have a network of off-site measurement stations.

1.4.3 Intermediate Phase Protective Action Guides and Protective Actions

Intermediate phase activities are intended to reduce or avoid dose to the public, to control worker exposures, to control the spread of radioactive contamination, and to prepare for late phase cleanup operations. During the intermediate phase, relocation is the principal protective action against whole body external exposure from deposited radioactive material and internal exposure from inhalation of radioactive particulates. People may need to be relocated for weeks or months.

It is necessary to distinguish between evacuation and relocation. Evacuation is the urgent removal of people from an area to avoid or reduce high-level, short-term exposure from the plume or deposited radioactivity. Relocation is the removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. Site-specific conditions may allow some groups evacuated in

an emergency to return, while others may have to relocate. In other cases, some groups that were not previously evacuated may have to relocate (see Section 4.2.3 for more details).

Intermediate phase PAGs are based on doses projected in the first several years. The PAG for relocation of the public is 2 rem (20 mSv) in the first year and 0.5 rem (5 mSv) in any subsequent year. (Note: Relocation PAGs are treated separately from food and water ingestion. That is, projection of intermediate phase doses should not include these ingestion pathways. In some instances, however, where withdrawal of food and/or water from use would, in itself, create a health risk, relocation may be an appropriate alternative protective action. In this case, the ingestion dose should be considered along with the projected dose from deposited radionuclides via other pathways, for decisions on relocation.) When projected doses are less than the relocation PAG of 2 rem (20 mSv) in the first year, focused environmental decontamination and cleanup may be able to reduce doses to populations that are not relocated. Decontamination and focused cleanup techniques can range from simple actions such as the scrubbing and flushing of surfaces with uncontaminated water to the removal and disposal of soil and contaminated debris.

Keeping projected doses below the 0.5 rem (5 mSv) PAG – in the second and subsequent years – may be achieved through the decay of shorter half-life radioisotopes (as in the case of an accident at an NPP), through environmental decontamination and cleanup efforts or through other means of controlling public exposures, such as limiting access to certain areas. Information on food and animal feeds protective action guidance is contained in FDA's "Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies" (FDA 1998). Workers and members of the public may be allowed to re-enter a relocation area for tasks related to critical infrastructure and key resources, to care for animals and to assess the condition of closed zones. By the intermediate phase when relocation has been implemented, it is likely that no more lifesaving missions would be needed. Some critical infrastructure/key resources or lifesaving missions may arise in later phases, however, for which the emergency worker guides in Chapter 3, Section 3.1.2 would apply. Reoccupancy may be allowed under dose constraints acceptable to the community. In this Manual, the term reoccupancy refers to households and communities moving back into relocation areas where the cleanup process is still ongoing, based on radiation levels acceptable to those communities.

As data are obtained from monitoring, officials should benchmark observed concentrations against default derived response levels (DRLs) in FRMAC Assessment Manual, Volume 1, Appendix C,[2] or incident-specific DRLs that account for nuclide mix present, release patterns, and decay. Officials would then be in a position to make informed decisions about the need to implement protective actions.

During the intermediate phase, government officials may convene to discuss late phase cleanup and site restoration strategies. All actions taken during the early and intermediate phases should be considered with respect to the impact they may have on late phase remediation, such as avoiding the use of fixatives that could hinder surface decontamination at a later date.

1.4.4 Late Phase

The late phase, as used in this Manual, is the period beginning when cleanup and recovery actions have begun and ending when all recovery actions have been completed. This phase may extend from months to years.

The late phase cleanup process, as described in this guidance, begins sometime after the commencement of the intermediate phase and proceeds independently of intermediate phase protective action activities. The transition is characterized by a change in approach, from strategies predominantly driven by urgency, to strategies aimed at both reducing longer-term exposures and improving living conditions. The late

[2] See FRMAC Assessment Manuals at http://nnss.gov/pages/programs/FRMAC/FRMAC_DocumentsManuals.html.

phase involves the final cleanup of areas and property at which contamination directly attributable to the incident is present. It is in the late phase that final cleanup decisions are made and final recovery efforts following a radiological incident are implemented.

During the late phase of a radiological incident, decision-makers will have more time and information allowing for better data collection, more complex modeling, stakeholder involvement, and options analysis. Community members will influence decisions such as if and when to allow people to return home to contaminated areas. There will be populations, who were not relocated or evacuated, living in contaminated areas where efforts to reduce exposures will be ongoing. Implicit in these decisions is the ability to balance health protection with the desire of the community to resume normal life.

Radiation protection considerations must be addressed in concert with health, environmental, economic, social, psychological, cultural, ethical, political and other considerations. Many federal, state, and local agencies have important roles to play. It is recognized that experience from existing programs, such as the EPA's Superfund program, the NRC's process for decommissioning and decontamination to terminate a nuclear facility license, and other national recommendations may be useful for designing cleanup and recovery efforts that could apply to a radiological incident. The cleanup process described in Chapter 5, however, does not rely on and does not affect any authority, including the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 42 U.S.C. 9601 et seq., and the National Contingency Plan (NCP), 40 CFR Part 300. For information on roles, responsibilities and authorities during emergency response and recovery please refer to the National Response Framework: http://www.fema.gov/national-response-framework (FEMA 2008a) and specifically for radiological incidents, the Nuclear Radiological Incident Annex: http://www.fema.gov/pdf/about/divisions/thd/IncidentNucRad.pdf (FEMA 2008b).

The late phase or cleanup process described in Chapter 5 consists of multiple steps, namely: 1) characterization and stabilization; 2) development of goals and strategies; and 3) implementation and reoccupancy. Meaningful stakeholder involvement should be integrated *throughout* the process.

While radioactive waste handling and disposal will be an ongoing endeavor during the entire emergency response, brief planning guidance is provided in Chapter 5, the late phase. This guidance addresses two types of disposal locations – those that may be identified and regulated by state and local officials, and locations owned by the federal government – and lists criteria for evaluating their suitability for disposal, as well as actions that can be taken to facilitate their use. Legal and other considerations are also discussed. This guidance assumes that on-site disposal at a location affected by the incident, where appropriate, will be one of the locations of choice. Though recommended as the first consideration for discussion post-accident or attack, this guidance assumes that existing non-federal radioactive waste disposal capacity that is available to impacted states and their regions is overwhelmed or otherwise eliminated from consideration, which drives the need to identify other disposal options or develop new disposal capacity.

1.4.5 Precaution built into the PAGs

As noted above, a PAG is defined for purposes of this document as the projected dose to an individual from a release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended. PAGs do not establish an acceptable level of risk for normal, non-emergency conditions, nor do they represent the boundary between safe and unsafe conditions.

As described in Sections 2.5 and 4.7, a risk-benefit balancing process, designed to prevent acute effects, balance protection with other important factors and ensure that actions result in more benefit than harm, and reduce risk of chronic effects was used to derive the PAGs. Such a risk-benefit balancing incorporates a level of precaution into the PAGs.

Assumptions made to generate default parameters and derived response levels in the FRMAC Assessment Manual, Volume 1, Appendix C,[3] include some worst-case assumptions to ensure PAGs are appropriate emergency guides for all members of the public, including sensitive subpopulations such as young children. For example, early phase derived levels are based on the assumption that a person is outdoors 24 hours a day for four days being exposed to the plume. Intermediate phase derived levels also conservatively do not account for shielding provided by being indoors part of each day of the projection year. People are assumed to remain in the contaminated area during the entire time (not going to work or school in an uncontaminated area, for instance.) Another example of conservatism is assuming that radionuclides are in the chemical and physical form that yields the highest dose (e.g., the particle size is one micrometer mean aerodynamic diameter). These conservatisms allow dose assessors to project whole body doses or total effective dose (TED) to a reference person, for simplicity, and then decision-makers can make protective action decisions that apply to entire communities including children, adults and the elderly.

Radiological assessors are encouraged to utilize realistic inputs when site- or source-specific information is available to limit the amount of conservatism built into the calculations. For example, if the radionuclide does not exist in a chemical or physical form or particle size that yields the highest dose, then assessors should use appropriate inputs to avoid overly conservative dose estimates that may lead to unnecessary protective actions.

Other incident-specific factors that should be considered include: the nuclide mix released; the rate and timing of dispersion/deposition; the rate of natural attenuation in specific media; and realistic intake parameters, for example.

Certain guidelines that lend themselves to different PAGs for different subpopulations are the PAGs for KI (potassium iodide), food, and water. These guidelines provide age-specific recommendations because of the radiosensitivity of the thyroid and young children with respect to ingestion and inhalation doses in particular. Taking protective actions like use of KI, avoiding certain foods, or using alternative sources of drinking water can be relatively simple to implement by the parents of younger children. Clear public messages can convey which age groups should take which action, unlike how an evacuation or relocation order should apply to entire households or neighborhoods.

EPA evaluated the dose consequences to several age groups across many radiological scenarios and, for the early phase including the plume, child whole body doses are typically no more than 15 percent higher than adult whole body doses. That margin is well within the conservatism discussed above, so that separate PAGs or projections need not be required. Therefore, basing evacuation, shelter-in-place, and relocation dose projections on an adult is appropriate for all age groups. Sensitive age groups should be evaluated separately for KI, food, and water decisions. Keeping calculations and decision-making simple in the face of a disaster can enable timely actions to protect communities.

[3] See FRMAC Assessment Manuals at http://nnss.gov/pages/programs/FRMAC/FRMAC_DocumentsManuals.html.

KEY POINTS IN CHAPTER 1 – OVERVIEW

- A PAG is the projected dose to an individual from a release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended. PAGs are guides to help officials select protective actions under emergency conditions when exposures would occur over relatively short time periods.
- EPA provides the PAG Manual to assist public officials with their radiological emergency response planning activities. The PAG Manual is a guidance document, not a legally binding regulation and does not affect or supersede any environmental laws. The PAG recommendations do not represent the boundary between safe and unsafe conditions.
- PAGs may be implemented to protect the public in a wide variety of radiological emergencies, including terrorist incidents and accidents involving nuclear power plants (NPPs), transportation, and the space program.
- PAGs are appropriate for implementation in the early and intermediate phases of radiological incidents. The early phase—lasting hours to days—is the period beginning at the projected (or actual) initiation of a release when immediate decisions for effective use of protective actions are required and must therefore be based primarily on the status of the release and the prognosis for worsening conditions. Little environmental data may be available in the early phase. The intermediate phase—lasting weeks to months—is the period beginning after the source and releases have been brought under control and environmental measurements are available for use as a basis for decisions on protective actions.
- Reentry and reoccupancy decisions will be made using incident-specific circumstances and the Operational Guidelines (DOE 2009).
- Cleanup and waste disposal decisions may be informed by planning guidance provided in Chapter 5.
- What's new in this updated Manual—
  - The PAGs in this Manual are implemented using the calculations and methods in the FRMAC Assessment Manual. Dosimetry in that Manual has been updated using the ICRP Publication 60 series (ICRP 1991).
  - EPA adopts the FDA guidance issued in 2001 that recommended lowering the projected thyroid dose at which the administration of KI is warranted as a supplementary protective action.
  - EPA adopts the 1998 FDA food PAGs.
  - Planning guidance has been provided for reentry, late phase cleanup, and waste disposal.

CHAPTER 2. EARLY PHASE PROTECTIVE ACTION GUIDES

Decisions regarding protective actions for workers and the public during radiological incidents are risk management decisions and the recommendations in this Manual are provided in that context. Rapid action may be required to protect members of the public in the event of an incident involving a large release of radioactive materials into the environment. In all cases, all practical and reasonable means should be used to reduce or eliminate exposures.

This chapter presents PAGs for use in the early phase of a radiological incident. A PAG is the projected dose to an individual from a release of radioactive material at which a specific protective action should be taken to reduce or avoid that dose. The early phase begins at the actual or projected start of a release—most likely before ambient environmental and radiological data become available for quantitative risk-based actions. The exact duration of the early phase depends upon site conditions, but one should plan to project doses for four days.

Many radiological emergency scenarios would involve airborne releases, so this chapter provides guidance for estimating projected doses from exposure to an airborne plume of radioactive material and for implementing protective actions. Dose calculations for implementing the PAGs are made using the dose parameter (DP) and derived response level (DRL) methods referenced in the FRMAC Assessment Manuals.[4] Note that FRMAC refers to dose parameters in emergency response dose assessment methods to avoid confusion with dose coefficients and dose conversion factors published for radiation protection in general. Other calculation methods to implement PAGs may be appropriate.

2.1 EXPOSURE PATHWAYS DURING THE EARLY PHASE

To make decisions about rapid actions to protect the public in a radiological emergency, it is important to understand exposure pathways from airborne releases. It may also be necessary to make estimates about exposure patterns to make initial dose projections and determine whether protective actions are needed, before environmental monitoring is complete.

2.1.1 Exposure Pathways from Airborne Releases

During the early phase of an incident, there are three main exposure pathways from airborne releases—

- **Direct exposure** to radioactive materials in an atmospheric plume. The contents of such a plume will depend on the source of radiation involved and conditions of the incident. For example, in the case of an incident at an NPP, the plume may contain radioactive noble gases, radioiodines, and radioactive particulate materials. Many of these materials emit gamma radiation that can expose people in the vicinity of the passing plume.
- **Inhalation** of radionuclides from immersion in a radioactive atmospheric plume and inhalation of ground-deposited radionuclides that are resuspended into a breathing zone. Inhaled radioactive particulates, depending on their solubility in body fluids, may remain in the lungs or move via the bloodstream to other organs, prior to elimination from the body. Some radionuclides become concentrated in a single body organ, with only small amounts going to other organs. For example, a significant fraction of inhaled radioiodines will move through the bloodstream to the thyroid gland.
- **Deposition** of radioiodine and particulates from a radioactive plume. Deposited materials can continue to emit "groundshine" (e.g., beta and gamma radiation) after the plume has passed causing continued exposure to skin and internal body organs.

[4] See FRMAC Assessment Manuals at http://nnss.gov/pages/programs/FRMAC/FRMAC_DocumentsManuals.html.

A plume may deposit materials on surfaces, posing a risk of longer-term exposures via ingestion, direct external exposure, and inhalation pathways. If the release contains large quantities of radioactive iodines or particulates, the resulting long-term exposure to this "groundshine" can be more significant than external exposure from the passing plume if the exposure time to the ground contamination is long in comparison to the plume passage time. The early phase PAGs assume four days of exposure to ground contamination to address this possibility. Doses from groundshine can be readily measured by field monitoring teams dispatched at the onset of a significant radioactive release. Holding a detector probe horizontal and three feet (approximately one meter) above the contaminated surface provides a direct measurement that can be used to approximate groundshine dose. Such assessments can confirm dose projections based upon effluent release data and the adequacy of protective actions in the early phase. More detailed analyses (e.g., isotopic) would be needed to support long-term dose projections in the intermediate phase. Doses for groundshine can be calculated during the intermediate phase (see Chapter 4). Exposure pathways that contribute less than 10 percent to the total dose incurred need not be considered during the early phase.

2.1.2 Establishment of Exposure Patterns

It is unlikely that sufficient environmental data will be available for accurate dose projections during and immediately following the early response to a radiological incident. Dose projections are needed to determine whether protective actions should be implemented in additional areas during the early phase.

For dose projections in the early phase there are two sources of data: current data from initial environmental measurements or estimates of the source term and estimated data using modeled or historical atmospheric transport data. Source term measurements, or exposure rates or concentrations measured in the plume at a few selected locations, may be used to estimate the extent of the exposed area in a variety of ways, depending on the types of data and computation methods available. The most accurate method of projecting doses is through the use of an atmospheric diffusion and transport model that has been verified for use at the site in question or for similar site conditions. A variety of computer software packages can be used to estimate dose in real time, or to extrapolate a series of previously-prepared isopleths for unit releases under various meteorological conditions. The latter can be adjusted for the estimated source magnitude or environmental measurements at a few locations during the incident. If the model projections have some semblance of consistency with environmental measurements, extrapolation to other distances and areas can be made with greater confidence. If projections using a sophisticated site-specific model are not available, a simple but crude method is to measure the plume centerline exposure rate[5] at ground level measured at approximately three feet (one meter) height at a known distance downwind from the release point and then to calculate exposure rates at other downwind locations by assuming that the plume centerline exposure rate is a known function of the distance from the release point.

The following relationship can be used for this calculation:

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

where D_1 and D_2 are exposure rates at the centerline of the plume at distances R_1 and R_2 from the release, respectively and y is a constant that depends on atmospheric stability. For stability classes[6] A and B, y = 2; for stability classes C and D, y = 1.5; and for stability classes E and F, y = 1. Classes A and B (unstable) occur with light winds and strong sunlight and classes E and F (stable) with light winds at

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

[6] Pasquill stability classes categorize atmospheric turbulence into six stability classes named A, B, C, D, E and F, class A being the most unstable or most turbulence and class F the most stable or least turbulence. Pasquill, F. 1961. The Estimation of the Dispersion of Windborne Material. Meteorological Magazine. 90, 33-49. (Pasquill 1961)

night. Classes C and D generally occur with winds stronger than about 10 mph. This method of extrapolation is risky because the measurements available at the reference distance may be unrepresentative, especially if the plume is aloft and has a looping behavior. In the case of an elevated plume, the ground level concentration increases with distance from the source and then decreases, whereas any high-energy gamma radiation from the overhead cloud continuously decreases with distance. For these reasons, this method of extrapolation will perform best for surface releases or if the point of measurement for an elevated release is sufficiently distant (usually more than 1 mile or 1.61 kilometers (km)) from the point of release for the plume to have expanded to ground level. The accuracy of this method will be improved by the use of measurements from many locations averaged over time.

2.2 THE PROTECTIVE ACTION GUIDES AND PROTECTIVE ACTIONS FOR THE EARLY PHASE: EVACUATION, SHELTERING-IN-PLACE, AND ADMINISTRATION OF POTASSIUM IODIDE

The principal protective actions for the early phase are evacuation or sheltering-in-place. Evacuation is the urgent removal of people from an area to avoid or reduce high-level, short-term exposure from the plume or deposited radioactivity. Sheltering-in-place is the action of staying or going indoors immediately. The administration of KI (potassium iodide) to partially block the uptake of radioiodines by the thyroid is a supplemental protective action.

In addition, washing the body and changing clothing as soon as possible after significant exposure to a radioactive plume of any composition may be recommended protective actions. Changing of clothing is recommended to provide protection from particulate materials deposited on the clothing, as well as to minimize the spread of contamination.

The PAGs and corresponding protective actions for response during the early phase of an incident are summarized in Table 2-1. Evacuation or sheltering-in-place will be justified when the projected dose to an individual is 1 rem (10 mSv) projected over four days. This conclusion is based primarily on EPA's determination concerning acceptable levels of risk of health effects from radiation exposure in an emergency situation, while weighing costs and risks associated with any protective action.

2.2.1 Thyroid Based Evacuation

This revised PAG Manual does not include a footnote from the 1992 PAG Manual early phase PAG table, which noted that "thyroid and skin may be 5 and 50 times larger, respectively." That footnote effectively provided organ dose-based evacuation thresholds in addition to the whole body dose PAG range of 1 to 5 rem (10 to 50 mSv). Because of the factors described above, these organ dose-based early phase PAGs are not necessary.

Regarding sensitive subpopulations, child thyroid doses typically are about twice as high as adult thyroid doses. The former range recommended for thyroid dose-based evacuation (5 to 25 rem adult thyroid dose) is well covered by projections of whole body dose, with evacuation recommended at 1 to 5 rem (10 to 50 mSv) adult TED. The conservatism built into the PAG levels when they were set results in an appropriate level of dose avoidance for the whole community, including all age groups, for an emergency. Planners should consider instituting public messaging templates in advance to address concerns the public may have about how protective the PAG recommendations are for all members of an impacted community.

The PAG Manual is guidance, and intentionally not prescriptive. This set of recommendations does not preclude an emergency manager from setting local or state protective action guidelines for actions based on specific organ or age group dose levels, as warranted by specific needs of that community.

Table 2-1. PAGs and Protective Actions for the Early Phase of a Radiological Incident[a]

Protective Action Recommendation	**PAG**	**Comments**
Sheltering-in-place or evacuation of the public[b]	**PAG**: 1 to 5 rem (10 to 50 mSv) projected dose over four days[c]	Evacuation (or, for some situations, sheltering-in-place) should be initiated when projected dose is 1 rem (10 mSv).
Supplementary administration of prophylactic drugs – KI[d]	**PAG**: 5 rem (50 mSv) projected child thyroid dose[e] from exposure to radioactive iodine	KI is most effective if taken prior to exposure. May require approval of state medical officials (or in accordance with established emergency plans).

[a] This guidance does not address or impact site cleanups occurring under other statutory authorities such as the United States Environmental Protection Agency's (EPA) Superfund program, the Nuclear Regulatory Commission's (NRC) decommissioning program, or other federal or state cleanup programs.

[b] Should begin at 1 rem (10 mSv) if advantageous except when practical or safety considerations warrant using 5 rem (50 mSv); take whichever action (or combination of actions) that results in the lowest exposure for the majority of the population. Sheltering may begin at lower levels if advantageous.

[c] Projected dose is the sum of the effective dose from external radiation exposure (e.g., groundshine and plume submersion) and the committed effective dose from inhaled radioactive material.

[d] Provides thyroid protection from radioactive iodines only. See the complete 2001 FDA guidance, "Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies" (FDA 2001). Further information is also available in "KI in Radiation Emergencies – Questions and Answers" (FDA 2002), and "Frequently Asked Questions on Potassium Iodide (KI)." For information on radiological prophylactics and treatment other than KI, refer to http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness/ucm063807.htm, https://www.emergency.cdc.gov/radiation, and www.orau.gov/reacts.

[e] Thyroid dose. See Section 1.4.2. The one-year old age group is expected to receive the largest dose to the thyroid from exposure to radioactive iodine. Therefore, it is recommended that the one-year old age group is considered when considering the administration of prophylactic KI.

2.2.2 Evacuation vs. Sheltering-in-Place

Evacuation and sheltering-in-place provide different levels of dose reduction from the principal exposure pathways: direct gamma exposure and inhalation. Both sheltering-in-place and evacuation may be implemented during the same response in different areas or timeframes. Evacuation, if completed before plume arrival, can be 100 percent effective in avoiding radiation exposure. A decontamination station, with simple decontamination actions, may need to be collocated at shelters during the pre-evacuation period. This may reduce the spread of contamination and provide for greater protection during evacuation. Medical stations should also be collocated at shelters during the pre-evacuation period to ensure simple triage capabilities are met and to manage the distribution of prophylactic drugs. The effectiveness of evacuation will depend on many factors, such as how rapidly it can be implemented and the nature of the incident. For incidents where the principal source of dose is inhalation, evacuation could increase exposure if it is implemented during the passage of a short-term plume, because the air inside a vehicle rapidly equalizes with the outside air even when all of the windows and vents are closed (DOE 1990). When dose projections are at levels less than 1 rem (10 mSv) over the first four days, evacuation is not recommended due to the associated risks of moving large numbers of people.

Sheltering-in-place is a low-cost, low-risk protective action that can provide protection with an efficiency ranging from zero to almost 100 percent, depending on the type of release, the type of shelter available, the duration of the plume passage, and climatic conditions. Because of these advantages, planners and

decision-makers may consider implementing sheltering-in-place when projected doses are below 1 rem (10 mSv) over the first four days. More guidance on the unique challenges posed by an IND can be found in the "Planning Guidance for Response to a Nuclear Detonation" (NSS 2010).[7]

Sheltering-in-place may be preferred for special populations (e.g., those who are not readily mobile) as a protective action at projected doses of up to 5 rem (50 mSv) over four days. When environmental, physical, or weather hazards impede evacuation, sheltering-in-place may be justified at projected doses up to 5 rem (50 mSv) for the general population (and up to 10 rem (100 mSv) for special populations). It is also comparatively easy to communicate with populations that have sheltered-in-place. Dose projections use a four-day exposure duration, but sheltering-in-place duration is intentionally not specified. Incident-specific decisions must be made to determine how long people should shelter-in-place.

Selection of evacuation or sheltering-in-place is far from an exact science, particularly in light of time constraints that may prevent thorough analysis at the time of an incident. The selection process should be based on realistic or "best estimate" dose models and should take into account the unavoidable dose incurred during evacuation and potential failure scenarios for sheltering-in-place (e.g., leaking ventilation system).

Advance planning and exercises can facilitate the decision process. In a commercial NPP incident, early decisions should be based on information from the response plans for the emergency planning zone (EPZ) and on actual conditions at the nuclear facility. For transportation accidents, RDDs, INDs and other incident scenarios for which EPZs are not practicable, best estimates of dose projections should be used for deciding on evacuation, sheltering-in-place or a combination thereof.

Sheltering-in-place should be preferred to evacuation whenever it provides equal or greater protection.

Sheltering-in-place followed by informed evacuation may be most protective.

The following is a summary of planning guidance for evacuation and sheltering-in-place—

- Evacuation may be the only effective protective action close to the plume source.
- Evacuation will be most effective if it is completed before arrival of the plume.
- Evacuation may increase exposure if carried out during the plume passage.
- Evacuation is appropriate for protection from groundshine in areas with high exposure rates from deposited radioactive materials when suitable shelter is not available.
- Sheltering-in-place may be appropriate for areas not designated for immediate evacuation—
  - It may provide protection equal to or greater than evacuation for rapidly developing releases (e.g., RDDs) if followed by evacuation.
  - It positions the public to receive additional instructions.
  - Since it may be implemented rapidly, sheltering-in-place may be the protective action of choice (followed with evacuation when feasible) if rapid evacuation is impeded by:
    - severe environmental conditions (e.g., severe weather or floods);
    - uncertainty about contamination levels along routes;
    - health constraints (e.g., patients and workers in hospitals and nursing homes);
    - long mobilization times that may be associated with certain individuals, such as industrial and farm workers, or prisoners and guards; or
    - physical constraints to evacuation (e.g., inadequate roads or blockage due to debris).
- If a major release of radioiodine or particulate materials occurs, inhalation dose may be a controlling criterion for protective actions—

[7] See: https://remm.hhs.gov/PlanningGuidanceNuclearDetonation.pdf.

- Breathing air filtered through common household items (e.g., folded handkerchiefs or towels) may help reduce exposures.
- After confirmation that the plume has passed, continued sheltering-in-place should be re-evaluated. People should remain sheltered until receiving official notice about leaving high exposure areas to avoid exposure to deposited radioactive material. Shelters may be opened to vent any airborne radioactivity trapped inside.

Advance planning is essential to identify potential problems that may occur in an evacuation. An NRC case study cites the following aspects of planning as contributing to efficiency and effectiveness of evacuation (NRC 2005)—

- High level of cooperation among agencies.
- Use of multiple forms of emergency communications.
- Community familiarity with alerting methods, the nature of the hazard, and evacuation procedures.
- Community communication.
- Well-trained emergency workers.

The NRC 2005 study included an evaluation of 50 incidents of public evacuation involving 1,000 or more people. The evacuations studied were initiated in response to natural disasters, technological hazards, and malevolent acts occurring between January 1, 1990 and June 30, 2003. The report indicated that public familiarity with alerting methods and door-to-door notification were statistically significant factors for the efficiency of evacuation. The report also indicated that many communities are making improvements to response capabilities by modernizing communication systems, improving traffic flow, local education awareness, and developing interagency and cross-boundary coordination plans.

Large or small population groups can be evacuated effectively with minimal risk of injury or death. In the NRC report, only six of the 50 cases studied involved deaths from the hazard and of those six, only one involved death from the evacuation itself (NRC 2005).

However, in 2005, not long after this report was published, the gulf coast of the United States was hit by a series of hurricanes that resulted in the evacuation of approximately 5 million people. During the evacuation that accompanied Hurricane Rita in Houston, Texas, at least 106 people were reported to have died as a direct result of the evacuation. It is estimated that at least two-thirds of the evacuees did not need to evacuate but did so because of poor communication, fear, and poor traffic management (NRC 2008).

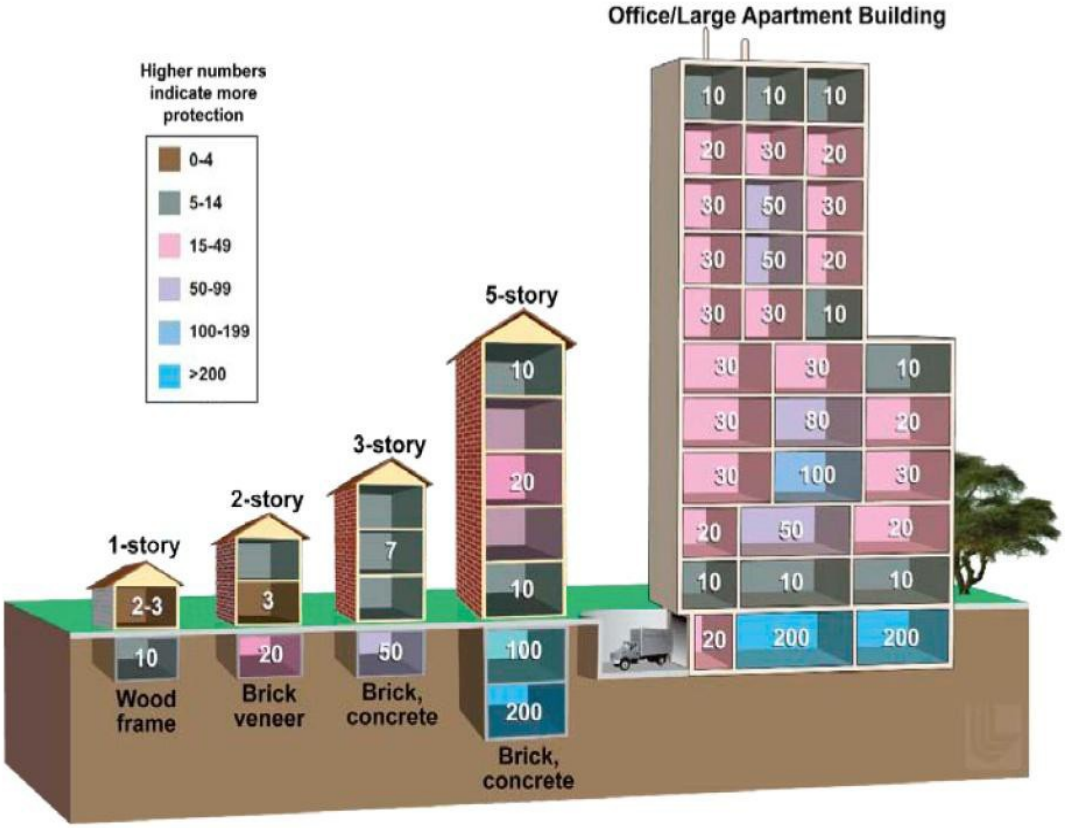
In a study of 230 mass evacuations in the U.S. ("Identification and Analysis of Factors Affecting Emergency Evacuations" NUREG/CR-6864 (NRC 2005)) only six cases involved deaths from the hazard itself, and of these six, only one case involved deaths during the evacuation itself. Only two cases involved injuries during the evacuation. Traffic issues, such as traffic congestion, were reported in 28 percent of the evacuation cases studied. However, traffic accidents occurred in only 8 percent of the cases.

During the tsunami and nuclear disaster response in Japan in 2011, over 1,000 deaths occurred during evacuations, primarily among elderly hospital patients being moved from areas without power. Compounded disaster conditions including aftershocks, widespread power outages, and radiation releases led to prolonged transit along routes extended to avoid hazards.

The emergency planning process for radiological incidents should include effective traffic management plans and communications plans, including pre-scripted messages, provisions for evacuation of special needs populations, such as children in schools and child care facilities, people in institutions, and people who have impaired mobility or lack personal transportation.

The degree of protection provided by structures is affected by factors such as attenuation of gamma radiation (shielding) by structural components (the mass of walls, ceilings, etc.) and outside/inside air exchange rates (see Figure 2-1). The use of large structures, such as shopping centers, schools, churches and commercial buildings, as collection points during evacuation mobilization will generally provide greater protection against gamma radiation than use of small structures. As with evacuation, delay in taking shelter during plume passage will result in higher exposure to radiation.

Figure 2-1. Exposure Reduction from External Radiation from Nuclear Fallout as a function of Building Type and Location



The numbers represent dose reduction factors. A dose reduction factor of 10 indicates that a person in that area would receive 1/10th of the dose of a person in the open. A dose reduction factor of 200 indicates that a person in that area would receive 1/200th of the dose of a person out in the open.

Figure taken from "Planning Guidance for Response to a Nuclear Detonation," Second Edition, National Security Staff, Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats, June 2010, courtesy of Lawrence Livermore National Laboratory. The protection factors in this figure are specific to nuclear detonation fallout, but the variations in factors throughout typical buildings may be informative for other airborne radiological releases.

2.2.3 Considerations for Potassium Iodide (KI)

FDA updated its guidance on the use of KI, also called "stable iodine," as a thyroid blocking agent during radiological emergencies in 2001 (FDA 2001[8] and FDA 2002[9]). FDA based these dose recommendations on a review of the thyroid cancer data from the Chernobyl reactor accident of April 1986 and the experience of Poland in administering KI following the Chernobyl release (FDA 2001).

However, FDA understands that a KI administration program that sets different projected thyroid radioactive exposure thresholds for treatment of different population groups may be logistically impractical to implement during a radiological emergency. In such cases, FDA recommends that KI be administered to both children and adults at the lowest intervention threshold (i.e., >5 rem (50 mSv) predicted internal thyroid exposure in children (FDA 2002). The one-year old age group thyroid dose is expected to be limiting. Therefore, it is recommended that the one-year old age group thyroid dose is projected when considering the administration of prophylactic KI. See Table 2-2 for a summary of recommended doses of KI for different risk groups.

Regarding dosage of KI, FDA's guidance adheres to principles of minimum effective dose and therefore recommends graded dosing according to age (and thus, in effect, body size). There is ample evidence that the recommended doses, as well as higher doses (e.g., up to 130 milligram), will effectively block thyroidal uptake of radioactive iodine if taken in advance of exposure. Furthermore, particularly among school-age children, higher milligram (mg) doses are extremely safe. However, FDA continues to emphasize attention to KI dosing in infants. Excess iodine intake can lead to transient iodine-induced hypothyroidism. Individuals who are intolerant of KI at protective doses, as well as neonates (i.e., a newborn infant, especially an infant less than one month old) and pregnant or lactating women, should be given priority with regard to other protective measures (i.e., sheltering, evacuation, and control of the food supply). In summary, if local emergency planners conclude that graded dosing is logistically impractical, FDA believes that for populations at risk for radioiodine exposure, the overall benefits of taking up to 130 mg of KI instead of the lower doses recommended for certain age groups far exceed the small risks of overdosing. However, where feasible, adherence to FDA guidance should be attempted when dosing infants (FDA 2002).

Note that KI is effective only against uptake of radioiodine, and is best taken prior to or just after exposure. The protective effect of a single dose of KI lasts approximately 24 hours. It should be administered as directed by state/local health officials until the risk of significant exposure to radioiodine (either by inhalation or ingestion) no longer exists (i.e., once the plume has passed). KI is a supplemental action, secondary to evacuation or sheltering. It should not be used as a substitute for evacuation or sheltering-in-place. Many communities do not use KI.

It should be noted that adults over 40 years of age need to take KI only in the case of a projected large internal radiation dose to the thyroid (>500 rem (5 Sv)) to prevent hypothyroidism which could lead to lifelong dependence on thyroid hormone replacement therapy. Thyroid irradiation in adults over 40 years of age is associated with an extremely low incidence of cancer (FDA 2001).

Some people should not take KI. As a rule, individuals with known allergy to iodine or with pre-existing thyroid disease (e.g., Graves' disease, thyroid nodules, Hashimoto's thyroiditis) that might predispose

[8] Food and Drug Administration [FDA]. Notice: Guidance on Use of Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies. Federal Register, 66, 64046: 2001. Published as "Guidance: Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies," FDA, Center for Drug Evaluation and Research. Procedural, December 2001. (FDA 2001)

[9] Food and Drug Administration [FDA]. "Guidance for Industry: KI in Radiation Emergencies – Questions and Answers," FDA, Center for Drug Evaluation and Research, Procedural, Revision 1, December 2002. (FDA 2002)

them to adverse reactions should avoid KI. Allergies to iodine and to shellfish are not related. People allergic to shellfish need not worry about cross reactions with KI.[10]

Table 2-2. Threshold Thyroid Radioactive Exposures and Recommended Doses of KI for Different Risk Groups

	Predicted Thyroid gland exposure (cGy) (1 cGy = 1 rem)	KI dose (mg)	Number or fraction of 130 mg tablets	Number or fraction of 65 mg tablets
Adults over 40 years	≥ 500	130	1	2
Adults over 18 through 40 years	≥ 10			
Pregnant or lactating women	≥ 5			
Adolescents, 12 through 18 years[a]		65	1/2	1
Children over 3 years through 12 years				
Children over 1 month through 3 years		32	Use KI oral solution[b]	1/2
Infants birth through 1 month		16	Use KI oral solution[b]	Use KI oral solution[b]

[a] Adolescents approaching adult size (≥ 150 pounds) should receive the full adult dose (130 mg).

[b] Potassium iodide oral solution is supplied in 1 ounce (30 mL) bottles with a dropper marked for 1, 0.5, and 0.25 mL dosing. Each mL contains 65 mg potassium iodide.

Source: FDA, "Guidance: Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies" (December 2001): http://www.fda.gov/downloads/Drugs/GuidanceComplianceRegulatoryInformation/Guidances/UCM080542.pdf (FDA 2001); and FDA, Frequently Asked Questions on Potassium Iodide (KI): http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness/ucm072265.htm (Last Updated: 10/27/2014).

Pregnant women should be given KI for their own protection and for that of the fetus, as iodine (whether stable or radioactive) readily crosses the placenta. However, because of the risk of blocking fetal thyroid function with excess KI, repeat dosing with KI of pregnant women should be avoided.

Lactating females should be administered KI for their own protection, as for other young adults, and potentially to reduce the radioiodine content of the breast milk, but not as a means to deliver KI to infants, who should be administered KI directly. As for direct administration of KI, stable iodine as a component of breast milk may also pose a risk of hypothyroidism in nursing neonates. Therefore, repeat dosing with KI should be avoided in the lactating mother, except during continuing severe contamination. If repeat dosing of the mother is necessary, the nursing neonate should be monitored.

Once the plume has passed, protective actions such as evacuation and/or sheltering-in-place and food control measures to limit exposure to radioiodine should be implemented and the administration of KI should be suspended. Food control measures include providing the public with non-contaminated food supplies while awaiting the eventual radioactive decay of contaminated food. Consumption of contaminated food may be permitted on a case-by-case basis after surveying the foodstuffs and determining the level of contamination consistent with FDA food and animal feeds guidance. As a result

[10] More information is available at: http://www.foodallergy.org/allergens/shellfish-allergy and http://www.acaai.org/allergist/Resources/ask-allergist/Pages/Is_Shellfish_Allergy_Related_to_Iodine.aspx.

of radioactive decay, grain products and canned milk and vegetables from sources affected by radioactive fallout will not present a risk from radioiodine if they have been stored for weeks to months after production.

An RDD is not likely to contain radioiodine, so administration of KI would not be necessary in such incidents. The administration of other prophylactic drugs should be evaluated on a case-by-case basis depending on the nature of the event and the radioisotopes involved. For more information on radiological prophylactics and treatments, see:
http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness.

2.2.4 PAGs and Nuclear Facilities Emergency Planning Zones (EPZ)

Under NRC regulations, before a nuclear power reactor may be issued a license, the NRC must find that licensee, state and local emergency plans are adequate and that they can be implemented. For nuclear power reactors, there is a plume exposure EPZ within a 10 mile (16.1 km) radius of the plant and for a separate ingestion pathway EPZ within a 50 mile (80.5 km) radius. The sizes of these EPZs were developed by the NRC/EPA Task Force Report on Emergency Planning, NUREG-0396/EPA-520/1-78-016 (NRC and EPA 1978) and are based, in part, on the numerical values of the PAGs for the plume exposure and ingestion pathway EPZ. The licensee develops and maintains a detailed emergency plan for its facility while state and local authorities within the EPZ develop and maintain detailed emergency response plans for their respective jurisdictions. Guidance to these licensees, states and local agencies for developing these emergency response plans, including guidance on arrangements for implementing immediate protective actions is primarily contained in NUREG-0654/FEMA-REP-1 (NRC 1980)[11] and supplemented with other guidance issued by NRC (for licensees) and FEMA (for off-site response organizations).

Planning for incidents at other types of nuclear facilities should be developed using similar considerations. Emergency preparedness requirements for non-power reactors (e.g., test and research facilities) are provided in 10 CFR Part 50 Appendix E with supporting guidance in NRC Regulatory Guide 2.6, "Emergency Planning for Research and Test Reactors" (NRC 1983). Emergency preparedness requirements for fuel cycle and materials facilities are provided in 10 CFR Parts 30, 40, and 70 with supporting guidance in NRC Regulatory Guide 3.67, "Standard Format and Content for Emergency Plans for Fuel Cycle and Materials Facilities" (NRC 2011). Because of the relatively limited number and diverse nature of these facilities, the size of the EPZ is determined, if needed, on a case-by-case basis for reactors with an authorized power level less than 250 megawatt thermal.

Within an EPZ, an area should be pre-designated for immediate response based on specified plant conditions prior to a release, or, given a release, prior to the availability of information on quantities of radioactive materials released. The shape of this area will depend on local topography, as well as political and other boundaries. Additional areas of the EPZ, particularly in the downwind direction, may require evacuation or sheltering-in-place, as determined by dose projections. The size of these areas will be based

[11] Immediate protective actions based on in-plant conditions and EPZs established by NUREG-0654/FEMA-REP-1 are not applicable to naval nuclear propulsion plants. The largest naval reactors are rated at less than one-fifth of a large U.S. commercial NPP. In addition, since reactor power is directly linked to propulsion requirements, naval nuclear propulsion plants typically operate at low power when the ship is close to shore where high speeds are not required and are normally shut down when in port. Prototype reactor plants are typically operated at low power because of their training mission. Therefore, less than about one percent of the radioactivity contained in a typical commercial NPP could be released from a naval nuclear propulsion plant, limiting the possible dose to the general public and the size of the area of potential concern. Therefore, there is no need for towns and cities to have special emergency response plans such as those required for cities near commercial NPPs. Instead, existing all-hazards emergency response plans for responding to natural and industrial disasters are adequate to protect the public in areas around facilities where naval nuclear propulsion plants are located. However, the Naval Nuclear Propulsion Program (NNPP) maintains close relationships with civil authorities to ensure that communications and emergency responses are coordinated, if required. Periodic exercises are conducted with all States and Guam where U.S. nuclear-powered warships are homeported and NNPP facilities are located.

on the potential magnitude of the release and on an angular spread determined by meteorological conditions and any other relevant factors.

The pre-designated areas for immediate protective action may be reserved for use only in the most severe incidents and in cases when the facility operator cannot provide a quick estimate of projected dose based on actual releases. For lesser incidents, or if the facility operator is able to provide prompt off-site dose projections, the area for immediate protective action may be specified at the time of the incident instead of using a pre-designated area. Regardless of the basis for the initial protective action, radiological assessments need to continue through the duration of the event, and if warranted, the initial protective actions extended into additional geographical areas.

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

The EPZs should be large enough to cover affected urban and rural areas and accommodate the various organizations needed for emergency response.[12] Although the size of the EPZ is based on the maximum distance at which a PAG might be exceeded, the actual boundary of an EPZ should be demarcated by features readily identifiable by people within that area. Such boundaries generally include major topographical features (e.g., rivers, roads, transmission line corridors, rail rights of way) and political boundaries. The EPZ should be further subdivided, using similarly identifiable features, to facilitate implementing protective actions when the entire EPZ is not affected. Maps, showing the boundaries of the EPZ and the sub-areas and evacuation routes, should be provided to the public within the EPZ on a periodic basis in a format that will likely be available if the emergency occurs (e.g., inserted sections in local phone directories, wall calendars, etc.).

2.3 DOSE PROJECTIONS

The PAGs in this chapter are specified in terms of the projected whole body dose. This projected dose is the sum of the effective dose from external exposure to the plume and the committed effective dose from inhaled radionuclides. Guidance is also provided on the thyroid equivalent dose. Further references to effective or organ dose equivalent refer to these two quantities, respectively. The FRMAC Assessment Manuals[13] provide detailed methods for estimating projected dose. These methods require knowledge of, or assumptions for, the intensity and duration of exposure and make use of standard assumptions on the relation, for each radioisotope, between exposure and dose. Exposure and dose projections should be based on the best estimates available. The FRMAC methods and models may be modified as necessary for specific sites for improved accuracy. Emergency response organizations are encouraged to use the most current, applicable tools and methods for implementing PAGs, understanding that differing approaches and assumptions will produce results with minor differences.

[12] The development of EPZs for nuclear power facilities is discussed in the NUREG-0396 (NRC 1978).
[13] See FRMAC Assessment Manuals at http://nnss.gov/pages/programs/FRMAC/FRMAC_DocumentsManuals.html.

2.3.1 Dose Projection during the Early Phase

PAGs are expressed in terms of projected dose. The calculation of projected doses should be based on realistic dose models, to the extent practicable. Public protection decisions should be based upon the dose that can be avoided (i.e., avoidable dose) by taking some protective action (e.g., evacuation, sheltering-in-place). Unavoidable dose or doses incurred before the start of the protective action being considered generally should not be included in evaluating the need for protective action. Similarly, doses that may be incurred at later times than those affected by the specific protective action should not be included. As noted earlier, the projection of doses in the early phase needs to include only those exposure pathways that contribute a significant fraction (i.e., more than 10 percent) of the dose to an individual.

In the early phase of an incident, parameters other than projected dose may provide a more appropriate basis for decisions to implement protective actions. When a facility is operating outside its design basis and a substantial release to the environment has started, or is imminent but has not yet occurred, data adequate to directly estimate the projected dose may not be available. Emergency response plans should anticipate specific conditions at the source of a potential release and the possible consequences off-site. Emergency response plans for NPPs and facilities should make use of emergency action levels (EALs), based on in-plant conditions, to trigger notification and initial protective action recommendations to off-site officials.[14] Once the initial protective actions have been implemented, accident assessment should continue. Although initial assessments may be uncertain, the subsequent assessments will be less uncertain as additional information on facility condition and prognosis, effluent radiation monitoring data and environmental data become available. The results of these continuing radiological assessments, including dose projections, should be used as the basis for refining the initial protective actions. In the case of transportation accidents, an RDD or IND, or other incidents that are not related to a facility, it may not be practicable to establish EALs.

Doses that may be incurred from ingestion of food and water, long-term radiation exposure (i.e., longer than four days), radiation exposure to deposited radioactive materials, or long-term inhalation of resuspended materials are chronic exposures for which neither emergency evacuation nor sheltering-in-place are appropriate protective actions. PAGs for the intermediate phase cover these exposure pathways (see Chapter 4).

2.3.2 Duration of Exposure

The projected dose for comparison to the early phase PAGs is calculated for exposure during the first four days following the anticipated (or actual) start of a release. The objective is to encompass the entire period of exposure to the radioactive plume and deposited material prior to implementation of any further, longer-term protective action such as relocation. For planning purposes, the four-day period is chosen as the duration of exposure during the early phase because it is a reasonable estimate of the time necessary to make measurements, reach decisions, and prepare to implement further protective actions (such as relocation) if necessary. However, officials at the site at the time of the emergency may decide that a different time frame is more appropriate.

For example, doses incurred through ingestion pathways or long-term exposure to deposited radioactive materials take place over a longer time period. Protective actions for such exposures should be based on guidance addressed in Chapter 4.

The projected dose from each radionuclide in a plume is proportional to the time-integrated concentration of the radionuclide in the plume at each location. This concentration will depend on the rate and the duration of the release and meteorological conditions. Release rates will vary with time and this time-

[14] Immediate protective actions based on in-plant conditions are not applicable to naval nuclear propulsion plants. See Footnote 10 for additional information. In addition, because of differences in design and operation, EALs based on in-plant conditions are not applicable to naval nuclear propulsion plants.

dependence cannot usually be predicted accurately. In the absence of more specific information, the release rate may be assumed to be constant.

Another factor affecting the estimation of projected dose is the duration of the plume at a particular location. For purposes of calculating projected dose from most pathways, exposure will start at a particular location when the plume arrives and will end when the plume is no longer present. Exposure from deposited materials will continue for an extended period as long as people are present. Other factors such as the aerodynamic diameter and solubility of particles, shape of the plume, and terrain may also affect estimated dose and may be considered on a site- or source-specific basis.

Prediction of time frames for releases is difficult because of the wide range associated with the spectrum of potential incidents. Therefore, planners should consider the possible time periods between an initiating event and arrival of a plume and the duration of releases in relation to the time needed to implement competing protective actions (i.e., evacuation and sheltering-in-place). Analyses of commercial nuclear power reactors (NRC 1975) have shown that some incidents may take several days to develop to the point of a release while others may begin as early as a half hour after an initiating event. Furthermore, the duration of a release may range from less than one hour to several days, with the major portion of the release likely occurring within the first day.

Wind speed also influences radiological exposure rates from a plume. As a general rule, air concentration is inversely related to the wind speed at the point of release. Concentrations are also affected by the turbulence of the air, which tends to increase with wind speed and sunlight and by wandering of the plume, which is greater at the lower wind speeds. This results in higher concentrations generally being associated with low winds near the source and with moderate winds at larger distances. Higher wind speed also shortens the travel time of the plume. Planning information on time frames for releases from nuclear power facilities may be found in references NRC 1978 and EPA 1978(a, b). Time frames for releases from other facilities will depend on the characteristics of the facility.

2.3.3 Derived Response Levels and Dose Parameters

A Derived Response Level (DRL) is a level of radioactivity in an environmental medium that would be expected to produce a dose equal to its corresponding PAG. Depending on the exposure pathway, many factors such as ground roughness, weathering, and resuspension may be required to calculate the Dose Parameter (DP) that converts an environmental measurement into a projected dose over a given time period (e.g., early phase).

The FRMAC Assessment Manuals[15] provide guidance in calculating DRLs and DPs based on the ICRP dosimetry models (currently the ICRP 60 series). In addition, the FRPCC encourages the use of computational tools such as DOE's Turbo FRMAC and NRC's Radiological Assessment System for Consequence Analysis (RASCAL) as well as other appropriate or more current tools to implement the PAGs.

In the early phase, for precautionary reasons, it is recommended that default DRLs provided in the FRMAC Assessment Manual, Appendix C, be used. These defaults allow local entities to make decisions quickly in the event of a radiological emergency. They include worst-case or most likely assumptions. Further into the intermediate phase when incident characteristics have been assessed, more realistic incident-specific factors may be considered by local decision makers in projecting risks and adapting mitigation measures.

[15] See FRMAC Assessment Manuals at http://nnss.gov/pages/programs/FRMAC/FRMAC_DocumentsManuals.html.

2.3.4 Higher PAGs for Special Circumstances

Hazardous environmental conditions (e.g., severe weather or a competing disaster) could create transportation risks from evacuation that would be higher than normal. It is therefore appropriate to allow higher projected doses for evacuation decisions under these circumstances. In the absence of any definitive information on such higher risks from evacuation, one should assume that it would be appropriate to increase the recommended projected dose for evacuation of the general population under hazardous environmental conditions up to a factor of five higher than that used under normal environmental conditions.

It is also recognized that people who are not readily mobile are at higher risk from evacuation than are average members of the population. It would be appropriate to adopt higher PAGs for evacuation of individuals who would be at greater risk from evacuation itself than for the typically healthy members of the population, who are at low risk from evacuation. In the absence of definitive information on the higher risk associated with the evacuation of this group, one should assume that it is appropriate to adopt PAGs a factor of five higher for evacuation of high risk groups under normal environmental conditions. If both conditions (high risk groups and hazardous environmental conditions) exist, projected doses up to ten times higher than the PAGs for evacuation of the general population under normal conditions may be justified.[16]

2.4 CONTAMINATION LEVELS AND MONITORING OF THE ENVIRONMENT AND POPULATIONS

Areas under the plume can be expected to contain deposited radioactive materials if aerosols or particulate materials were released during the incident. In extreme cases, individuals and equipment may be highly contaminated and monitoring stations will be required for emergency monitoring, decontamination of individuals, and medical evaluations. Equipment should be checked and decontaminated as necessary to avoid the spread of contamination to other locations. This monitoring service would be required for only a few days following plume passage until all have been evacuated. Guidance on surface contamination levels for use at such monitoring stations is provided below.

Adults may reenter restricted (limited access) areas under controlled conditions in accordance with occupational exposure standards. The need for monitoring stations should be evaluated along highways, which serve as the major evacuation or transportation routes, to control surface contamination at exits from the more highly contaminated areas. Decontamination and other measures should be implemented to maintain low exposure rates at monitoring stations.

As a general rule, contaminated items should not be released to an unrestricted area. Based on incident and locality specific considerations, it may be acceptable to release contaminated materials if the level of surface contamination is below acceptable release criteria. As an alternative to decontamination, contaminated items (i.e., not people or animals) may be retained in the restricted area while the radiological contamination decays.

In some extreme cases, decontamination may be impractical. Evacuating a large area requires resources, and decontamination may conflict with priority use of those resources. Screening and decontamination can slow egress, which could result in increased dose to the evacuees. Emergency managers should consult with their state radiation control authority to establish proposed radiation screening criteria. Refer to CDC's "Population Monitoring in Radiation Emergencies: A Guide for State and Local Public Health Planners" (CDC 2014b)[17] for additional in-depth discussion in Appendix D on radiological screening criteria for external contamination. These simple initial screening guides from CDC are more general than

[16] These doses are expected to satisfy Principle 4 without violating Principles 1 and 3. Although they violate Principle 2, Principle 4 becomes, for such cases, the overriding consideration. See Section 2.5 for more information about these principles.
[17] See: http://emergency.cdc.gov/radiation/pdf/population-monitoring-guide.pdf. (CDC 2014b)

FEMA REP-21 (FEMA 1995) and FEMA REP-22 (FEMA 2002) on use of handheld instruments and portal monitors for screening the public.

2.4.1 Surface Contamination Control

Surface contamination must be controlled both before and after evacuation protective actions are implemented. The contamination level for screening people, animals and objects for surface contamination at monitoring stations should be influenced by the potential for the contamination to be ingested, inhaled or transferred to other locations. The principal exposure pathways for loose surface contamination on people, clothing and equipment are:

- Internal doses from ingestion by direct transfer;
- Internal doses from inhalation of resuspended materials;
- Beta dose to skin from contaminated skin or clothing or from nearby surfaces;
- Dose to the whole body from external gamma radiation; and
- Internal doses from absorption of contamination into wounds.

It is not practical to set surface contamination screening levels significantly lower than residual contamination levels in uncontrolled areas. Although the contamination levels recommended in this Manual are accordingly set high, consideration should be given as the incident progresses to using lower contamination screening levels (and more sensitive monitoring instruments) once people are removed from areas causing high external doses. Such efforts will minimize cross-contamination of people located outside of the affected areas. For incidents involving fixed nuclear facilities, some evacuation reception centers or shelters will have walk-through portal monitors.

The recommended "2x existing background" level for screening for surface contamination at monitoring stations is merely a simplified basis for responders to set their own instrument trigger levels based on practical circumstances at the time and location of each screening center. Local and state officials may choose to establish a screening level expressed in measurement units (e.g., counts per minute (cpm), μR/h) that are compatible with radiation detection instruments being used and appropriate for local conditions, taking into account the number of people in need of screening and available resources.[18] The following guidance documents from the National Council on Radiation Protection and Measurements (NCRP) provide more detailed information about initial screening levels:

- "Population Monitoring and Radionuclide Decorporation Following a Radiological or Nuclear Incident," (NCRP Report No. 166), Bethesda, MD, 2011. (NCRP 2011)
- "Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers," (NCRP Report No. 165), Bethesda, MD, 2010. (NCRP 2010)
- "Management of Persons Contaminated with Radionuclides: Scientific and Technical Bases," (NCRP Report No. 161, Vol. II), Bethesda, MD, 2010. Chapter 5: Performing Surveys and Controlling Personnel and Area Contamination. (NCRP 2008)
- "Management of Persons Contaminated with Radionuclides: Handbook," (NCRP Report No. 161, Vol. I), Bethesda, MD, 2008. (NCRP 2008)

2.4.2 Priorities for Control of Contaminated Areas

The following priorities are recommended—

- Do not delay urgent medical care for decontamination efforts or for time-consuming protection of attendants, such as donning of additional anti-contamination clothing.

[18] See: http://emergency.cdc.gov/radiation/pdf/population-monitoring-guide.pdf. (CDC 2014b)

- In early phase scenarios where it might not be practical or would interfere with other lifesaving and public health protection priorities, do not waste effort trying to contain contaminated wash water but be sure to notify sewage treatment plants.
- Do not allow monitoring and decontamination to delay an ordered evacuation.
- *When early screening is needed after a major incident* — After plume passage, it may be necessary to establish emergency contamination monitoring stations in areas not qualifying as low background areas. These monitoring stations should be used only during the early phase after major atmospheric releases to monitor people emerging from possible high exposure areas. The stations should be set up to provide simple (rapid) decontamination if needed and to evaluate whether affected people should undergo more extensive decontamination or other special care. Section 2.4.3 provides guidance on surface contamination levels for use, if such emergency contamination monitoring stations centers are needed.
- *Establish screening to control surface contamination* — Establish monitoring and decontamination (e.g., bathing) facilities at evacuation centers or other locations in low background areas (less than 0.1 mrem (1 µSv) per hour gamma exposure rate). Section 2.4.4 provides surface contamination guidance for monitoring stations in low background areas. These surface contamination screening levels are examples derived primarily on the basis of easily measurable radiation levels using portable instruments. The background may be elevated because of the incident, so these screening levels refer to a "2x existing background" level in a low radiation area.
- *Encourage self-decontamination* — Encourage evacuated people who were exposed in areas where release of particulate materials would have warranted evacuation to change and bag the clothes they were wearing and store them in an area away from people and pets until authorities provide further instructions on their disposition, to wash other exposed surfaces such as cars and trucks and their contents, and then report to evacuation centers or other established locations for monitoring.
- After the evacuation area has been established, consider the need to set up monitoring and decontamination stations at exits from the more highly contaminated parts of the area. Low levels of contamination may be undetectable because of high background radiation levels at these locations. Monitoring should be done at lowest practical background levels. Nevertheless, these individuals should be advised to bathe and change clothes at their first opportunity—no later than within the next 24 hours. If, after decontamination, people still exceed the surface contamination screening levels for the station, they should be sent for further decontamination or for medical or other special attention.

2.4.3 Recommendations for Emergency Screening in Areas Not Qualifying as Low Background Areas

This section provides the recommended surface contamination screening levels for emergency screening of people and objects at monitoring stations in areas with elevated background radiation (exceeding 0.1 mR/h or 1 µSv/h gamma exposure rate). Monitoring stations in such high exposure rate areas are for use only during the early phase of an incident involving major atmospheric releases of particulates (otherwise see Section 2.4.4). For such emergency screening at monitoring stations, recommended actions for a detection instrument reading at either less than or greater than 2x existing background are outlined below.

- **Before Decontamination**:
  - If <2x existing background — *Recommended action:* Release for further screening outside affected area.
  - If >2x existing background — *Recommended action:* Perform gross decontamination (carefully remove outer layer of clothing) and/or simple decontamination (examples include washing hands and face, wiping of exposed skin, washing feet or soles of shoes). Equipment may be stored for decay, reuse, or disposal in the same area, as appropriate.

- **After Decontamination**:
  - If <2x existing background — *Recommended action:* Release for further screening outside affected area.
  - If >2x existing background — *Recommended action:* Continue to decontaminate or refer to low background monitoring and decontamination station. Equipment may be stored for decay, reuse, or disposal in the same area, as appropriate.

2.4.4 Recommendations for Screening in Low Background Areas

This section provides the recommended surface contamination screening levels for people and objects at monitoring stations in low background radiation areas (<0.1 mR/h or 1 µSv/h gamma exposure rate). People reporting to monitoring stations in low background radiation areas have been previously instructed to change and bag clothes, wash other exposed surfaces such as cars and their contents, and then report to these centers for monitoring. Levels higher than 2x existing background (not to exceed the meter reading corresponding to 0.1 mR/h) may be used to speed the monitoring of evacuees in very low background areas. For screening at monitoring stations in low background areas, recommended actions for a detection instrument reading at either less than or greater than 2x existing background are outlined below.

- **Before Decontamination**:
  - If <2x existing background — *Recommended action:* Unconditional release.
  - If >2x existing background — *Recommended action:* Perform gross decontamination (carefully remove outer layer of clothing) and/or simple decontamination (examples include washing hands and face, wiping of exposed skin, washing feet or soles of shoes).

- **After Simple Decontamination Effort**:
  - If <2x existing background — *Recommended action:* Unconditional release.
  - If >2x existing background — *Recommended action:* Full decontamination.

- **After Full Decontamination Effort** (Changing clothes and/or showering are examples of a full decontamination effort. Washing or gentle scrubbing with soap or other mild detergent followed by flushing is another example of a full decontamination effort.):
  - If <2x existing background — *Recommended action:* Unconditional release.
  - If >2x existing background — *Recommended action:* Continue to decontaminate people.

- **After Additional Full Decontamination Effort**:
  - If <2x existing background — *Recommended action:* Unconditional full release.
  - If >2x existing background — *Recommended action:* Send people for further evaluation.

The recommended "2x existing background" level for screening for surface contamination at monitoring stations is merely a simplified basis for responders to set their own instrument trigger levels based on practical circumstances at the time and location of each screening center. Local and state officials may choose to establish a screening level expressed in measurement units (e.g., cpm, µR/h) that are compatible with radiation detection instruments being used and appropriate for local conditions, taking into account the number of people in need of screening and available resources.[19]

2.5 BASIS FOR EARLY PHASE PAGS

For a full description of the risk-benefit analysis used to set the PAG levels, refer to the 1992 PAG Manual, Appendices B, C and E. The 1992 PAG Manual is available online in a searchable format. Below is a short summary of the basis for the early phase evacuation/sheltering PAG of 1 to 5 rem (10 to 50 mSv) projected over four days.

[19] See: http://emergency.cdc.gov/radiation/pdf/population-monitoring-guide.pdf. (CDC 2014b)

PAGs are intended to apply to all individuals in a population. However, there may be identifiable groups that have different average sensitivity to radiation or, because of their living situation, will receive higher or lower doses. In addition, some groups may be at greater risk from taking a given protective action. Special circumstances and age groups (e.g., fetal dose) were considered, when appropriate, in establishing values for the PAGs.

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

1. Acute effects on health (those that would be observable within a short period of time and which have a dose threshold below which they are not likely to occur) should be avoided.
2. The risk of delayed effects on health (primarily cancer and genetic effects, for which linear non-threshold relationships to dose are assumed) should not exceed upper bounds that are judged to be adequately protective of public health, under emergency conditions, and are reasonably achievable.
3. PAGs should not be higher than justified on the basis of optimization of cost and the collective risk of effects on health. That is, any reduction of risk to public health achievable at acceptable cost should be carried out.
4. Regardless of the above principles, the risk to health from a protective action should not itself exceed the risk to health from the dose that would be avoided.[20]

EPA considered the acceptable range of costs for avoiding a statistical death from pollutants other than radiation and using a rounded value from the BEIR III risk of 0.0003 cancer deaths per person-rem.[21] Further evaluation of thyroid, skin, and fetal dose consequences was conducted as well.

Costs of evacuation:

Based on a prior published study (EPA 1987a), evaluating evacuation options for several accident types, an analysis focused on the smallest category of fuel melt accident yielding effective dose equivalents during the first four days of exposure that are greater than 0.5 rem outside the assumed 2-mile evacuation circle for all stability classes. For that scenario, total and incremental costs were calculated for several different sized evacuation areas. Data on costs versus dose avoided for several meteorological stability classes and evacuation options (sizes) were summarized in tables in the 1992 PAG Manual, Appendix C.

For a risk of 0.0003 cancer deaths per person-rem, the range of evacuation costs can be compared to the marginal cost-effectiveness (dollars per person-rem) of evacuation over an angle of 90 degrees. The resulting ranges of upper bounds on dose are found in tables in the 1992 PAG Manual, Appendix C, for three different accident scenarios. The maximum upper bounds (based on minimum costs for avoiding risk) range from 1 to 10 rem, with most values being approximately 5 rem. The minimum upper bounds (based on maximum costs for avoiding risk) range from 0.15 to 0.8 rem, with 0.5 rem dose incurred being representative of most situations.

From these data we conclude that, based on the cost of evacuation, a PAG larger than the range of values 0.5 to 5 rem would be incompatible with Principle 3.

Based on comparison of exposures from evacuation versus the presumed alternative of sheltering in various building types for several timeframes, the dose actually avoided by evacuation is one half of the projected dose.

[20] These four principles were used in developing the 1992 PAG Manual; now presented as three principles.

[21] For more information on BEIR III risk, see the 1992 PAG Manual. BEIR III refers to the 1980 report from the Committee on the Biological Effects of Ionizing Radiation (BEIR) of the National Academy of Sciences (NAS), National Research Council, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: BEIR III*. (NAS 1980)

Risk from evacuation:

Principle 4 requires that the risk of the protective action not exceed the risk associated with the dose that will be avoided. Risk from evacuation can come from several sources, including: 1) transportation incidents for both pedestrians and vehicle passengers; 2) exposure to severe weather conditions or a competing disaster; and 3) in the case of immobile persons, anxiety, unusual activity, and separation from medical care or services. While all these factors must be considered, transportation incidents is the only category for which the risk has been quantified.

Conformance to Principle 1 (avoidance of acute health effects) is assured by the low risk required to satisfy Principle 2 (acceptable risk of delayed health effects), and thus requires no additional consideration. Based on Principle 2, evacuation of the general population is not justified below 0.5 rem. This represents a risk of about 0.0002 of fatal cancer. Maximum lifetime risk levels considered acceptable by EPA from routine operations of individual sources range from 0.000001 to 0.0001. Risk levels that are higher than this must be justified on the basis of the emergency nature of a situation. In this case, we judge that up to an order of magnitude higher combined risk from all phases of an incident may be justifiable. The choice of 0.5 rem avoided dose as an appropriate criterion for an acceptable level of risk during the early phase is a subjective judgment that includes consideration of possible contributions from exposure during other phases of the incident.

Principle 4 (risk from the protective action must be less than that from the radiation risk avoided) supplies a lower bound of 0.03 rem on the dose at which evacuation of most members of the public is justified. The lower bound was derived from the risk of death from traffic accidents in emergency evacuations, using the factor of 0.0003 cancer deaths per person-rem. Finally, under Principle 3 (cost/risk considerations) evacuation is justified only at values equal to or greater than 0.5 rem. This will be limiting unless lower values are required for purely health-based reasons (Principle 2). But this is not the case.

In summary, we have selected the value 0.5 rem as the avoided dose which justifies evacuation, because: 1) it limits the risk of delayed effects on health to levels adequately protective of public health under emergency conditions; 2) the cost of implementation is justified; and 3) it satisfies the two bounding requirements to avoid acute radiation effects and to avoid increasing risk through the protective action itself.

The value of the PAG for evacuation of the general public is therefore chosen as one rem projected total effective dose from inhalation of radionuclides and exposure to external radiation.

KEY POINTS IN CHAPTER 2 – EARLY PHASE

- The principal protective actions for the early phase are evacuation or sheltering-in-place. Evacuation is the urgent removal of people from an area to avoid or reduce high-level, short-term exposure from the plume or deposited radioactivity. Sheltering-in-place refers to the use of a readily available structure that will provide protection from exposure to the plume.
- The PAG for evacuation or sheltering-in-place is a projected whole body dose of 1 to 5 rem (10 – 50 mSv) total effective dose (TED) over four days.
- Evacuation is appropriate when its risks and secondary effects are less severe than the risk of the projected radiation dose. Evacuation will be most effective in avoiding dose if completed before plume arrival.
- In general, sheltering-in-place should be preferred to evacuation whenever it provides equal or greater protection. After confirmation that the plume has passed, continued sheltering-in-place should be re-evaluated by public officials.
- The administration of KI to partially block the uptake of radioiodines by the thyroid is a supplemental protective action. The PAG for administration of KI is 5 rem (50 mSv) projected child thyroid dose.
- Dose calculations for PAGs are made using the dose parameter (DP) and derived response level (DRL) calculation methods referenced in the FRMAC Assessment Manuals. Emergency response organizations are encouraged to use the most current, applicable tools and methods for implementing the PAGs.

CHAPTER 3. EMERGENCY WORKER PROTECTION

The emergency worker guidelines in this chapter were developed for a wide range of possible radiological scenarios, from a small transportation accident that may impact a single roadway to an IND that could potentially impact a large geographic region. Therefore, the 5, 10 and 25 rem (50, 100 and 250 mSv) guidelines (see Table 3-1, Section 3.1.2) should not be viewed as inflexible limits applicable to the range of early phase emergency actions covered by this guidance. For instance, by the intermediate phase when relocation has been implemented, it is likely that no more lifesaving missions would be needed. Some critical infrastructure/key resources or lifesaving missions may arise in later phases, however, for which the emergency worker guides in Section 3.1.2 would apply.

Because of the range of impacts and case-specific information needed, it is impossible to develop a single turn-back dose level for all responders to use in all events, especially those that involve lifesaving operations. Indeed, with proper preparedness measures (training, personal protective equipment (PPE), etc.) most radiological emergencies addressed by this document, even lifesaving operations, may be manageable within the 5 rem (50 mSv) occupational limit.[22] Moreover, incident commanders should make every effort to employ the "as low as reasonably achievable" (ALARA) principle after an incident. Still, in some incidents doses above the annual occupational 5 rem (50 mSv) dose limit may be unavoidable. For instance, in the case of a catastrophic incident, such as an IND, incident commanders may need to consider raising the lifesaving and critical infrastructure (i.e., necessary for public welfare) emergency worker guidelines in order to prevent further loss of life and prevent the spread of massive destruction. It is essential that emergency workers have full knowledge of the associated risks prior to initiating emergency action and receive medical evaluations after such exposure.

Worker and public protection guidance and standards for normal operations are developed through risk management approaches and are implemented in federal and state regulations (e.g., 10 CFR Part 20; 10 CFR Part 835; 29 CFR Part 1910.1096). However, many factors or decision criteria in a radiological emergency differ from those in normal operations. Standards for normal operations provide a margin of safety that is greater than that in guidelines for emergency response because that margin can be provided in a manner that ensures no significant increase in public health risk or detriment to the public welfare. Currently, the development of standards and guidelines for normal operations is done in a manner that provides reasonable assurance that implementation of the standards will not cause more risk than it averts.

Response organizations need to develop plans and protocols that address radiation protection during a radiological incident and that ensure appropriate training is provided to responders and decision-makers. Detailed reports on radiation risk, risk management decision-making, training and public communication should be consulted in the development of plans, protocols and training materials and may be obtained from organizations such as ICRP, NCRP, International Atomic Energy Agency (IAEA), the American Nuclear Society (ANS), and the Health Physics Society (HPS). Detailed information on the risks of radiological emergency response and worker protection procedures can be found in the FRMAC "Radiological Emergency Response Health and Safety Manual" (DOE 2012) and the NCRP's "Management of Terrorist Events Involving Radioactive Material, Report No. 138" (NCRP 2001) and "Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers, Report No. 165" (NCRP 2010).

[22] See 29 CFR Part 1910.1096 (Ionizing Radiation) for OSHA's occupational limit. Under the OSHA Ionizing Radiation standard, the annual occupational limit for whole body radiation exposure for adults (age ≥18 years) is 5 rem (50 mSv). Employers must comply with all applicable OSHA requirements, including worker dose limits for ionizing radiation, during emergency response and recovery operations.

3.1 CONTROLLING OCCUPATIONAL EXPOSURE AND DOSES TO EMERGENCY WORKERS

This section provides guidance on occupational doses of radiation during an emergency response. In many radiological incidents, actual exposure of workers, including emergency responders, may be controlled to low doses when proper precautions are taken. During some emergencies, radiation exposures to responders may be unavoidable and may have the potential to exceed limits used for normal operations.

However, even in emergency conditions, every reasonable effort should be made to control doses to levels that are as low as practicable (consider NCRP 138[23] and NCRP 165[24] for recommendations that support ALARA).

3.1.1 Maintaining the ALARA Principle

To minimize the risks from exposure to ionizing radiation, employers of emergency workers (or incident commanders, who may or may not be the same) should prepare emergency response plans and protocols in advance to keep worker exposures ALARA, an acronym for "as low as reasonably achievable," which means making every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical consistent with the purpose for which the activity is undertaken. Plans and protocols should include the following health physics and industrial hygiene practices to the maximum extent possible—

- Minimizing the time spent in the contaminated area.
- Maximizing the distance from sources of radiation.
- Shielding of radiation sources.
- Tailoring of hazard controls to the work performed.
- Properly selecting and using respirators (see 29 CFR Part 1910.134) and other PPE.
- Using prophylactic medications, where medically appropriate, that either block the uptake or reduce the retention time of radioactive material in the body.

The incident commander's staff should be prepared to identify, to the extent possible, all hazardous conditions or substances and to perform appropriate site hazard analysis. Emergency management plans need to include protocols to control worker exposures, establish exposure guidelines in advance, and outline procedures for worker protection. Emergency procedures need to include provisions for exposure monitoring, worker training commensurate with the hazards involved in response operations, ways to control those hazards, and medical monitoring.

3.1.2 Understanding Dose and Risk Relationships

Emergency worker guidelines are based on cumulative dose constraint levels. These are based on an assumption that doses acquired in response to a radiological incident would be "once in a lifetime" doses and that future radiological exposures would be substantially lower.

Recommendations in this Manual provide a guideline level of 5 rem (50 mSv) for worker protection and alternative emergency worker guidelines (see Table 3-1) for certain activities where doses above 5 rem (50 mSv) cannot be avoided. For most radiological incidents, radiation control measures (e.g., minimizing time, maximizing distance, using shielding) will prevent doses from reaching the 5 rem (50 mSv) occupational exposure guideline while performing typical emergency response activities such as transportation, firefighting and medical treatment of contaminated victims at hospitals. However, in those situations in which victims are injured or trapped in high radiation areas or can only be reached via high radiation areas, or for protection of critical infrastructure, exposure control options may be unavailable or insufficient and doses above 5 rem (50 mSv) may be unavoidable.

[23] "Management of Terrorist Events Involving Radioactive Material, Report No. 138." (NCRP 2001)
[24] "Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers, Report No. 165." (NCRP 2010)

Decisions to take response actions that could result in doses in excess of 5 rem (50 mSv) can only be made at the time of the incident, under consideration of the actual situation. In such situations, incident commanders and other responders need to understand the risk posed by such exposures in order to make informed decisions. The emergency worker guidelines for life and property saving activities in Table 3-1 are provided to assist such decision-making. These guidelines apply to doses incurred over the duration of an emergency and are assumed to be once in a lifetime. After the early phase, it is likely that no more lifesaving missions would be needed. However, some critical infrastructure/key resources or lifesaving missions may arise in the intermediate phase, where these guidelines would apply.

Emergency personnel may be exposed to increased radiation during the unique catastrophic event of an IND detonation resulting in firestorm and widespread destruction of structures. The emergency intervention needed to prevent further destruction and loss of life may result in increased exposure. Exceeding the emergency worker guidelines in Table 3-1 may be unavoidable in responding to such events. For all exposures, emergency workers must be fully informed of the risks of exposure they may experience, including numerical estimates of the risk of delayed health effects, and must be trained, to the extent feasible, on actions to be taken. Each emergency worker should make an informed decision as to how much radiation risk they are willing to accept to complete a particular mission.

Table 3-1. Emergency Worker Guidelines

Guideline	Activity	Condition
5 rem (50 mSv)	All occupational exposures	All reasonably achievable actions have been taken to minimize dose.
10 rem (100 mSv)[a]	Protecting critical infrastructure necessary for public welfare (e.g., a power plant)	Exceeding 5 rem (50 mSv) unavoidable and all appropriate actions taken to reduce dose. Monitoring available to project or measure dose.
25 rem (250 mSv)[b]	Lifesaving or protection of large populations	Exceeding 5 rem (50 mSv) unavoidable and all appropriate actions taken to reduce dose. Monitoring available to project or measure dose.
>25 rem (250 mSv)	Lifesaving or protection of large populations	All conditions above and only for people fully aware of the risks involved (see Tables 3-2 and 3-3)

[a] For potential doses >5 rem (50 mSv), medical monitoring programs should be considered.

[b] In the case of a very large incident, such as an IND, incident commanders may need to consider raising the property and lifesaving emergency worker guidelines to prevent further loss of life and massive spread of destruction.

This guidance does not address or impact site cleanups occurring under other statutory authorities such as the United States Environmental Protection Agency's (EPA) Superfund program, the Nuclear Regulatory Commission's (NRC) decommissioning program, or other federal or state cleanup programs.

The 25 rem (250 mSv) lifesaving emergency worker guidelines provide assurance that exposures will not result in detrimental deterministic health effects (i.e., prompt or acute effects). However, it could increase the risk of stochastic (chronic) effects, such as the risk of cancer. Response actions that could cause exposures in excess of the 25 rem (250 mSv) emergency worker guideline should only be undertaken with an understanding of the potential acute effects of radiation to the exposed responder (see Table 3-2) and

only when the benefits of the action (i.e., lifesaving or critical infrastructure/key resource protection) clearly exceed the associated risks.

Table 3-2. Acute Radiation Syndrome[a]

Feature or Illness	**Effects of Whole Body Absorbed Dose from External Radiation or Internal Absorption, by dose range in rad (Gray)**				
	0-100 (0-1 Gy)	100-200 (1-2 Gy)	200-600 (2-6 Gy)	600-800 (6-8 Gy)	>800 (>8 Gy)
Nausea, Vomiting	None[25]	5-50%	50-100%	75-100%	90-100%
Time of Onset		3-6 hr	2-4 hr	1-2 hr	< 1 hr to minutes
Duration		< 24 hr	< 24 hr	< 48 hr	< 48 hr
Lymphocyte Count	Unaffected	Minimally Decreased	<1000 at 24 hr	< 500 at 24 hr	Decreases within hours
Central Nervous System Function	No Impairment	No Impairment	Cognitive impairment for 6-20 hr	Cognitive impairment for > 20 hr	Rapid incapacitation
Mortality	None	Minimal	Low with aggressive therapy[26]	High	Very High: Significant neurological symptoms indicate lethal dose

[a] Percentage of people receiving whole body doses within a few hours expected to experience acute health effects.

Source: Medical Management of Radiological Casualties, Second Edition, Armed Forces Radiobiology Research Institute. Bethesda, MD, April 2003 (DoD 2003).

Higher doses could be received by emergency workers performing what NCRP Report No. 165, "Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers" calls "Time-Sensitive Mission-Critical" activities that could result in radiation doses higher than 25 rem (250 mSv) (NCRP 2010). NCRP Report No. 165 expands the discussion on a Decision Dose of 50 rad (approximately 50 rem or 500 mSv). A Decision Dose can be used by the incident commander as a tool to address the need to and the consequences of exposing emergency workers to higher doses to accomplish Mission Critical actions. This is especially important in an IND incident.

The estimated excess risk of fatal cancer[27] for workers exposed to 10 rem (100 mSv) is slightly less than the corresponding general population risk of 0.6 percent (6 cases per thousand exposed). Workers exposed to 25 rem (250 mSv) have an estimated excess risk of fatal cancer of 1.5 percent (15 cases per thousand

[25] A small number of exposed individuals may experience symptoms such as nausea and vomiting at doses between 50 and 100 rad (0.5 and 1 Gy).

[26] The LD 50/60 or the lethal dose with NO medical intervention to 50 percent of the population after 60 days is between 320 and 450 rad or 3.2 - 4.5 Gy.

[27] Risk per dose of a fatal cancer is assumed to be about $6x10^{-4}$ per rem ($6x10^{-5}$ per mSv). Cancer incidence is assumed to be about $8x10^{-4}$ per rem ($8x10^{-5}$ per mSv). (EPA 1999)

exposed). Because of the latency period of cancer, younger workers face a larger risk of fatal cancer than older workers (e.g., when exposed to 25 rem (250 mSv), 20 to 30-year-olds have a 9.1 per thousand risk of premature death, while 40 to 50-year-olds have a 5.3 per thousand risk of premature death).[28]

More specific risk determinations can be made when there is adequate information about the contaminants and the potential for human exposure. EPA's Federal Guidance Report #13 (EPA 1999) and Health Effects Assessment Summary Tables (EPA 1997) have risk factors for specific radionuclides.

Prior to the 5 rem (50 mSv) guideline being exceeded, workers should be provided the following—

- Site-specific training, if no prior training was available, with respect to the risk associated with exposure to ionizing radiation (incident commanders and responders should consider having someone on each team with radiation safety experience).
- A thorough explanation of the latent risks associated with receiving exposures greater than 5 rem (50 mSv).
- After this training and thorough explanation of the risks, each emergency worker should make an informed decision as to how much radiation risk they are willing to accept when undertaking a particular mission.

If the 5 rem (50 mSv) guideline is exceeded, workers should be provided with a medical follow-up and monitoring should be considered.

In addition, these guidelines represent dose constraint levels (e.g., when this level of dose is accumulated, the responder should not take part in the later stages of the response that may significantly increase their dose). The FRMAC "Radiological Emergency Response Health and Safety Manual" (DOE 2012) provides detailed information. Additional resources for advance planning are available on the Radiation Emergency Medical Management (REMM) website: http://www.remm.hhs.gov/.

3.2 OCCUPATIONAL SAFETY REGULATIONS FOR RADIOLOGICAL EMERGENCY RESPONSE

The Occupational Safety and Health Act requires employers to be responsible for the health and safety of their employees during routine and emergency operations. The primary occupational safety and health standard for emergency response is the Hazardous Waste Operations and Emergency Response (HAZWOPER) standard (29 CFR Part 1910.120). Information about how the Occupational Safety and Health Administration (OSHA) applies HAZWOPER and other OSHA standards to emergency responses and cleanup operations is available at www.osha.gov.

Many U.S. states operate their own OSHA-approved state plans, which are required to be "at least as effective as" Federal OSHA standards and may impose additional or more stringent requirements.[29] Some states operate "complete" plans that cover both the private sector and state and local government employees, while others cover state and local government employees only. EPA's Worker Protection Standard (40 CFR 311) applies the HAZWOPER standard to state and local government workers in states that do not have occupational health and safety plans.

[28] The numerical estimate of cancer risk presented above (from Federal Guidance Report #13) was obtained by linear extrapolation using the nominal risk estimates based on data from human exposures at high doses and high dose rates. Other methods of extrapolation to the low-dose region could yield higher or lower numerical estimates of cancer deaths. Studies of human populations exposed at low doses are inadequate to demonstrate the actual magnitude of risk at low doses (about 0.1 Sv or 10 rem and below). There is scientific uncertainty about cancer risk in the low-dose region below the range of epidemiological observation and the possibility of no risk cannot be excluded. (EPA 1999)

[29] For a list of state plans, see: http://www.osha.gov/dcsp/osp/index.html.

In addition to OSHA, several federal agencies (DOE and NRC) and Agreement States issue occupational radiation safety standards (see Table 3-3). The occupational standards are not guidelines but instead are regulatory limits that cannot be exceeded except under certain conditions. These occupational limits allow workers to receive radiation exposure during the course of performing their jobs.

Some federal and state radiation safety standards may allow workers to exceed dose limits in order to take critical lifesaving actions. However, even during emergency response and recovery operations, OSHA standards always apply. During the initial emergency response following a nuclear detonation, OSHA will likely operate in a technical assistance and support mode, pursuant to the National Response Framework, rather than issuing citations for workplace violations. OSHA retains its enforcement authority under the Occupational Safety and Health (OSH) Act of 1970.

Table 3-3. Regulations for Worker Protection

Agency	Regulatory Requirement	Title
Occupational Safety and Health Administration[a]	29 CFR Part 1910.120	Safety and Health ─ HAZWOPER
	29 CFR Part 1910.1096	Ionizing Radiation
Environmental Protection Agency[a]	40 CFR Part 311	Occupational Radiation Protection
Nuclear Regulatory Commission[b]	10 CFR Part 20	Standards for Protection Against Radiation
Department of Energy[c]	10 CFR Part 835	Radiation Protection Regulations

[a] Worker safety and health is regulated in all states by federal OSHA or by respective state regulations under an OSHA-approved state plan. 40 CFR Part 311 applies the OSHA HAZWOPER standard (29 CFR 1910.120) to public-sector workers in states that do not operate their own occupational safety and health programs.

[b] It is the NRC's position (56 FR 23365) that dose limits for normal operations should remain the primary guideline in emergencies to the extent practicable. However, in accordance with 10 CFR 20.1001(b), conformance with such dose limits should not hinder an NRC licensee from taking actions that may be necessary to protect public health and safety in an emergency.

[c] These requirements apply to all DOE employees and contractors (except for Naval Nuclear Propulsion Program (NNPP)) who may be exposed to ionizing radiation as a result of their work for DOE, including work relating to emergency response activities. The NNPP has established requirements consistent with those contained in 10 CFR Part 835.

KEY POINTS IN CHAPTER 3 – EMERGENCY WORKER PROTECTION

- Emergency worker guidelines of 5, 10 or 25 rem (50, 100 or 250 mSv) are based on the urgency of activities and knowledge of the risks involved.
- Worker safety is key to a successful emergency response.
- Incident commanders are responsible for balancing the individual risks and public benefits of each worker action.
- Emergency workers should be adequately informed of, and have an adequate understanding of, the risks they may experience during any missions they accept, including the risk of short-term and long-term health effects from exposure to ionizing radiation.
- Emergency workers should have relevant training, personal protective equipment (PPE), and monitoring instruments so they are able to protect themselves and others.
- Since there is assumed to be no threshold below which there is not an associated risk from radiation dose, workers who are reasonably expected to receive more than 25 percent of the occupational dose limit should be properly trained and monitored.
- Emergency workers should be trained, to the extent feasible, on actions to be taken. All reasonable steps should be taken to provide appropriate protection during the emergency activity.
- Worker protection regulations are listed in Table 3-3.

CHAPTER 4. INTERMEDIATE PHASE PROTECTIVE ACTION GUIDES

This chapter presents PAGs for the intermediate phase and provides guidance for the implementation of corresponding protective actions. A PAG is the projected dose to an individual from the release of radioactive material at which a specific protective action should be taken to reduce or avoid that dose. The intermediate phase is defined as the period beginning after the source and releases have been brought under control and environmental measurements are available for use as a basis for decisions on protective actions and extending until these protective actions are terminated. The intermediate phase may last from weeks to months but is projected for one year for calculation purposes.

During the early phase, decisions must be made and implemented quickly by state and local officials before federal assistance may be available. In contrast, many decisions and actions during the intermediate phase may be taken after federal resources are present, as described in the "Nuclear Radiological Incident Annex of the National Response Framework" (FEMA 2008b). Decisions will be made during the intermediate phase concerning whether particular areas or properties from which people have been evacuated will be decontaminated and reoccupied or the occupants relocated for an extended period.

This chapter provides the PAGs and corresponding protective actions for use by state and local officials in developing their radiological emergency response plans to protect the public from exposure to radiation from deposited radioactive materials. Due to the wide variety of types of radiological incidents and radionuclide releases that could occur, it is not practical to provide implementing guidance for every possible situation.

This chapter also provides guidance for translating radiological conditions in the environment into projected doses that serve as the basis for decisions to take appropriate protective actions and basic planning guidance on reentry as informed by the Operational Guidelines (DOE 2009).

4.1 EXPOSURE PATHWAYS DURING THE INTERMEDIATE PHASE

During the intermediate phase, the following are the principal exposure pathways for the public occupying areas contaminated with deposited radioactive materials—

- **External exposure** to radiation from deposited radioactive materials (groundshine). External gamma radiation is the expected dominant pathway for NPP incidents and incidents involving RDDs and INDs. Typically, the health risks from other pathways are expected to be minor in comparison to the risks from external gamma radiation.
- **Internal exposure** from the inhalation of resuspended materials. Although normally expected to be of only minor importance for NPP incidents, the inhalation pathway would contribute additional doses to internal organs. Inhalation dose, however, would be an important exposure pathway for radiological incidents with significant fractions of pure beta emitters or alpha emitters.
- **Internal exposure** from the ingestion of food and water. In rare cases, where food or drinking water are contaminated to levels above the PAG for ingestion, and withdrawal of food and/or water from use would, in itself, create a health risk greater than that from the radiation dose, the committed effective dose from ingestion should be added to the dose from the above pathways for comparison to the relocation PAG.

Other potentially significant exposure pathways include exposure to beta radiation from surface contamination (e.g., beta dose to skin) and direct ingestion of contaminated soil. These pathways are not expected to be controlling for NPP incidents (Aaberg 1989).

4.2 THE PROTECTIVE ACTION GUIDES AND PROTECTIVE ACTIONS FOR THE INTERMEDIATE PHASE: RELOCATION AND DOSE REDUCTION

The principal protective actions for reducing exposure of the public to deposited radioactive materials are:

- Relocation;
- Decontamination;
- Shielding;
- Time limits on exposure; and
- Control of the spread of surface contamination.

The most effective of these actions is relocation—the removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. Relocation is highly disruptive and therefore only implemented when the dose is sufficiently high to warrant it. The PAG for relocation is 2 rem (20 mSv) projected over the first year of exposure. After the first year, the PAG for relocation is 0.5 rem (5 mSv) per year.

The PAG level for relocation applies to doses that can be avoided by relocation; doses already incurred prior to relocation are not included in the calculations. PAGs for protection from deposited radioactivity during the intermediate phase are summarized in Table 4-1. The decision to relocate will be considered on a case-by-case basis. Efforts to decontaminate and remediate the contaminated area and the shielding offered by buildings and the residency factor attributable to the building, must be considered to see if either relocation PAG will be exceeded.

It may be difficult to avoid exceeding the relocation PAGs for the radionuclides most likely associated with RDDs because of their longer half-lives. If these radionuclides are released, it may be necessary to relocate people in the affected areas even if exposure is less than 2 rem (20 mSv) in the first year, provided decontamination and remediation measures during the first year are unsuccessful.

In most scenarios, relocation decisions will be based on doses from external exposure to the whole body from deposited radioactive materials and internal exposure from inhalation of resuspended deposited material.

Food and milk ingestion dose should be considered separately with decisions based on the FDA PAGs (FDA 1998).[30] The FRMAC Assessment Manuals[31] provide guidance in calculating Ingestion Derived Response Levels (DRLs) that indicate the levels of deposited radioactive materials that may result in food exceeding the FDA PAGs.

Other protective actions, such as simple dose reduction techniques, can be applied in areas where levels of deposited radioactivity are not high enough to warrant relocation. Dose reduction actions can range from the simple—scrubbing or flushing surfaces, removal and disposal of small spots of highly contaminated soil (e.g., from settlement of water), and spending more time than usual in lower exposure rate areas (e.g., indoors)—to the difficult and time consuming processes of removal, disposal and replacement of contaminated surfaces. The simple processes would probably be most appropriate in contaminated areas outside the relocation area. Many of these can be carried out by the residents with support from officials for monitoring and guidance on appropriate actions and disposal. The more difficult processes will be appropriate for recovery of areas where contamination is fixed (not removable) and from which the population is relocated.

[30] See: http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM094513.pdf.
[31] See FRMAC Assessment Manuals at http://nnss.gov/pages/programs/FRMAC/FRMAC_DocumentsManuals.html.

Access to and/or activities within large areas may have to be restricted under these PAGs. As the land area increases, protective actions become more difficult and costly to implement, especially when the affected area is densely populated. There may be situations where full implementation of early and intermediate phase protective actions is impracticable (e.g., a release in a large city). Informed judgment must be exercised to assure priority of protection for individuals in areas having the highest exposure rates.

Table 4-1. PAGs and Protective Actions for Exposure to Deposited Radioactivity during the Intermediate Phase of a Radiological Incident[a]

Protective Action Recommendation	**PAG or Guideline**	**Comments**
Relocation of the public[b]	**PAG**: ≥ 2 rem (20 mSv) projected dose[c] in the first year, 0.5 rem (5 mSv)/year projected dose[c] in the second and subsequent years	Projected dose over one year of exposure.
Apply simple dose reduction techniques[d]	**Guideline**: < 2 rem (20 mSv) projected dose[c] in the first year	These protective actions should be taken to reduce doses to as low as practicable levels.
Food interdiction[e]	**PAG**: 0.5 rem (5 mSv)/year projected whole body dose, or 5 rem (50 mSv)/year to any individual organ or tissue, whichever is limiting	
Drinking Water	**PAG:** 100 mrem (1 mSv or 0.1 rem) projected dose, for one year, to the most sensitive populations (e.g., infants, children, pregnant women and nursing women); 500 mrem (5 mSv or 0.5 rem) projected dose, for one year, to the general population	See Section 4.6
Reentry	**Guideline**: Operational Guidelines[f] (stay times and concentrations) for specific reentry activities (see Section 4.5)	

[a] This guidance does not address or impact site cleanups occurring under other statutory authorities such as the United States Environmental Protection Agency's (EPA) Superfund program, the Nuclear Regulatory Commission's (NRC) decommissioning program, or other federal or state cleanup programs.

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

[c] Projected dose refers to the dose that would be received, by default, in the absence of shielding from structures or the application of dose reduction techniques. These PAGs may not provide adequate protection from some long-lived radionuclides (see Section 4.4). Incident-specific factors should be considered.

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

[e] For more information on food and animal feeds guidance, the complete FDA guidance (FDA 1998) may be found at http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM094513.pdf.

[f] For extensive technical and practical implementation information please see "Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident" (DOE 2009).

4.2.1 Removal of the 50 Year Relocation PAG

For simplicity, the 1992 relocation PAG of 5 rem (50 mSv) over 50 years has been removed from this Manual. It is rarely, if ever, the driver for extending a relocation area beyond that prompted by the first or second year relocation PAGs in scenarios that have been analyzed. Additionally, dose projections over 50 years after a radiological incident for various age groups show no significant differences for individuals exposed at 3 months of age versus adult. A response organization may wish to project 50-year doses to inform decision-making, but should consider weathering, decay, credit for time spent indoors, and to the extent it can be predicted, dose reduction from mitigation activities. To keep emergency management decisions as simple as possible, the recommended relocation PAGs are 2 rem (20 mSv) projected over the first year, and 0.5 rem (5 mSv) projected over any subsequent year.

4.2.2 The Population Affected

The PAGs for relocation are intended for use in establishing the boundary of a relocation area within an area where radioactive materials have been deposited. The relocation PAGs have been established at a level that will provide adequate protection for the general population, including higher risk groups such as children and fetuses. People residing in contaminated areas outside the relocation area will be at some risk from radiation dose. Therefore, guidance on the reduction of dose during the first year to residents outside this zone is also provided. Monitoring and simple dose reduction efforts are recommended in these areas to reduce doses to the extent practical. Such actions are unlikely to be practical where the dose reduction achieved is less than 10 percent.

Affected populations may perceive that intermediate phase protective actions are not consistent with those taken in the early phase. Early-phase decisions on sheltering-in-place and evacuation may have been implemented prior to verification of the path of the plume. Therefore, some people may have been evacuated from areas where validated doses are much lower than were projected. Others who were in the path of the plume may have been sheltered or not protected at all. During the intermediate phase of the response, dose projections may be revised based on environmental measurements. People should be relocated from areas where the projected dose exceeds the PAG for relocation without regard to prior evacuation status.

4.2.3 Areas Involved

Figure 4-1 provides a generalized example of the areas affected by different protective actions. Area 1 represents the plume deposition area. (In reality, variations in meteorological conditions would almost certainly produce a more complicated shape, but the same principles would apply.)

In situations such as an NPP accident, where early warning is given prior to a release of radioactive materials, people may already have been evacuated from Area 2 and sheltered in Area 3. People who have been evacuated from Area 2 or sheltered in Area 3 may go home if environmental monitoring verifies that their residences are outside the plume deposition area (Area 1).

Area 4 is the relocation area where projected doses are equal to or greater than the relocation PAG. People residing just outside the boundary of the relocation area may receive a dose approaching the PAG for relocation if decontamination or other dose reduction efforts are not implemented.

Area 1, with the exception of the relocation area, represents the area of contamination that may continue to be occupied by the general public during the intermediate phase. Nevertheless, there will be contamination levels in this area that will require continued monitoring and dose reduction efforts other than relocation. Incident-specific levels below the PAGs may be used to control exposure to contamination. The relative positions of the boundaries shown in Figure 4-1 depend on areas evacuated and sheltered and the radiological and meteorological characteristics of the release. For example, Area 4 (the relocation area) could fall entirely inside Area 2 (area evacuated), so that the only people to be

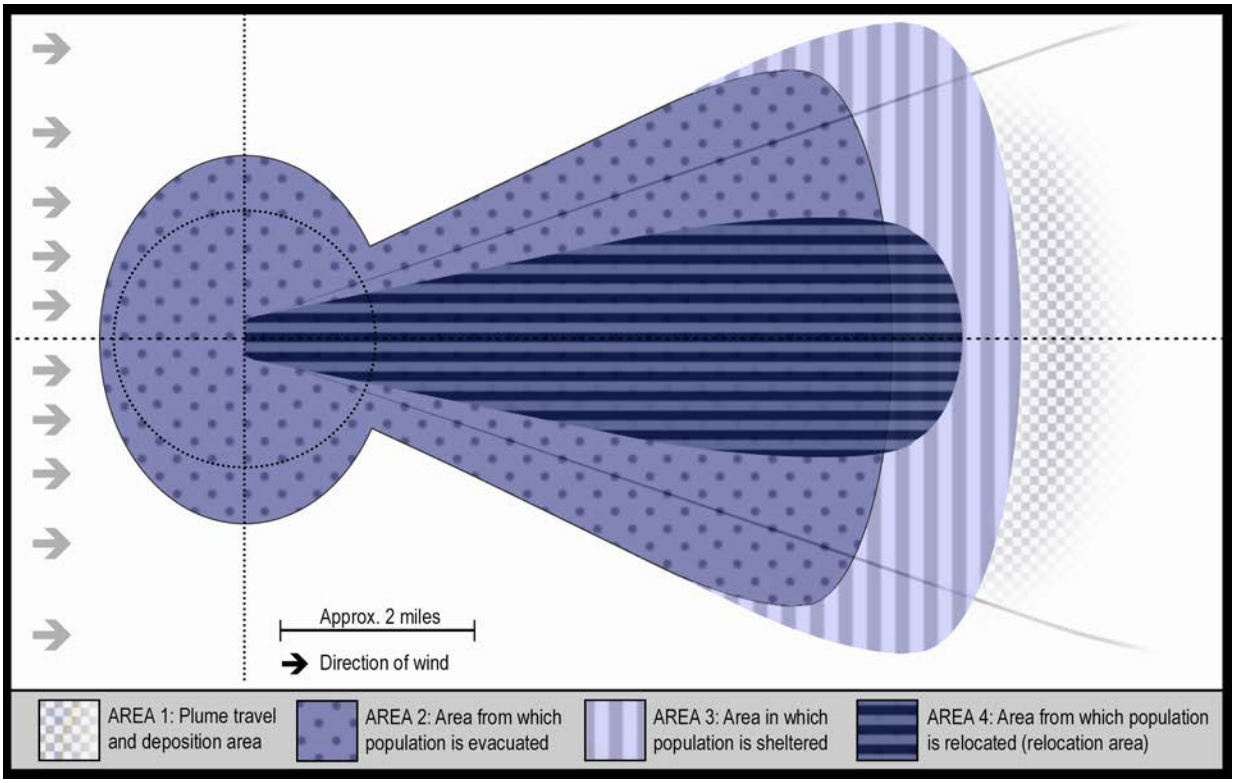
relocated would be those residing in Area 4 who were either missed in the evacuation process or who, because of mobility constraints for their evacuation, had remained sheltered-in-place during plume passage.

Establishing the boundary of a relocation area creates three groups of affected people—

- People who have already been evacuated from an area that is now designated as a relocation area and who now must be assigned relocation status.
- People who were not previously evacuated, but who reside inside the relocation area and should now relocate.
- People who were previously evacuated, but reside outside the relocation area and may now return home. A staged and deliberate return is recommended.

Small adjustments to the boundary of the relocation area established based on the PAG may be justified based on ease of implementation. For example, the use of a convenient natural boundary could be a logical reason for adjustment of the relocation area. However, such decisions should be supported by demonstration that exposure rates to people not relocated can be promptly reduced by methods other than relocation to meet the PAG, as well as the longer-term dose guidelines addressed in Section 4.4.

Figure 4-1. Generalized Protective Action Areas for NPP Incident



The relocation PAGs apply principally to personal residences but may impact other facilities as well. For example, it could impact work locations, hospitals and park lands as well as the use of highways and other transportation facilities. For each type of facility, the occupancy time of individuals should be taken into account to determine the criteria for using a facility or area. It might be necessary to avoid continuous use of homes in an area because radiation levels are too high. However, a factory or office building in the same area could be used because occupancy times are shorter. Similarly, a highway could be used at

higher contamination levels because the exposure time of highway users would be considerably less than the time spent at home.

4.2.4 Priorities

In most cases, protective actions during the intermediate phase will be carried out over a relatively long period of time (e.g., months). Setting priorities will be important, especially when the affected area is so large that it is impractical to relocate members of the public from areas that barely exceed the relocation PAGs. The following priorities are appropriate—

- First, protect all people from doses that could cause acute health effects from all exposure pathways, including previous exposure to the plume.
- Conduct radiological surveys to verify or adjust estimates of radiological impacts.
- Recommend that affected people reduce their exposures by using simple decontamination techniques and remaining indoors.

4.3 SEQUENCE OF EVENTS

The high-priority decisions on whether to relocate people from high exposure rate areas requires exposure rate measurements and dose analyses. Monitoring and dose assessment will be an ongoing process, with priority given to the areas with the highest exposure rates.

Following passage of the airborne plume, a number of tasks must be accomplished for the timely protection of the public. The general sequence of events is itemized below, but the time frames will overlap.

1. Determine the areas where the projected first-year dose will exceed the 2 rem (20 mSv) relocation PAG and relocate people from those areas, with priority given to people in the highest exposure rate areas.
2. Allow previously evacuated people to return as quickly as possible to areas where field measurements indicate that exposure rates are near normal background levels. If there is a possibility that particles from high deposition areas could drift into the occupied areas, establish a buffer zone to restrict residential use until radiological measurements and assessments confirm that it is no longer necessary. Buffer zones are set with the understanding that conservatism is inherent in the PAGs.
3. Based on isodose-rate boundary (see Section 4.3.1), assign any evacuees who reside within the relocation area to be relocated. Evacuated people whose residence is in the area between the boundary of the plume deposition and the boundary to the relocation area may return gradually as dose projections allow.
4. Evaluate the dose reduction effectiveness of simple decontamination techniques and of sheltering-in-place in response to exposure from partial occupancy of residences and workplaces. Results of these evaluations may influence recommendations for reducing exposure rates for people who are not relocated from areas near, but outside, the relocation area.
5. Control access to and egress from the relocation area. This would be accomplished through control points at roadway accesses to the relocation area.
6. Establish monitoring and decontamination stations to support control of the relocation area.
7. Implement simple decontamination techniques in contaminated areas outside the relocation area, giving priority to areas with higher exposure rates.
8. Collect data needed to establish long-term radiation protection criteria for decontamination and dose reduction and data to determine the effectiveness of various decontamination or other dose reduction techniques.
9. Begin operations to clean up and recover contaminated property in the relocation area.

10. If not already done, evaluate whether foods grown or produced within the plume deposition area need to be interdicted per the FDA PAGs and evaluate drinking water systems within the plume deposition area. Provide guidance on planting or harvesting specific agricultural products.

4.3.1 Establishment of Isodose-Rate Lines

As soon as federal or other assistance is available for aerial and ground monitoring, a concentrated effort should begin to establish isodose-rate lines on maps and identify boundaries of the relocation area. Standard maps should be developed on which all response organizations would record monitoring data. Records on monitoring and decontamination of the public and workers should also be collected.

Aerial monitoring can be used to collect data for establishing general patterns of radiation exposure rates and may form the primary basis for the development of dose lines out to the limit of aerial detectability.

Initially during the early phase, detectability is limited to exposure rate changes of a few times natural background levels. Later during the intermediate phase, more sensitive measurements detect levels of radioactivity that are a small fraction of the natural background. Periodic air sample measurements will also be needed to verify the contribution to dose from inhalation of resuspended materials.

Gamma exposure rates measured at approximately three feet (one meter) will vary within a very small area because different surfaces have different deposition rates (e.g., smooth surfaces versus heavy vegetation). Rinsing or precipitation could also reduce levels in some areas and raise levels in others (e.g., where runoff settles). In general, where exposure rates vary within designated areas, dose projections should be estimated using an appropriate average exposure rate.

4.3.2 Dose Projections

The FRMAC Assessment Manuals[32] provide detailed guidance for dose projection and calculating DRLs and DPs. The FRMAC Assessment Manuals incorporate the ICRP dosimetry models (currently the ICRP 60 series). In addition, the FRPCC encourages the use of computational tools such as DOE's Turbo FRMAC and NRC's RASCAL or other appropriate tools and methods to implement the PAGs.

The primary dose of interest in the intermediate phase is the sum of the effective dose from external exposure and the committed effective dose from inhalation. The exposure periods of interest are the first year and subsequent years after the incident. Other pathways should also be evaluated and their contributions considered, if significant. For example, any time alpha-emitting radionuclides are involved, the inhalation of resuspended material must be considered. Although beta exposure will contribute to skin dose, its contribution to the overall risk of health effects from the radionuclides expected to be associated with reactor incidents should not be controlling in comparison to the whole body gamma dose (Aaberg 1989). However, the skin beta dose may be important for particulates deposited or transferred to the skin, as may be the case for an RDD that contains Strontium-90.

The dominant intermediate phase exposure pathway for incidents involving alpha-emitters (e.g., a weapons accident) is inhalation of resuspended material. For these incidents, dispersal of alpha-emitting material must be monitored carefully using proper measurement techniques. It is possible that there will be little or no associated gamma radiation or beta activity.

Calculation of the projected gamma dose from measurements will require knowledge of the principal radionuclides contributing to exposure and their relative abundances. Radiological characteristics can be compiled either through the use of portable gamma spectrometers or by radionuclide analysis of environmental samples. Several measurement locations may be required to determine whether any selective radionuclide deposition occurred as a function of meteorology, surface type, distance from the

[32] See FRMAC Assessment Manuals at http://nnss.gov/pages/programs/FRMAC/FRMAC_DocumentsManuals.html.

point of release, or other factors. In accordance with the "Nuclear Radiological Incident Annex to the National Response Framework," DOE, EPA and other federal agencies have the capability to assist state officials in performing environmental measurements, including determination of radiological characteristics of deposited materials (FEMA 2008b).

The gamma exposure rate may decrease rapidly if deposited materials include a significant fraction of short-lived radionuclides. Therefore, the relationship between instantaneous exposure rate and projected first- and second-year annual doses will change as a function of time. These relationships must be established for the particular mix of deposited radioactive materials present at the time of the gamma exposure rate measurement. Over time, residual doses from gamma emitters will depend largely upon the half-lives of the radionuclides involved and could potentially remain significant over many years. It should be noted that natural attenuation as well as nuclear decay can affect long-term dose assessments.

Because intermediate phase public protection decisions (e.g., relocation, reentry) have less urgency than early phase decisions and the contamination is better characterized in the intermediate phase, it may be possible to improve the public protection decisions by modifying dose estimates with more realistic inputs. For example, the external dose reductions provided by building structures and dose reductions resulting from partial occupancy in the contaminated zone, which accounts for routine time spent outside the contaminated zone (e.g., work, school, shopping), may be included in the dose projections to make improved public protection decisions.

Projected dose considers exposure rate reduction from radioactive decay and, generally, weathering. When one also considers the anticipated effects of shielding from normal part time occupancy in homes and other structures, people who are not relocated are likely to receive a dose substantially less than the projected dose. For commonly assumed reactor source-terms, it is estimated that 2 rem (20 mSv) projected dose in the first year will be reduced to about 1.2 rem (12 mSv) by this factor. The application of simple decontamination techniques shortly after the incident can be assumed to provide a further 30 percent or more reduction so that the maximum first year dose to people who are not relocated is expected to be less than 1 rem (10 mSv). Taking account of decay rates assumed to be associated with releases from NPP incidents (SNL 1982) and shielding from partial occupancy and weathering, a projected dose of 2 rem (20 mSv) in the first year is likely to amount to an actual dose of 0.5 rem (5 mSv) or less in the second year. The application of simple dose reduction techniques would reduce the dose further. Calculations supporting these projections are summarized in Table E-6 of the 1992 PAG Manual.[33]

Keeping below the 0.5 rem (5 mSv) PAG for subsequent years—the second year and beyond—may be achieved through natural decay of shorter half-life radioisotopes, through decontamination efforts, or through other means of controlling public exposures (such as limiting access to certain areas). In the case of an RDD, in which a longer half-life radioisotope would likely be utilized, reductions in dose may prove difficult to achieve without longer-term measures (see Chapter 5).

Exposure from ingestion of food and water is considered independently of decisions for relocation and decontamination. In rare instances, however, where withdrawal of food or water from use would pose a health risk in itself, relocation may be an appropriate protective action against exposure via ingestion. In this case, the dose from ingestion should be considered along with the projected dose from other exposure pathways for decisions on relocation.

4.3.3 Projected External Gamma Dose

Projected whole body external gamma doses at approximately three feet (one meter) height at particular locations during the first year and second year after the incident are the parameters of interest (DOE

[33] The 1992 PAG Manual is available as a historical reference online at: http://www.epa.gov/radiation/protective-action-guides-pags.

1988). Measurements made at 1 meter to project whole body dose from gamma radiation should be made with instruments of the "closed window" type to avoid the detection of beta radiation. The environmental information available for calculating these doses is expected to be the current gamma exposure rate at 1 meter height and the relative abundance of each radionuclide contributing significantly to that exposure rate. Calculation models are available for predicting future exposure rates as a function of time with consideration of radioactive decay and weathering.

Relocation decisions can generally be made on the basis of the first year projected dose. However, projected doses during the second year are needed for decisions on protective actions for people who are not relocated. Conversion factors are therefore needed to convert environmental measurements to projected dose during the first year and second year following the incident (see FRMAC Assessment Manuals).[34] Of the many types of environmental measurements that can be made to project whole body external gamma dose, gamma exposure rate in air is the easiest to make and is the most directly linked to gamma dose rate. However, analyses of a few environmental samples (particularly soil samples) must be coupled with the gamma exposure rate to properly project decreasing dose rates.

In addition, measurements should be conducted to determine the dose reduction factors associated with simple, rapid, decontamination techniques so that these factors can be used in calculating dose to people who are not relocated. However, assumptions about these factors should not be included in calculating projected dose for decisions on relocation. Only dose reductions already accomplished should be considered.

4.3.4 Exposure Limits for People Reentering the Relocation Area

After the relocation area is established, people will need to reenter for a variety of reasons, including recovery activities, retrieval of property, security patrol, operation of vital services and, in some cases, care and feeding of farm and other animals. It may be possible to quickly decontaminate access ways to vital institutions and businesses in certain areas so that they can be occupied by adults either for living (i.e., institutions such as nursing homes and hospitals) or for employment. Clearance for occupancy of such areas will require dose reduction to meet exposure limits (EPA 1987b). Dose projections should include both external exposure from deposited material and inhalation of resuspended deposited material for the duration of the planned exposure. People working in areas inside the relocation area should operate under the controlled conditions established for occupational exposure (EPA 1987b). The emergency worker dose limitation does not need to include ongoing doses received from living in a contaminated area outside the relocation area. It is also not necessary to consider dose received previously from the plume or groundshine during the early phase of the radiological incident. See the Reentry Matrix in Section 4.5, Table 4-2. It provides a quick reference for public and emergency worker dose guidelines and considerations for decontamination ongoing during this phase.

4.4 LONGER-TERM OBJECTIVES OF THE PROTECTIVE ACTION GUIDES FOR THE INTERMEDIATE PHASE

It is an objective of the PAGs to ensure that doses in any single year after the first year will not exceed 0.5 rem (5 mSv). For source terms from NPP incidents, the PAG of 2 rem (20 mSv) projected dose in the first year is expected to meet this longer-term objective through radioactive decay, weathering, and normal part-time occupancy in structures. If the release contains long-lived radionuclides, decontamination of areas outside the relocation area may be required during the first year to meet these objectives. For situations where it is impractical to meet these objectives through decontamination, relocation should be considered even if the projected first-year dose is lower than the relocation PAG.

[34] See FRMAC Assessment Manuals at http://nnss.gov/pages/programs/FRMAC/FRMAC_DocumentsManuals.html.

Based on the relocation PAGs, reentry guidance can be found in the Reentry Matrix in Section 4.5, as well as in the "Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident" (DOE 2009),[35] referred to as "Operational Guidelines." After the population has been protected in accordance with the PAGs for relocation, reoccupancy of the relocation areas should be governed on the basis of cleanup criteria and late phase cleanup activities should proceed. Refer to the Operational Guidelines manual for more information on how to implement the reentry guides in emergency plans.

4.5 REENTRY MATRIX FOLLOWING A RADIOLOGICAL INCIDENT OR ACCIDENT

During the intermediate phase, people will need to enter the relocation area to collect their belongings, maintain or repair critical infrastructure, and to work on preliminary recovery activities. The Reentry Matrix in Table 4-2 provides a quick reference for public and worker dose guidelines and considerations for decontamination ongoing during this phase.

The "Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident" (DOE 2009), referred to as "Operational Guidelines," includes detailed numeric guidance, developed by a multi-agency working group as a follow-up to the RDD/IND Planning Guidance (DHS 2008). That work focused specifically on response and recovery for an RDD event; however, that work can be expanded to include isotopes from a variety of incident types.

The Operational Guidelines are informative for this guidance, specifically the discussions about applicable dose-based limits, timeframes and pathways of exposure related to reentry tasks. The term reentry is used for emergency workers and members of the public going into radiologically contaminated areas, temporarily, under controlled conditions. Food and agriculture guides use FRMAC methods and models as well as the Operational Guidelines for implementation. These tools allow derivation of decontamination thresholds for the early and intermediate stages of a response.

As part of the U.S. response to the Japanese Fukushima accident, scientists performed dose calculations to ensure that passengers and workers on train trips through contaminated areas do not exceed doses typically received from cosmic radiation during an international flight. DOE's Argonne National Laboratory scientists utilized the RESRAD-RDD tool and hand calculations to approximate doses from the NPP radionuclides.[36]

[35] The Operational Guidelines were developed by federal agencies and published by DOE in February 2009, DOE/HS-0001; ANL/EVS/TM/09-1, online at http://web.ead.anl.gov/resrad/documents/ogt_manual_doe_hs_0001_2_24_2009c.pdf. (DOE 2009)
[36] RESRAD Family of Codes; Environmental Science Division of Argonne National Laboratory, online at https://web.evs.anl.gov/resrad.

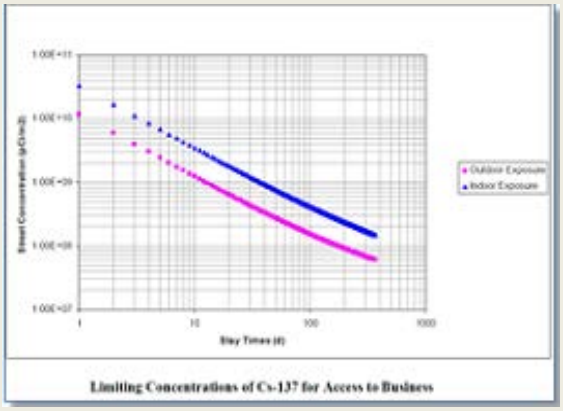
Table 4-2. Reentry Matrix: Quick Reference to Operational Guidelines[a]

PHASE	ACTIVITY	SUGGESTED LEVELS	CLEANUP ACTIONS[b]
Early Phase	**Sheltering or Evacuation for the Public**	**Public**: 1-5 rem (10-50 mSv) projected over four days (see Chapter 2). A decision to evacuate weighs anticipated dose against feasibility of evacuating within a determined time frame, along with the risks associated with the evacuation itself.	It is too early for organized cleanup, due to chaos of the situation and higher priorities such as lifesaving activities and clearly identifying shelter and evacuation zones. Any cleanup or decontamination information should focus on personal decontamination. It is doubtful any large-scale effort could change evacuation or shelter recommendations during this period (first 4 days). Once evacuation is completed, there are simple actions that cities can implement themselves: rinsing roofs and streets, street sweeping. The objective of these actions is to move the bulk amounts of contamination away from occupied areas or areas where reoccupation is a priority. These actions should be based on measured amounts of contamination and priority of the location. Workers may face high dose levels and will need health physics support.
	Emergency Worker Protection	**Emergency Worker**: 5/10/25 rem (50/100/250 mSv) incurred over the response duration. The higher limits are based on task (e.g., protecting large populations or critical infrastructure or lifesaving). Emergency worker doses will be tracked with dosimeters. Emergency workers have knowledge of the risks associated with radiation exposure, training to protect themselves, and dosimeters to track their doses (see Chapter 3).	
Inter-mediate Phase	**Relocation for the Public**	**Public**: 2 rem (20 mSv) projected first year, 0.5 rem (5 mSv) per year projected in subsequent years (see Chapter 4). In this phase, scientists run dose calculations with RESRAD-RDD or Turbo FRMAC; the user can choose sensitive age groups, or enter lower guidelines, if desired. Additionally, local decision-makers can adapt the guidelines with incident-specific considerations and implement variations as needed.	Early cleanup efforts should focus on the removable portion of the contamination: vacuuming, washing, vegetation removal. ▪ Vacuuming has the advantage of collecting removable contamination without water or surface impact, but is limited by equipment availability and can also expose the operators to high dose levels as the vacuums collect the contamination. ▪ Washing and rinsing are simple to implement, but only move the contamination to less-populated areas and may move contamination deeper into porous surfaces. ▪ For unpaved areas, vegetation removal can effectively reduce the amount of contamination present, but is labor intensive and can produce a large amount of waste.

Table 4-2. Reentry Matrix: Quick Reference to Operational Guidelines[a]

PHASE	ACTIVITY	SUGGESTED LEVELS	CLEANUP ACTIONS[b]
Intermediate Phase	**Reentry For Use of Critical Infrastructure**	**Public**: 2 rem (20 mSv) in first year (Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident,[c] *Operational Guidelines Group C*). Dosimeters could be considered for the public.	Having addressed the removable part of the contamination, later efforts can focus on fixed contamination. ▪ Paved surface removal is very effective, but requires specialized equipment and trained operators. ▪ Surface sealing is easier, but leaves the contamination in place, making it viable only in locations where the dose rates are low enough for occupation, or in low-occupancy areas. ▪ Repaving roads, lots and other paved surfaces is easy to implement, but can generate significant waste volumes. ▪ Unpaved areas can be further remediated by soil skimming (surface removal), deep plowing (turning the top foot or so of soil over), and appropriate chemical soil amendment methods like liming or chelating. As the intermediate phase progresses, knowledge and experience increases and these methods can be re-applied, refined or customized for problem areas. Decisions about more difficult areas will benefit from professional judgment, additional analyses, and application of more sophisticated technologies.
	Emergency Worker Protection	**Emergency Worker Protection**: (dose not to exceed) 5 rem (50 mSv) per year (*Radiation Protection Guidance to Federal Agencies for Occupational Exposure*, EPA 1987). Emergency workers have knowledge of the risks associated with radiation exposure, training to protect themselves, and dosimeters to track their doses (see Chapter 3). During an incident response, workers (police, waste handlers) needed in contaminated areas could be trained and given dosimeters. The guidance for emergency workers applies throughout the response.	
	Reentry For Use of Roads and Walkways	**Public**: 2 rem (20 mSv) first year, 0.5 rem (5 mSv) per year in subsequent years (*Operational Guidelines, Group E*). While the dose values here are similar to those for Use of Critical Infrastructure above, the derived concentrations measured as triggers are different because the exposure conditions are different.	

Table 4-2. Reentry Matrix: Quick Reference to Operational Guidelines[a]

PHASE	ACTIVITY	SUGGESTED LEVELS	CLEANUP ACTIONS[b]
Inter-mediate Phase	**Reentry** For Access to the Relocation Zone *"Stay time" is a term of art used in the radiation safety field. Stay times are the amount of time a person may access the contaminated area. These times vary based upon site-specific factors or incident character-istics such as indoor or outdoor work, sensitive populations, and level of radioactivity.*	**Public**: 0.5 rem (5 mSv) over one year for temporary access with stay times (see definition below) dependent on reentry tasks and site-specific conditions (*Operational Guidelines, Group D*). Section 7.1 of the Operational Guidelines, "Worker Access to Businesses for Essential Actions," provides tables and graphs of stay times at various limiting concentrations (see adjacent graph and table). For example, if the maximum surface street concentration of Cesium-137 is 3.00E+09 pCi/m^2 (1.11E+08 Bq/m^2), people limited to 0.5 rem (5 mSv) should be in the contaminated area less than four 8-hour days if staying outdoors. This may apply to individuals retrieving belongings from homes or to workers providing security patrols, or even to people reopening businesses in the area. As contamination levels are reduced during cleanup, stay times can be extended and total doses reduced.	These graphics below are examples based on Operational Guidelines.[c] Please refer to the full report for tables and graphics for use in emergency preparedness.  **Operational Guidelines for 0.5 rem Annual Dose: Residents Access to Houses (Indoor Exposure)** Surface Street Concentration (pCi/m^2) Radionuclide / 1 Day / 4 Days / 12 Days Am-241 7.51E+07 2.86E+07 1.59E+07 Cf-252 3.50E+08 1.32E+08 7.13E+07 Cm-244 1.27E+08 4.82E+07 2.68E+07 Co-60 2.72E+09 6.87E+08 2.33E+08 Cs-137 1.14E+10 2.94E+09 1.01E+09 Ir-192 9.93E+09 2.54E+09 8.92E+08 Po-210 1.17E+09 3.86E+08 1.74E+08 Pu-238 6.56E+07 2.50E+07 1.39E+07 Pu-239 6.01E+07 2.29E+07 1.27E+07 Ra-226 6.08E+08 2.10E+08 9.97E+07 Sr-90 2.48E+10 7.70E+09 3.18E+09

Operational Guidelines provide stay times and concentrations for several different sets of assumptions about the exposure. Residents retrieving possessions may spend most of their time indoors, where stay times are longer than they are for outdoor tasks. Stay time recommendations can be used to guide decisions about allowing entry into the contaminated area for a limited time and dose reduction techniques like wearing dust masks, cleaning shoes and car tires upon exit, and using time wisely to keep radiation exposure "ALARA" below the Operational Guideline.

[a] This guidance does not address or impact site cleanups occurring under other statutory authorities such as the United States Environmental Protection Agency's (EPA) Superfund program, the Nuclear Regulatory Commission's (NRC) decommissioning program, or other federal or state cleanup programs.

[b] This cleanup process does not rely on and does not affect any authority, including the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 42 U.S.C. 9601 et seq. and the National Contingency Plan (NCP), 40 CFR Part 300. This document expresses no view as to the availability of legal authority to implement this process in any particular situation.

[c] The Operational Guidelines were developed by federal agencies and published by DOE in February 2009, DOE/HS-0001; ANL/EVS/TM/09-1, online at http://web.ead.anl.gov/resrad/documents/ogt_manual_doe_hs_0001_2_24_2009c.pdf. (DOE 2009)

4.6 PROTECTIVE ACTION GUIDANCE FOR FOOD AND DRINKING WATER

Information on food and animal feeds protective action guidance is contained in FDA's "Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies" (FDA 1998).

EPA developed a new drinking water PAG as non-regulatory guidance to protect the public in the event of a radiological incident that affects drinking water supplies. The drinking water PAG will help federal, state, local and public water system officials make decisions about use of water during radiological emergencies.

The drinking water PAG is for use only during an emergency; it is not a substitute for compliance with EPA's National Primary Drinking Water Regulations (NPDWRs) for Radionuclides. EPA expects that any drinking water system adversely impacted during a radiation incident will take action to return to compliance as soon as possible.

4.6.1 Protective Action Guide for Drinking Water

The purpose of the protective action for the drinking water exposure pathway is to restrict the use of contaminated water for drinking and to provide recommendations for local communities to consider in providing alternative drinking water for the affected community during a nationally significant radiological incident, such as a disaster at a nuclear power plant, an RDD or an IDD. The drinking water PAGs apply during the intermediate phase of an incident, which may last for weeks to months but not longer than one year.[37] This guidance only provides recommendations and does not confer any legal rights or impose any legally binding requirements upon any member of the public, states, or any other federal agency.[38]

EPA recommends a two-tier drinking water PAG for use during the intermediate phase following a nationally significant radiation incident: 500mrem (5 mSv or 0.5 rem) projected dose[39] for the general population (defined as anyone over age 15, excluding pregnant women and nursing women), and 100 mrem (1 mSv or 0.1 rem) projected dose for pregnant women, nursing women, and children age 15 and under.[40]

This guidance does not in any way affect public water systems' compliance obligations under applicable NPDWRs promulgated under the Safe Drinking Water Act (SDWA). EPA expects that the responsible party for any drinking water system adversely impacted during a radiation incident will take action to return to compliance with SDWA maximum contaminant levels (MCLs) as soon as practicable. The drinking water PAG provides a level of protection for the general population consistent with PAGs currently in place for other media in the intermediate phase (i.e., the FDA's 500 mrem PAG for ingestion of food; FDA 1998, FDA 2004) and provides an additional level of protection for the most sensitive life stages. Intermediate phase doses can be projected using a 1-year duration and compared to the PAG so

[37] The intermediate phase is defined as the period beginning after the source and releases have been brought under control (has not necessarily stopped but is no longer growing) and reliable environmental measurements are available for use as a basis for decisions on protective actions and extending until these protective actions are no longer needed. The intermediate phase includes protective action recommendations for relocation of the public, worker exposure, reentry, food interdiction, and water interdiction.

[38] This guidance does not address or impact actions occurring under other statutory authorities such as the United States Environmental Protection Agency's (EPA) Superfund program, the Nuclear Regulatory Commission's (NRC) decommissioning program, or other federal or state programs. As indicated by the use of non-mandatory language such as "may," "should" and "can," this guidance only provides recommendations and does not confer any legal rights or impose any legally binding requirements upon any member of the public, states, or any other federal agency.

[39] All dose values are expressed as Committed Effective Dose projected over a person's lifetime based on one year of intake.

[40] Emergency management officials may consider whether it is appropriate to extend the lower tier to individuals beyond age 15 or to women who are trying to get pregnant or who believe they might be pregnant.

that actions can be taken to avoid the exposure. PAG levels were calculated based on a maximum 1-year exposure and provide a level of protection roughly equivalent to applicable NPDWRs for radiation, which are based on 70 years of exposure.

The FDA food PAG (FDA 1998) and the drinking water PAG are designed to complement each other, and allow emergency response officials to account for and address doses from both eating contaminated food and drinking contaminated water. The food ingestion and drinking water pathways are inherently related because both address exposure through ingestion. In addition, water may be used in the preparation of some food products, and radionuclides in water may affect crops and ultimately enter the food supply. The FDA food PAG accounts for water intrinsic in food as purchased and EPA's water PAG accounts for drinking water, including water added to foods during preparation.[41]

PAGs for both food and drinking water are needed because a radiological incident may affect the food supply and drinking water differently. In addition, because drinking water is usually locally controlled and food is frequently shipped in from distant locations, different and separate interdiction approaches would be appropriate. Finally, the various PAGs are designed to work in concert, allowing emergency responders to choose the exposure reduction strategies that match the exposure scenario, community needs, and resources available in the particular emergency.

While food safety and drinking water personnel would work closely together in a radiological response, the authorities related to food and drinking water safety are separate, and different strategies may be needed to protect drinking water and the food supply.

A PAG is intended as a point of reference to aid emergency response managers in their decision-making. After an emergency situation stabilizes and becomes more clearly defined, local authorities may wish to modify the PAG level they consider to be appropriate in order to implement longer-term dose reduction strategies. EPA expects that the responsible party for any drinking water system adversely impacted during a radiation incident will take action to return to compliance with SDWA MCLs as soon as practicable.

Should a major radiological event occur, emergency response officials should consider potential doses from all affected pathways (e.g., airborne plume, ground contamination, drinking water, foods) when making protective action decisions. The drinking water PAG is focused solely on drinking water exposures and does not take into account other exposure pathways; decision makers may want to adjust to account for cumulative doses (see Section 1.4.3). Consideration of the specific conditions facing a community should be used in determining how each PAG should be implemented. Protective actions might include restrictions on consumption of garden produce or locally produced foods, or an embargo on sales of certain products, as well as drinking water actions described in Section 4.6.5 of this guidance. Local decision makers will need to determine the appropriate protective actions depending on projected dose. Guidance in this Manual is intentionally flexible to allow the many different potential protective actions to be tailored to the specific risks that must be addressed.

Section 4.6.6 explains how to calculate Derived Response Levels (DRLs) for radionuclides likely to appear in drinking water following a radiological contamination incident.[42] DRLs are concentrations of radionuclides in drinking water that correspond to EPA's recommended PAGs of 100 mrem and 500 mrem. DRLs are essential because a PAG identifies a radiation dose rather than a quantity of radionuclides that can be measured directly in drinking water. DRLs are expressed in units of picocuries per liter (pCi/L) or becquerel per liter (Bq/L), and can be directly compared to measured radionuclide

[41] Liquid beverages as well as milk are covered under the FDA food PAG (FDA 1998).

[42] EPA selected I-131, Sr-90/Y-90, and Cs-137 as indicator isotopes likely to appear in water following a radiation contamination incident, and these were selected based on previous documented experience. However, DRLs can be calculated for different isotopes by using dose conversion factors included in Federal Guidance Report #13 (EPA 1999).

concentrations in finished drinking water. In most situations, by the intermediate phase, responders will have enough information about the source of radiation to develop site-specific DRLs. In the absence of information about local emissions sources and isotopes, particularly in the early phase, EPA recommends using conservative assumptions to fill information gaps, which might include assuming no decay of isotopes over the calculated 1-year exposure period, to guide actions to protect the public in the event of a major radiological incident that affects drinking water sources.

4.6.2 Factors EPA considered when establishing the drinking water PAG

Section 1.3.2 of this PAG manual provides the following three principles for establishing PAGs.

1. Prevent acute effects.
2. Balance protection with other important factors and ensure that actions result in more benefit than harm.
3. Reduce risk of chronic effects.

EPA crafted the drinking water PAG with these same principles in mind. Specifically, consideration was given to the acute effects of exposure to radiation and lifetime risk of cancer based on age and drinking water intake. EPA made use of the risk conversion factors set forth in Federal Guidance Report #13 (EPA 1999) and considerations of risk to the unborn set forth in NCRP Report No. 174 (NCRP 2013).

The drinking water PAG was developed based on reducing risks associated with ingesting drinking water contaminated with radionuclides. EPA also considered the potential radiation dose people could receive from various other uses of contaminated water, including showering, bathing, and dishwashing. In the United States, people typically shower, bathe, and wash dishes using the same source of water that they use to drink, but, for the radionuclides of interest, dermal and inhalation exposures from these activities generally represent much smaller risk than drinking contaminated water. Protection of a community's drinking water supply based on assumptions about ingestion will also protect the population from undue risk from contaminated drinking water by other routes of exposure.

4.6.3 Rationale for a two-tier Drinking Water PAG

The two-tier PAG consists of 500 mrem (5 mSv or 0.5 rem) for the general population, and a more stringent PAG of 100 mrem (1 mSv or 0.1 rem) to inform protective actions for pregnant women, nursing women, and children age 15 and under. Fetuses, infants and children are at greater risk from radiological exposures than adults due to the greater sensitivity of the developing body to the potential harmful effects of radiation and the longer dose commitment period for the longer-lived radionuclides that clear slowly from the body. A newborn that ingests radioactive material in water (e.g., through formula) would be expected to be subject to the effects of that radiation for a longer period of time than if the same dose was experienced by an adult.

For the sake of establishing clear and executable decisions in the intermediate phase of emergency response, EPA recommends a uniform PAG for fetuses, infants and children, even though there may be considerable differences in the transmission of radiological drinking water contaminants to a fetus via the placenta, to an infant via formula or breast milk, and to a child via direct consumption. Specifically, we have developed a PAG level designed to provide additional protection to the most sensitive of the three subgroups from exposure to radioactivity in drinking water following a radiological incident. Keeping PAGs relatively simple helps to minimize confusion during their implementation; however, federal, state, and local officials should consider resource availability as they determine when and how to apply either of these guidelines.

The PAG of 500 mrem (5 mSv or 0.5 rem) for the general population is designed to be used in concert with the FDA food PAG (FDA 1998) since many of the considerations for a food PAG also apply to drinking water. It is also consistent with the guidance value of 500 mrem over one year established by the

DHS as an intermediate-phase PAG for drinking water interdiction (DHS 2008). A PAG of 100 mrem (1 mSv or 0.1 rem) for the most sensitive members of the population provides them with a significant additional protection from exposure to radioactivity in drinking water following a radiological incident.

4.6.3.1 Other Standards

NRC regulations (i.e., 10 CFR Part 20.1301) have established a public radiation protection standard of 100 mrem per year effective dose. The ICRP recommends reference levels in the range of 2,000 to 10,000 mrem (20 to 100 mSv) for protection of human health in emergencies, and in the range of 100 to 2,000 mrem (1 to 20 mSv) for occupational exposure, exposure by caregivers, or residential radon exposure (ICRP 2007). Based on a risk reduction approach, EPA recommends that the drinking water PAGs be set at the lower (more stringent) end of the latter range to ensure protection of public health.

Under the SDWA, EPA established MCLs for radiological contaminants in drinking water. The NPDWR for Radionuclides, set forth in 40 CFR Part 141, effectively adopted a dose-based limit of 4 mrem per year for beta particle and photon radioactivity. These requirements are based on lifetime exposure criteria, which assume 70 years of continued exposure to contaminants in drinking water. EPA determined that it may not be possible to base protective actions during short-term emergency incidents on lifetime exposure criteria. While the SDWA framework is appropriate for day-to-day normal operations, it does not provide the necessary tools to assist emergency responders with determining the need for prioritizing protective actions during the intermediate phase of a response. However, regardless of the cause of an incident, EPA expects that actions will be taken to return the impacted drinking water system to compliance with the NPDWR levels by the earliest feasible time.

4.6.4 Interpreting and Applying the PAG

The drinking water PAG is intended primarily to guide planning and decision-making efforts by local and state officials, including drinking water providers, during the intermediate phase of a radiological emergency when surface water sources are particularly vulnerable to contamination from deposition of radioactive material from the atmosphere. Actions to protect water sources may be implemented at other levels and at any time following a radiological incident, and even before an anticipated release occurs. The goal is to keep the dose to the public as low as reasonably achievable. Radiation doses should be reduced to below SDWA MCLs as soon as practicable.

4.6.4.1 Interpreting the Two-tier PAG

EPA recommends a two-tier PAG: 500 mrem (5 mSv or 0.5 rem) for the general population (anyone over age 15, excluding pregnant women and nursing women) and 100 mrem (1 mSv or 0.1 rem) for pregnant women, nursing women, and children age 15 and under.

Authorities have flexibility on how to apply the PAG. In some cases they may find it feasible to use the PAG of 100 mrem as a target for the whole population, while in other circumstances, authorities may find that it makes sense to use both targets simultaneously. For example, emergency managers can use a two-tiered approach to focus on protecting the most sensitive population with limited alternate water resources. If bottled water must be rationed, for example, authorities may make the bottled water available to children, pregnant women and nursing women, and instruct the rest of the population to use a public drinking water supply that will not trigger the 500 mrem PAG.

As stated above, the PAGs are intended as guidance only, and local authorities should take into account local circumstances (e.g., incident scope and community needs) when implementing any course of action to protect the public.

4.6.4.2 Converting PAGs into Derived Response Levels (DRLs)

The PAG specifies a radiation dose to avoid via drinking water exposure projected over one year. In order to determine whether a PAG should be implemented, authorities will need to establish a relationship between the measured concentration of one or more radionuclides in finished drinking water and the radiation dose members of the population might experience as a result of drinking contaminated water. Incident-specific factors that may be taken into consideration include:

1. The particular radionuclides being emitted in this emergency situation
2. The rate and timing of entry of the radionuclides into the drinking water supply, via atmospheric deposition or by other means
3. The rate of natural attenuation of the radionuclides
4. The estimated potential duration of public exposure to contaminated drinking water
5. The estimated daily consumption of contaminated drinking water.

Those responsible for implementing PAGs will need to convert PAGs into Derived Response Levels (DRLs) in units of Bq/L or pCi/L for each radionuclide of interest. Section 4.6.6 of this Manual provides DRLs and explains how they can be calculated. Selected dose conversion factors and standard estimates of daily drinking water consumption for various age groups are also provided, along with references to informational resources.

While the PAG Manual is primarily for advance planning, there are specific radionuclides, including cesium-137 (Cs-137), iodine-131 (I-131) and strontium/yttrium-90 (Sr-90/Y-90) that are of particular interest for major radiological incident scenarios where drinking water sources might be contaminated. Section 4.6.6 presents default DRLs for these radionuclides to aid emergency managers in making water restriction decisions involving these contaminants. DRLs for these radionuclides are presented as examples for purpose of illustration. If other radionuclides are present, DRLs should be calculated using the same methodology, as discussed in Section 4.6.6.

4.6.4.3 Practical Considerations

After deposition has ended, radionuclide concentrations present in a water supply may decline at rates determined by the half-lives of the individual nuclides, may decline faster by dilution with uncontaminated water, or may even increase after rainfall and seasonal thaw events in an affected watershed. The concentration of radionuclides in drinking water as a function of time after the incident can be measured, estimated or modeled based on knowledge of the incident, including radionuclide sources and the properties of the drinking water supply. Models and estimates should be validated by monitoring or sampling, as discussed in Section 4.6.5.1.

Unlike naturally-occurring radionuclide contamination of drinking water from minerals present in geological formations, for a radiation release incident, ground water sources are expected to be less vulnerable to contamination than surface water sources, but this should be confirmed by monitoring or sampling. The potential for ground water to become contaminated will greatly depend on whether the ground water resource is close to the surface or is from a deep aquifer bounded by an aquitard, as well as on rainfall rate and the composition of the overlying soil (which will affect the rate at which contaminants deposited on soil will migrate to the ground water resource).

Section 4.6.5.3 discusses actions that authorities can take to minimize radiation doses from drinking water. Because radionuclides decay over time, early interventions such as restricting use of contaminated water immediately after the incident may be most effective in reducing radiation dose to the population. Such decisions may need to be made based on limited information. Authorities may find it prudent to take

such action even before field sample measurements or modeled estimates of radiation dose have been calculated and validated.

4.6.5 Planning and Taking Action

This section discusses actions that state and/or local authorities and drinking water utilities can take to protect the public in the event that a water supply is affected by a nationally significant radiological contamination incident. Different actions described here may be appropriate for early and intermediate phases depending on local resources. This section does not constitute a complete handbook for radiological emergency response, but it describes considerations that can be included in comprehensive emergency planning at the state, local and utility level. Actions that public authorities and drinking water providers should take are described below, including water monitoring, public notification, and mitigation measures to protect the water supply and the water-consuming public.

Preventive action, such as temporary closure of water system intake valves to prevent a contaminant plume from entering the system, may be taken in advance of an anticipated release; it is not necessary to wait until drinking water contamination is detected. Emergency response plans need to consider whether sufficient storage capacity is available to support the community's fire suppression and sanitation needs while the intake valves are closed.

Emergency planning provides the opportunity to develop state, local and utility-specific plans and implementation procedures that reflect the unique needs of a particular community. Advance planning can provide clarity and facilitate the decision-making process during a radiological emergency.

4.6.5.1 Monitoring and Characterization of Contaminants

A comprehensive radiological surveillance program to monitor concentrations of radionuclides of interest in both source water (including both upstream and downstream of intakes, as applicable) and finished drinking water would provide an indication of whether any adjustments are necessary or if the actions being taken are effective.

The NPDWR for radionuclides requires community water systems (CWSs) to conduct monitoring at each entry point to the distribution system to ensure that every customer's water does not exceed the MCLs for radionuclides.[43] All CWSs are required to monitor for gross alpha, radium-226/228, and uranium. In addition, CWSs designated by the state as "vulnerable"[44] and those using waters "contaminated"[45] by effluents from nuclear facilities must also conduct monitoring for beta particle and photon radioactivity. If a water system is directed by the primacy agency to collect samples for compliance purposes, approved analytical methods must be used.

In the event of a radiological contamination incident, state officials may require public water systems to immediately collect additional samples for radionuclides, including beta particle and photon activity. However, EPA recognizes that during an emergency situation it may be necessary to identify alternative sampling and analytical approaches to obtain data to inform short-term actions by emergency response personnel. Many states have established Radiological Emergency Preparedness[46] programs designed to guide sample collection and analysis and to advise emergency managers in a radiological emergency. Additionally, FRMAC can deploy monitoring and sampling field teams and provide dose assessment expertise to assist states and local communities in responding to an emergency. See the National

[43] For more information about monitoring requirements for the Radionuclides Rule see the "Radionuclides Rule: A Quick Reference Guide" EPA-816-F-01-003 (EPA 2001) or "Implementation Guidance for Radionuclides" EPA-816-F-00-002 (EPA 2002b).
[44] For more information see 40 CFR 141.26(b)(1).
[45] For more information see 40 CFR 141.26(b)(2).
[46] See: http://www.fema.gov/radiological-emergency-preparedness-program.

Response Framework, Nuclear Radiological Incident Annex (FEMA 2008b) for information on roles and capabilities.

EPA provides rapid laboratory analysis methods for selected radionuclides to expedite the analytical turnaround time while simultaneously meeting measurement quality objectives (EPA 2014).[47] Samples should be collected from entry points to the distribution system. Challenges may arise from variability in environmental matrices. Advance emergency planning can help to achieve sample representativeness and homogeneity relative to routine samples.

Once the situation is better characterized and systems are working towards returning to compliance, monitoring should be conducted at entry points to the distribution system using only approved analytical compliance methods.

If members of the public are served by drinking water from household cisterns or private wells, local officials should consider how monitoring should be undertaken to determine levels of target radionuclides and assess the risks posed to these populations.

4.6.5.2 Public Notification

An emergency response plan should include a strategy for keeping the community informed of the actions being taken by authorities and clearly delineate roles and responsibilities of local officials and emergency responders. This includes communicating to customers of CWSs and (if applicable) to those who rely on household cisterns and private wells. It is critical for water utilities to participate in the emergency response planning activities.

If compliance monitoring indicates that contamination levels exceed the MCL for any radionuclide, water systems are required to issue public notice on a "Tier 2" time frame (i.e., as soon as practical, but no later than 30 days after the system learns of the violation). CWSs should be able to issue repeat notices as required. However, states may determine that the notification requirement should be elevated to a "Tier 1" Public Notification (i.e., as soon as practical, but no later than 24 hours) based on a significant potential for serious adverse effects on human health due to short-term exposure.[48]

During a response to a major radiological incident, water systems may have difficulty with issuing public notifications in addition to managing the response to the contamination event. The state may issue public notification on behalf of the water system (40 CFR 141.210(a)). This would allow the state to deliver a consistent message to all affected customers and allow the system to concentrate its efforts on returning to operation or returning to compliance in the event of radionuclide(s) MCL violation(s). For more information see the Revised Public Notification Handbook, EPA-816-R-09-013 (EPA 2010b).

State and local authorities should be proactive in communicating about risks and uncertainties and providing clear instructions to the public. For any incident response requiring coordinated federal support, refer to the National Response Framework and Emergency Support Function 15, External Affairs Annex (FEMA 2016b), for roles and response protocols.

4.6.5.3 Additional Actions to Reduce Levels of Contamination

In the initial phase following a radiological incident, officials should take reasonable precautionary measures (i.e., closing intake valves) to protect water sources as soon as notification of a radiological release or impending release is received. Moving into the intermediate phase, as data are obtained from

[47] Rapid methods are available online at: http://www.epa.gov/narel/rapid_methods.html.
[48] For more information see 40 CFR 141.202(a), Table 1(9), Special public notices: Occurrence of a waterborne disease outbreak or other waterborne emergency.

monitoring programs (including sampling and analysis of water upstream and downstream of a water system intake structure and within the distribution system), officials should benchmark observed concentrations against the default DRLs discussed in Section 4.6.6 or situation-specific DRLs that account for specific isotopes present, release patterns, and decay. Officials would then be in a position to make informed decisions about the need to implement protective actions. Water system officials should be in close communication with their drinking water regulatory agency (e.g., state) prior to taking protective actions.

Options available to water systems to reduce radiation dose to drinking water customers include applying treatment technologies, relying on back-up storage, blending water, accessing alternative water sources, and rationing of uncontaminated water or a combination of these actions. Examples of these options are described briefly below. Technical and economic burden on smaller systems may be reduced by pooling resources with other water systems (e.g., establishing interconnections, sharing technical and operator staff, and sharing of supplies and equipment). As part of emergency planning efforts, local officials should consider the possibility of temporary rationing of uncontaminated or treated water if supplies are inadequate to meet normal demand.

All of these options require advanced planning and should be evaluated and included in state plans as appropriate. Guidance on developing emergency drinking water supplies is available from EPA (EPA 2011b). The CDC also provides resources and guidance for establishing emergency water supplies and communicating water advisories to the public (CDC 2014a).[49]

- **Treating Contaminated Water**

Systems with the appropriate technology in place can treat contaminated water to reduce elevated radionuclide levels. Four treatment technologies are classified by EPA as Best Available Technologies (BATs) for removing radionuclides from drinking water: coagulation/filtration, ion exchange, lime softening and reverse osmosis. EPA has also listed these BATs as Small System Compliance Technologies (SSCTs) for radionuclides treatment, along with less commonly used techniques such as green sand filtration, co-precipitation with barium sulfate, electrodialysis/electrodialysis reversal, pre-formed hydrous manganese oxide filtration and activated alumina. Further information on radionuclide treatment options is available from EPA (EPA 2015, EPA 2002c).[50]

Removal efficiency for specific radionuclides will vary across available technologies and may depend on technology-specific parameters (e.g., ion exchange effectiveness depends on pH, resin selected and presence of other ions). In addition, liquid and solid treatment residuals with elevated radiation levels may have special disposal requirements. Disposal options may vary from one jurisdiction to another, and may depend on the type, concentration and volume of residuals. Further information on residual disposal considerations is available from EPA (EPA 2006a, EPA 2006b).

- **Temporarily Closing Intake Valves**

If the deposition of radionuclides into a river is limited in duration, only a portion of the water may become contaminated. A water system with enough storage capacity can temporarily close its intake valves and allow the contaminants to flow past the intake to prevent contamination from entering the distribution system.

[49] See: http://www.cdc.gov/healthywater/emergency/drinkingwateradvisory.html. (CDC 2014a)
[50] See: http://cfpub.epa.gov/safewater/radionuclides/radionuclides.cfm (EPA 2015); Also see: http://www.epa.gov/safewater/radionuclides/pdfs/guide_radionuclides_smallsystems_compliance.pdf. (EPA 2002c)

If stored water supplies are not sufficient to meet community fire suppression and sanitation needs while intake valves are closed, the system could take other actions discussed in this section, including supplementing water supplies with alternate sources or implementing water use restrictions.

- **Establishing Interconnections to Neighboring Systems**

If the water system is part of a larger, regional supply system, existing interconnections to uncontaminated neighboring water supplies could be activated. It might also be possible to construct temporary pipelines on an impromptu basis.

If this option is implemented, steps should be taken to prevent backflow from the contaminated system. Care will also need to be taken to ensure that the supply of water and treatment capacity at the uncontaminated system will adequately serve the larger population.

- **Blending Water Sources**

If a source of uncontaminated water is available, a water system may choose to blend water from contaminated and uncontaminated sources of drinking water to minimize radiation doses from drinking water. The water may be blended using storage tanks or a common header to allow for complete mixing prior to distribution to customers.

- **Importing Water in Tanker Trucks**

Under some circumstances (e.g., difficult terrain, urgent need), it may be more efficient or expedient to temporarily transport clean water by truck, rail or barge to distribution centers in the affected community than to lay down pipelines. State and local departments of public health, as well as emergency management agencies, typically have standards and requirements related to hauling water. Water systems would benefit from having procedures for importing water in tanker trucks documented in an emergency response plan. All water systems importing water by tanker should verify that their plan adheres to state and local requirements. If the water system's distribution system is not being used to provide the imported water, the needs of residents with limited transportation options and physical disabilities should be taken into account when selecting locations for distribution centers. The availability of suitable transport vehicles may limit use of this option.

- **Importing Bottled Water**

Providing bottled water to the affected community is another possible option during an emergency situation. The water may come from a nearby water system or from a water bottling company. This option may be cost-effective during an emergency if water is needed quickly and if the length of the emergency does not require long-term action, such as the construction of an interconnecting pipe.

4.6.6 Derived Response Levels (DRLs)

Once the incident characteristics have been assessed, information regarding duration of the radiological release and the half-life of nuclides involved as well as other factors may be considered by local decision makers in projecting doses and adapting mitigation measures. All radionuclides are covered by the assessment tools provided by FRMAC. For instance, if an alpha emitting isotope was of concern following a radiation contamination incident, it would be included in any calculations regarding protective actions for drinking water. As such, local officials may choose to work with FRMAC to calculate situation-specific DRLs that are based on information gained during the intermediate phase, including identification of specific isotopes, release patterns, and associated decay functions.

In the unlikely scenario where radioactive isotopes are continuously replenished, EPA recommends using the conservative assumption that radionuclide levels will remain constant over the course of one year.

Such an assumption provides an added level of protection in light of the many unknowns involved in an emergency. In fact, after the initial deposition event has occurred, concentrations usually decline at rates determined by the half-lives of individual isotopes, or decline faster due to dilution with uncontaminated water, or could even increase after rainfall or subsequent deposition events. Some nuclides, like I-131, have half-lives measured in days, while others, like Cs-137, have half-lives measured in years.

Table 4-3 provides default DRLs for those unlikely scenarios. These default DRLs provide for convenience to allow local entities to make quick decisions about drinking water provided by public water systems in the event of a radiological emergency.

Early exceedance of the default DRL does not suggest that doses will stay at that level. In most cases, levels will drop below PAGs as radionuclide concentrations in water decline by a combination of radioactive decay and natural attenuation. If the concentrations of radionuclides do not exceed DRLs over the course of one year, doses will remain below the PAG.

Table 4-3. Default Derived Response Levels (DRLs)[51] – Drinking Water Concentrations Corresponding to Specified Doses (mrem) of Select[52] Radionuclides, Assuming One Year of Exposure at Constant Levels[53]

Isotope	**DRLs for pregnant women, nursing women and children age 15 and younger – 100 mrem dose**	**DRLs for the general population – 500 mrem dose**
Sr-90/Y-90[54]	1,000 pCi/L	7,400 pCi/L
Cs-137	6,200 pCi/L	17,000 pCi/L
I-131	820 pCi/L	10,000 pCi/L

The DRLs provided in Table 4-3 were derived by calculating life-stage-specific DRLs (as described in section 4.6.6.2) for eight different ages (fetus, breastfed infant, infant, 1, 5, 10, 15, and adults). For the most sensitive life-stages, concentrations of individual radionuclides yielding a 100 mrem dose were calculated for each age group, then the most protective/lowest radioactivity concentration was selected as the DRL for the entire sensitive life-stage group, including pregnant and nursing women. The calculated values differ across individual life-stages because each age group has a different dose conversion factor and drinking water ingestion rates.

For example, the sensitive life-stage group DRL for I-131 was derived by calculating the concentration of I-131 which yields a 100 mrem dose for each age group. In this case the resulting concentrations were: fetus (2,500 pCi/L), breastfed infants (820 pCi/L), infants (2,100 pCi/L), 1 year (1,900 pCi/L), 5 years

[51] The DRLs in Table 4-3 indicate the concentration of each radionuclide which results in the corresponding radiation dose value if such radionuclide was the radiation emitter in drinking water. Values provided in this table have been rounded to two significant figures.

[52] Table 4-3 does not present DRLs for all radionuclides that may occur in drinking water following a contamination incident; however, DRLs can be calculated for any isotope of interest by using the provided reference documents and calculation methodology.

[53] The calculated values provided in Table 4-3 are intended to illustrate the methodology and conservative assumptions EPA believes are adequate to provide a reasonable level of protection to sensitive populations. Dose conversion factors, calculation methodologies as well as other comprehensive information regarding DRL development will be available and updated as needed in the FRMAC Assessment Manual.

[54] Y-90 is a radioactive decay product of Sr-90 and will normally be found alongside Sr-90 in the case of a Sr-90 release; therefore, they are treated together. Solubility differences may cause less yttrium to be present; however, it is a conservative assumption to include both in DRLs. When calculating the combined DRL, note that the dose coefficients (see Table 4-5) are additive.

(1,300 pCi/L), 10 years (2,000 pCi/L), and 15 years (2,400 pCi/L). Since the lowest calculated concentration is that of the breastfed infant (820 pCi/L), this value is the DRL that will be applied to be the most protective for the entire sensitive life-stage group.

4.6.6.1 Calculation of Default DRLs

DRLs may be calculated with the help of the following equations.

The dose (mrem or Sv) due to the ingestion of radionuclide *i* to age group *a* over time period *T* is calculated as follows:

$$D_{iaT} = I_{iaT} \times DCF_{ia}$$

Where:

D_{iaT} = Dose (in mrem or Sv) due to the ingestion of radionuclide *i* to age group *a* over time period *T*.

I_{iaT} = The total intake of radionuclide *i* for age group *a* (in pCi or Bq) over time period *T*.

DCF_{ia} = The dose conversion factor (also referred to as dose coefficient) for the ingestion of radionuclide *i* in drinking water and age group *a* (in mrem/pCi or Sv/pCi, or mrem/Bq or Sv/Bq). See below for guidance on dose conversion factors (DCFs).

The quantity of radionuclide *i* ingested by age group *a* over a given time period, *T*, is calculated as follows:

$$I_{iaT} = C_i \times Ing_a \times T$$

Where:

I_{iaT} = The total intake of radionuclide *i* for age group *a* (in pCi or Bq) over time period *T*.

C_i = The concentration of radionuclide *i* in drinking water (in pCi/L or Bq/L). A simplifying assumption is made that the concentration of the radionuclide is constant over the time period *T*.

Ing_a = The daily ingestion rate of water for age group *a*, in L/day. See below for guidance on daily water ingestion rates.

T = The time period that the population is drinking contaminated water (days). In this analysis, the time period of interest for fetus exposure is 280 days, for all other age groups the exposure timeframe is 365 days.

For each age group *a* and radionuclide *i*, substituting the applicable PAG for the dose D_{iaT} and then solving for C_i yields the applicable DRL.

For example, the DRL for iodine-131 for an adult is calculated as follows:

$$DRL = PAG / (Ing_a \times T \times DCF_{ia})$$

$$DRL = 500 \text{ mrem} / (1.643 \text{ L/day} \times 365 \text{ days} \times 8.05 \text{ E-05 mrem/pCi})$$

= 500/4.83 E-02

= 10,352 pCi/L

Which is rounded to 10,000 pCi/L (two significant figures) in consideration of the uncertainties involved.

4.6.6.2 Combining Default DRLs for Multiple Radionuclides

If multiple radionuclides are present in the water supply, the measured concentrations of each radionuclide should be divided by the provided DRL values and summed. Each quotient represents a fraction of the allowed concentration (the radionuclide-specific DRL) and the permissible dose (the PAG). If the sum of the fractions is less than 1, the total dose does not exceed the PAG value. Emergency response personnel may need to calculate the sum of fractions on an ongoing basis, as the concentrations of individual radionuclides may change over time.

The sum of the fractions is expressed as follows:

$$F = \sum (C_i / DRL_i)$$

Where:

F = sum of the fractions

C_i = the concentration of radionuclide *i* in the water supply (pCi/L or Bq/L)

$DRL_{i\ (100\ or\ 500\ mrem);}$ = derived response level for the i^{th} radionuclide (pCi/L or Bq/L)

For example, if Sr-90/Y-90 and Cs-137 are the only radionuclides present in the drinking water, and Sr-90/Y-90 are present at 900 pCi/L and Cs-137 is present at 4,500 pCi/L, the combined dose exceeds the PAG of 100 mrem for fetuses, infants, and children:

$$F = \sum (C_i / DRL_i)$$

= (900 pCi/L / 1,000 pCi/L) + (4,500 pCi/L / 6,200 pCi/L)

= 0.90 + 0.73

= 1.63

1.63 > 1, so the PAG is exceeded.

The same concentrations do not exceed the PAG of 500 mrem for the general population:

$$F = \sum (C_i / DRL_i)$$

= (900 pCi/L / 7,400 pCi/L) + (4,500 pCi/L / 17,000 pCi/L)

= 0.12 + 0.26

= 0.38

0.38 < 1, so the PAG is not exceeded.

4.6.6.3 Water Ingestion Rates

Table 4-4 presents mean values for tap water consumption taken from the CD supplement to Federal Guidance Report #13 (EPA 2002a). Other sources of estimated drinking water ingestion rates are available (e.g., EPA's Exposure Factors Handbook (EPA 2011a)), but the ingestion rates presented in Federal Guidance Report #13 (EPA 1999) were specifically designed with corresponding age ranges to be used in conjunction with other data from Federal Guidance Report #13 (EPA 1999).

Values are provided for males and females in various age groups. Since the ingestion rates for males are higher (and therefore more conservative) than those for females, EPA elected to use the intake values for males to represent each age group in the calculation of DRLs in Table 4-3. In addition, for the calculation of the DRLs for the pregnant women (fetus), nursing women (breastfed infant) and adult, EPA made the conservative choice of assigning the drinking water ingestion rate within the adult category, at an estimated 1.643 L/day.

Table 4-4. Mean Drinking Water Ingestion Rates from Federal Guidance Report #13

Age (years)	**Tap Water (L/day)**	
	Male	**Female**
0	0.191	0.188
1	0.223	0.216
5	0.542	0.499
10	0.725	0.649
15	0.900	0.712
20	1.137	0.754
50	1.643	1.119
75	1.564	1.179

Source: CD Supplement to Federal Guidance Report #13 (EPA 2002a), Table 3.1.

4.6.6.4 Dose Coefficients, or Dose Conversion Factors (DCF) (Sv/Bq Ingested)

The effective whole body dose per Bq ingested of various radionuclides in water, for various age groups, can be found on the CD supplement to Federal Guidance Report #13 (EPA 2002a). These DCF values apply to both males and females. In addition, DCFs used to calculate DRLs for the fetus[55] and the breastfed infant[56] are taken from ICRP Publication 88 (ICRP 2002) and ICRP Publication 95 (ICRP 2005) respectively. Table 4-5 presents DCFs for a few representative radionuclides of interest, converted to U.S. units for convenience.

[55] ICRP Publication 88, Doses to the Embryo and Fetus from Intakes of Radionuclides by the Mother. (ICRP 2002)
[56] ICRP Publication 95, Doses to Infants from Ingestion of Radionuclides in Mother's Milk. (ICRP 2005)

Table 4-5. Dose Conversion Factors[57]

Age	DCFs (mrem per pCi ingested), from Federal Guidance Report #13			
	Sr-90	**Y-90**	**Cs-137**	**I-131**
Infant (100 day old)	8.40E-04	1.16E-04	7.79E-05	6.82E-04
1 year old	2.68E-04	7.41E-05	4.58E-05	6.62E-04
5 year old	1.73E-04	3.69E-05	3.58E-05	3.83E-04
10 year old	2.21E-04	2.18E-05	3.75E-05	1.94E-04
15 year old	2.92E-04	1.24E-05	4.95E-05	1.27E-04
Adult	1.02E-04	9.94E-06	5.02E-05	8.05E-05

Source: CD Supplement to Federal Guidance Report #13 (EPA 2002a).

4.7 BASIS FOR INTERMEDIATE PHASE PAGs

For a full description of the risk-benefit analysis used to set the PAG levels, refer to the 1992 PAG Manual, Appendices B, C and E. The 1992 PAG Manual is available online in a searchable format. Below is a short summary of the basis for the intermediate phase relocation PAGs.

In a prior section (see Section 2.5) for early phase (evacuation) PAGs, analysis was provided for the risks of health effects as a function of dose (Principles 1 and 2). Considerations for selection of PAGs for the intermediate phase of a radiological incident differ from those for selection of PAGs for the early phase primarily with regard to implementation factors (i.e., Principles 3 and 4). Specifically, they differ with regard to cost of avoiding dose, the practicability of leaving infirm people and prisoners in the restricted zone, and avoiding dose to fetuses. Although sheltering is not generally a suitable alternative to relocation, other alternatives (e.g., decontamination and shielding) are suitable.

For several assumed cumulative annual doses, the cost per day divided by the risk of fatality avoided by relocation was plotted for a radionuclide mixture from a hypothetical NPP accident. The cost per day of relocation is assumed to be constant, but with some nuclides decaying rapidly, the cost-effectiveness of relocation diminishes over time. Drawing only general trends from this, the cost analysis supports relocation at doses as low as 1 rem (10 mSv) for the first week and 2 rem (20 mSv) for up to 25 days after an accident.

Based on the avoidance of acute effects alone (Principle 1), relocation of the general population and fetuses at 50 rem and 10 rem (500 and 100 mSv), respectively, is justified. However, on the basis of control of chronic risks (Principle 2), a lower upper bound is appropriate. Five rem (50 mSv) is taken as an upper bound on acceptable risk for controllable lifetime exposure to radiation, including avoidable exposure to accidentally deposited radioactive materials.

Analyses based on Principle 3 (cost/risk) indicate that considering cost alone would not drive the PAG to values less than 5 rem (50 mSv). Analyses in support of Principle 4 (risk of the protective action itself) provide a lower bound of 0.15 rem (1.5 mSv) for the relocation PAGs. Based on the above, 2 rem (20

[57] The DCFs in this table show the variation across age groups and nuclides and are provided to illustrate the conservative methodology and assumptions EPA believes are adequate to provide a reasonable level of protection to sensitive populations. Additional information including updated dose conversion factors, calculation methodologies and other comprehensive information regarding DRL development, will be appended to the FRMAC Assessment Manual.

mSv) projected committed effective dose equivalent from exposure in the first year is selected as the PAG for relocation. Implementation of relocation at this value will provide reasonable assurance that, for a reactor accident, a person relocated from the outer margin of the relocation zone will, by such action, avoid an exposure rate which, if continued over a period of one year, would result in a dose of about 1.2 rem (12 mSv). This assumes that 0.8 rem (8 mSv) would be avoided without relocation through normal partial occupancy of homes and other structures.

Contrary to the situation for evacuation during the early phase of an incident, it is generally not practical to leave a few people behind when most members of the general population have been relocated from a specified area for extended periods of time. It will usually be practicable to reduce these risks by establishing a high priority for efforts other than relocation to reduce the dose in cases where pregnant women reside near the boundary of the restricted zone.

The implementation of simple dose reduction techniques will further reduce dose to people who are not relocated from contaminated areas. In the case of non-reactor accidents, decay and weathering effects differ, and it may be necessary to base relocation decisions on the second and subsequent year dose projections.

KEY POINTS IN CHAPTER 4 – INTERMEDIATE PHASE

- The principal protective actions for reducing exposure of the public to deposited radioactive materials are relocation, decontamination and time limits on exposure. The PAG for relocation is 2 rem (20 mSv) over the first year of exposure. After the first year, the PAG for relocation is 0.5 rem (5 mSv) per year.
- Boundaries of relocation areas should be established based on the relocation PAGs and site-specific geographical features such as rivers, mountains or roadways.
- Projections should be based on incident-specific monitoring and modeling, taking into account realistic dose assessment factors.
- Exposure limits must be set for people who must enter the relocation area to perform vital services.
- Other protective actions, such as focused decontamination and time limits on exposure, are applied to people in areas where levels of deposited radioactivity are not high enough to warrant relocation.
- Protective action guidance for food is contained in FDA's "Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies" (FDA 1998).
- Drinking water guidance is based on a two-tiered approach to help officials prioritize potentially scarce water resources:
    - 500 mrem (5 mSv or 0.5 rem) projected dose, for one year, to the general population.
    - 100 mrem (1 mSv or 0.1 rem) projected dose, for one year, to the most sensitive populations (e.g., infants, children, pregnant women and nursing women).
- To inform temporary reentry into relocation areas, use the Operational Guidelines (DOE 2009).

CHAPTER 5. PLANNING GUIDANCE FOR THE LATE PHASE

This chapter provides planning guidance for the long-term cleanup process for the late phase. As used in this Manual, the late phase is the period beginning when cleanup and recovery actions have begun and ending when all recovery actions have been completed. This phase may extend for months to years. This chapter also provides brief planning guidance and discusses options for radioactive waste disposal for a large-scale radiological incident.

5.1 LATE PHASE CLEANUP PROCESS

This section describes the remediation cleanup process for the late phase of a nationally significant radiological incident, such as a disaster at an NPP, an RDD or an IND. It should be noted that the extent and scope of contamination as a result of an NPP, RDD or IND incident may be at a much larger scale than a site or facility decommissioning or remedial cleanup. This process identifies the late phase remediation or cleanup process steps, including factors for decision-makers to consider in determining final cleanup actions while emphasizing opportunities to involve key stakeholders in providing sound, cost-effective cleanup recommendations. For information on roles, responsibilities and authorities during emergency response and recovery, please refer to—

- National Response Framework: http://www.fema.gov/national-response-framework (FEMA 2008a), and
- Nuclear Radiological Incident Annex, specifically for radiological incidents: http://www.fema.gov/pdf/about/divisions/thd/IncidentNucRad.pdf (FEMA 2008b).

5.1.1 Transitioning from Intermediate to Late Phase Cleanup

The late phase cleanup process begins sometime after the commencement of the intermediate phase and proceeds independently of intermediate phase protective action activities. The transition is characterized by a change in approach, from strategies predominantly driven by urgency, to strategies aimed at both reducing longer-term exposures and improving interim living conditions. At this point, the extent of radiological contamination will be very well characterized. The late phase involves the final cleanup of areas and property at which contamination directly attributable to the incident is present. It is in the late phase that final cleanup decisions are made and final recovery efforts following a radiological incident are implemented.

Unlike the early and intermediate phases of a radiological incident, decision-makers will have more time and information during the late phase to allow for better data collection, stakeholder involvement and options analysis. Generally, early (or emergency) phase decisions will be made directly by elected public officials, or their designees, with limited stakeholder involvement due to the need to act within a short timeframe. Longer-term decisions should be made with stakeholder involvement and can also include incident-specific technical working groups to provide expert advice to decision-makers on impacts, costs and alternatives. Community members will influence decisions such as if and when to allow people to return home to contaminated areas. There will be people living in contaminated areas, outside the evacuation and relocation zones, where efforts to reduce exposures will be ongoing.

Because of the extremely broad range of potential impacts that may occur from NPP incidents, RDDs and INDs (e.g., light contamination of one building to widespread destruction of a major metropolitan area), a process should be used to determine acceptable cleanup criteria based on the societal objectives for expected land uses and the options and approaches available. Implicit in these decisions is the ability to balance health protection with the desire of the community to resume normal life. Radiation protection considerations should be addressed in concert with health, environmental, economic, social, psychological, cultural, ethical, political, and other considerations. It is recognized that experience from existing programs, such as the EPA's Superfund program, the NRC's process for decommissioning and

decontamination to terminate a nuclear facility license, and other national recommendations may be useful in planning cleanup and recovery efforts.

Consistent with the "Framework for Environmental Health Risk Management," mandated by the 1990 Clean Air Act Amendments and published by the Commission on Risk Assessment and Risk Management in 1997 (CRARM 1997), the late phase cleanup process consists of multiple steps, including: 1) characterization and stabilization; 2) development of goals and strategies; and 3) implementation and reoccupancy. Stakeholder involvement should be integrated throughout the process. Characterization in this phase consists of delineation, in detail, of the nature and extent of contamination in areas impacted by the incident. Stabilization is intended to reduce the spread of contamination to clean areas, the airborne inhalation hazards, and the volume of radioactive waste generated. Establishment of cleanup goals and strategies should consider overall community health, along with a variety of factors described further below; they are based upon anticipated land use and a variety of selection criteria. Key to these steps is the involvement and acceptance of the impacted state and local community. These steps are discussed in more detail below.[58]

5.1.2 Characterization and Stabilization

The first step in the late phase remediation or cleanup process is characterization, or the comprehensive mapping and monitoring of the distribution and level of radioactive contamination. Characterization activities are necessary in the preparation for and verification of a successful remediation or cleanup effort. The late phase characterization work is designed to define, in detail, the nature and extent of the contamination and to provide information needed to develop and evaluate cleanup alternatives.

The characterization performed in support of the late phase will be much more detailed and comprehensive than the earlier characterization work to support PAG decisions made during the early and intermediate phases. It delineates the nature of any actual threat posed to human health or the environment and defines the extent of that threat.

Stabilization techniques are designed to immobilize radioactive contamination on soils, buildings, roads and equipment. This becomes paramount in a large-scale radiological incident where the spread of contamination can occur from natural weathering effects to human and animal interactions with the environment. Stabilization reduces chronic low-level exposures to residual radiation, airborne hazards, and volumes of secondary waste. These reductions can result in significant benefits to the long-term recovery in terms of time-to-normalcy and economic recovery.

5.1.3 Goals and Strategies

After late phase characterization and stabilization activities are accomplished, areas impacted by radioactive contamination are documented and defined to the best extent possible. At this point, decision-makers should establish cleanup goals and strategies for moving forward. The development of goals and strategies marks the second step in the late phase remediation or final cleanup process. As part of an ongoing iterative process, cleanup goals are informed by the feasibility of cleanup strategies and specific cleanup strategies adjust as experience is gained. That is, risk management goals may be refined as decision-makers and stakeholders gain appreciation for what is feasible, the costs and benefits of alternative strategies, and the effectiveness of such strategies in reducing exposures and risks to human and ecological health.

[58] This cleanup process does not rely on and does not affect any authority, including the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), 42 U.S.C. 9601 et seq. and the National Contingency Plan (NCP), 40 CFR Part 300. This document expresses no view as to the availability of legal authority to implement this process in any particular situation.

As cleanup levels for areas are determined, many factors come into play in decision-making, such as balancing risk reduction with other societal goals and tolerance for voluntary versus involuntary risk. Determining these levels will require consideration of a number of factors—

- The types of contamination including nuclide mix and chemical form, as well as risk from non-radiological hazards.
- The technical feasibility, cost, timeliness and effectiveness of decontamination measures; and the availability and cost of options for the disposal of wastes.
- The size and character of the areas that are contaminated; past and projected future uses for these areas; and the preservation or destruction of places of historical, economic, national, or regional significance.
- Site-specific natural and anthropogenic background levels of radioactivity.
- Estimates of the impacts of both contamination and options for decontamination, on human health, communities, the economy, ecosystems and ecosystem services.
- Public acceptability and intergenerational equity.

Community involvement and sentiment are vital to this process. The stress from both the incident itself as well as the longer-term effects of separation from home will be important factors as overall community health is considered. In the United States, a range of one in a population of ten thousand (10^{-4}) to one in a population of one million (10^{-6}) excess cancer incidence outcomes is generally considered protective for both chemical and radioactive carcinogenic contaminant exposures. This range is the regulatory standard generally used in the context of EPA Superfund response actions. The NRC's decommissioning and decontamination process outcomes are usually in or near this range as well. A similar risk range may be an appropriate goal for radiological events that affect areas of comparable size. However, such risk ranges may not be practically achievable for major incidents that result in the contamination of very large geographical areas or impacts on the economy. Every incident is unique. In making decisions about cleanup goals and strategies for a particular event, decision-makers should balance the desired level of exposure reduction with the technical feasibility, timing and cost of the measures that would be necessary to achieve it, in an effort to maximize overall human welfare.

While it may take many years to achieve final cleanup levels, a timely return to normalcy, including reoccupancy and a viable community, will require a cleanup process that is flexible, iterative and inclusive. Decisions should be made on a site-specific basis and should reflect the interim risks that are reasonable and acceptable to the affected community while active remediation, radioactive decay, and natural weathering move the site toward long-term cleanup goals.

Cleanup strategies are adopted as decision-makers and stakeholders gain an understanding of all relevant factors. Tradeoffs between alternatives should be considered and balanced so that the best options are chosen. Local acceptance will be a key component of a fully transparent approach to long-term remediation and cleanup. Factors to consider in determining cleanup actions include evaluating:

- Areas impacted (e.g., size, location relative to population);
- Actions already taken during the early and intermediate phases;
- Ability of a remedy to maintain reliable protection of overall human health and the environment over time;
- Assessing the relative performance of treatment technologies on the toxicity, mobility or volume of contaminants;
- Success or effectiveness of the cleanup or remediation as the cleanup progresses (contaminant removal);
- Adverse impacts on human health and the environment that may be posed in the time it takes to implement the remedy and achieve the community-based remediation goals;

- Impacts of alternative cleanup levels on the local and regional economy (e.g., job loss due to closed businesses, job creation due to decontamination and waste handling operations) and on residents' sense of place (e.g., continued limited access to one's home and community until cleanup levels have been reached);
- Preservation or destruction of places of historical, national or regional significance;
- Technical and administrative feasibility of the remedy, including the availability of materials and services needed to implement each component of the option in question;
- Cost of each alternative, including the estimated capital and operation and maintenance costs and net present value of capital and operation and maintenance costs;
- State concurrence with the remedy; and
- Community support for the remedy.

This may be an iterative process. As experience is gained, adjustments may be required to achieve long-term goals.

5.1.4 Implementation and Reoccupancy

To implement cleanup actions in each community, measurable quantities associated with cleanup goals should be derived taking into account exposures from all potential pathways and through all environmental media (e.g., soil, ground water, surface water, sediment, air, animals or plants). These values typically are derived considering reasonably anticipated future land use, dietary habits, and commerce patterns. If meeting acceptable cleanup levels based upon the reasonably anticipated post-incident land use is not practicable and cost-effective, decision-makers can look to more restrictive land uses through institutional and engineering controls. This approach is based on the belief that early community involvement focusing on desired post-incident uses of the property will result in expedited, cost-effective and publicly-supported cleanups. Overall community health, including stress factors from the initial event and separation from home or family is a necessary consideration.

In some situations, a site or area may reasonably be anticipated to support a range of uses, so cleanup goals may be different for different subareas of the impacted area. Although it may take years to achieve the final cleanup goals for all land uses, reoccupancy of the affected area will be possible when interim cleanup can reduce short-term exposures to acceptable levels during the time it takes to achieve the long-term goals. There may be institutional or engineering controls placed on some portions of the site to prevent excessive exposures until further active remediation, radioactive decay, or natural weathering allow the site to meet cleanup goals. An example of an institutional control might be a restriction on planting vegetable gardens to avoid ingesting radionuclides that may be taken up by the plant roots from the soil. An example of an engineering control to limit exposures might be adding a layer of pavement or cement over gamma emitting radionuclides that have become fixed in place by sorbing onto the street and sidewalks.

In complex cases such as the situation represented by a wide-area NPP, RDD or IND event, cleanup and reoccupancy are likely to occur subarea by subarea in order of priority and community assessments. Critical infrastructure is likely to have been restored to some level of functionality and further remediation of the infrastructure should be evaluated against the cleanup goal. A community-based and transparent development of priorities would follow, resulting in sequential actions, whereby areas (e.g., residential, commercial) would be remediated and reoccupied utilizing temporary cleanup levels that would be considered acceptable for an interim period of time prior to final cleanup goals being achieved. Land use may need to be changed in a subarea where it is not feasible with a combination of remediation with engineering and institutional controls to support the pre-incident land use in a manner that protects human health. In all cases, an appropriate population health monitoring program should be implemented proportionate to the potential or estimated health risk.

5.1.5 Stakeholder Involvement

Generally, early (or emergency) phase decisions will be made directly by elected public officials, or their designees, with limited stakeholder involvement due to the need to act within a short timeframe. With additional time and an increased understanding of the situation, there will be opportunities to involve key stakeholders in providing sound, cost-effective cleanup recommendations that are protective of human health and the environment.

Affected citizens should be involved in all phases of cleanup planning and long-term remediation of their communities. Early in the process, decision-makers should bring together a broad group of stakeholders (e.g., residents, local business owners, local government officials and others) interested in the processes that will be required to restore their communities. The credibility of a community group is a function of its inclusiveness. It should represent all stakeholder interests to ensure it is a voice for the entire community rather than a few interested parties. Empowering individuals to assist in the process is important and effective. The affected local community will need to be involved until the site remediation activities are complete and possibly beyond that if institutional and engineering controls are placed on some subareas of the site.

5.1.6 Cleanup Process Implementation and Organization: An Example

This example, adapted closely from the "Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents" (DHS 2008), describes a hypothetical organization to integrate federal cleanup support activities with state and local governments and the public. In particular, it addresses a scenario where the federal government is expected to be the primary funding entity for cleanup and recovery activities. For some radiological scenarios, states might take the primary leadership role in cleanup and contribute significant resources toward recovery of the site. This example does not address such a scenario, although states may choose to follow a similar process.

5.1.6.1 Cleanup Implementation

This approach describes how federal departments and agencies may coordinate during a response with state and local government counterparts and the public, consistent with the National Response Framework (NRF) (FEMA 2008a) and the National Disaster Recovery Framework (NDRF) (FEMA 2016a). The approach does not attempt to provide detailed descriptions of state and local roles and expertise. It is assumed those details will be provided in state and local level planning documents that address radiological/nuclear terrorism incidents.

During the intermediate phase, site cleanup planners should begin the process described below, under the direction of the on-site incident command or unified command (IC/UC) and in close coordination with federal, state and local officials. After early and intermediate phase activities have come to conclusion and only long-term cleanup activities are ongoing, the IC/UC structure may continue to support planning and decision-making for the long-term cleanup. The IC/UC may make personnel changes and structural adaptations to suit the needs of a lengthy, multifaceted and highly visible remediation process. For example, a less formal and structured command, more focused on technical analysis and stakeholder involvement, may be preferable for extended site cleanup than what is required under emergency circumstances.

Radiological and nuclear incidents cover a broad range of potential scenarios and impacts. This example assumes that the incident is of sufficient size to trigger a state request for federal assistance and that the federal government is the primary funding agent for site cleanup. In particular, the process described for the late phase cleanup assumes an incident of relatively large size. For smaller incidents, all of the elements in this section may not be warranted. The process should be tailored to the circumstances of the particular incident. Decision-makers should recognize that for some radiological/nuclear incidents, states

will take the primary leadership role and contribute significant resources toward cleanup of the site. This section does not address such a scenario, but states may choose to use the process described here.

5.1.6.2 Cleanup Activities Overview

As described earlier in the document, radiological/nuclear emergency responses are often divided roughly into three phases: 1) the early phase, when the plume is active and field data are lacking or not reliable; 2) the intermediate phase, when the plume has passed and field data are available for assessment and analysis; and 3) the late phase, when long-term issues are addressed, such as cleanup of the site. For purposes of this example, the response to a radiological or nuclear incident is divided into two separate, but interrelated and overlapping, processes. The first is comprised of the early and intermediate phases of response, which consists of the immediate and near-term on-scene actions of state, local and federal emergency workers under the IC/UC. On-scene actions include incident stabilization, lifesaving activities, dose reduction actions for members of the public and emergency workers, access control and security, emergency decontamination of people and property, "hot spot" removal actions, and resumption of basic infrastructure functions.

The second process pertains to environmental cleanup, which is initiated soon after the incident (during the intermediate phase) and continues into the late phase. The process starts with convening stakeholders and technical subject matter experts to begin identifying and evaluating options for the cleanup of the site. The environmental cleanup process overlaps the intermediate phase activities described above and should be coordinated with those activities. This process is interrelated with the ongoing intermediate phase activities and the intermediate phase protective actions may continue to apply through the late phase until cleanup is complete.

Cleanup planning and discussions should begin as soon as practicable after an incident to allow for selection of key stakeholders and subject matter experts, planning, analyses, contractual processes, and cleanup activities. States may choose to pre-select stakeholders for major incident recovery coordination. These activities should proceed in parallel with ongoing intermediate phase activities and coordination between these activities should be maintained. Preliminary remediation activities during the intermediate phase—such as emergency removals, decontamination, resumption of basic infrastructure function, and some return to normalcy in accordance with intermediate phase PAGs—should not be delayed for the final site remediation decisions.

A process for addressing environmental cleanup is presented below. This is a flexible process in which numerous factors are considered to achieve an end result that considers local needs and desires, health risks, costs, technical feasibility and other factors. The general process outlined below provides decision-makers with input from both technical experts and stakeholder representatives and also provides an opportunity for public comment. The extent and complexity of the process for an actual incident should be tailored to the needs of the specific incident; for smaller incidents, the workgroups discussed below may not be necessary.

The goals of the process described below are: 1) transparency—the basis for cleanup decisions should be available to stakeholder representatives and to the public at large; 2) inclusiveness—representative stakeholders should be involved in decision-making activities; 3) effectiveness—technical subject matter experts should analyze remediation options, consider established dose and risk benchmarks, and assess various technologies in order to assist in identifying a final solution that is optimal for the incident; and 4) shared accountability—the final decision to proceed will be made with input from federal, state and local officials.

Under the National Response Framework (NRF) (FEMA 2008a) and the National Disaster Recovery Framework (NDRF) (FEMA 2016a), FEMA may issue mission assignments to the involved federal agencies, as appropriate, to participate in the overall recovery process. Additional funding may be

provided to state/local governments to perform response or recovery activities through other mechanisms. The components of the process are described below:

5.1.6.3 General Management Structure

Planning for the long-term cleanup should begin during the intermediate phase and at that time, a traditional National Incident Management System (NIMS) response structure should still be in place. However, NIMS was developed specifically for emergency management and may not be the most efficient response structure for long-term cleanup. If the cleanup will extend for years, the IC/UC may decide to transition at some point to a different long-term project management structure.

Under the National Response Framework and NIMS, incidents are managed at the lowest possible jurisdictional level. In most cases, this will be at the level of the IC/UC. The IC/UC directs on-scene tactical operations. Responding local, state and federal agencies are represented in the IC/UC and Incident Command Post (ICP) in accordance with NIMS principles regarding jurisdictional authorities, functional responsibilities, and resources provided. For a wide-area radiological incident, multiple ICPs may be established to manage the incident with an Area Command or Unified Area Command supporting the ICPs and prioritizing resources and activities among them. If the incident happens on a federal facility or involves federal materials, the representatives in the UC may change appropriately and the response will be conducted according to the applicable federal procedures.

Issues that cannot be resolved at the IC/UC or Unified Area Command level may be raised with the Joint Field Office (JFO) and JFO Unified Coordination Group for resolution. The JFO coordinates and prioritizes federal resources and when applicable, issues mission assignments to federal agencies under the Stafford Act. Issues that cannot be resolved at the JFO level may be raised to the DHS National Operations Center senior-level interagency management groups and the White House Homeland Security Council and National Security Council.

Day-to-day tactical management, planning and operations for the cleanup process will be managed at the IC/UC level, but for large-scale cleanups involving significant federal resources, it is expected that the JFO Unified Coordination Group and national level federal officials will review proposed cleanup plans and provide strategic and policy direction. The federal agency(s) with primary responsibility for site cleanup should be represented in the JFO Unified Coordination Group. The IC/UC will need to establish appropriate briefing venues as the cleanup process proceeds, including the affected mayor(s) and governor(s).

The discussion below assumes a traditional NIMS IC/UC structure; if the IC/UC transitions later to a different management structure for a longer-term cleanup, the IC/UC would need to determine the appropriate way to incorporate the workgroups described below into that structure.

This environmental cleanup process will be managed by the IC/UC, who ultimately determines the structure and organization of the ICP, but the discussion below provides one recommended approach for managing the cleanup process within a NIMS Incident Command System (ICS) response structure. The ICP Planning Section has the lead for response planning activities, working in conjunction with other sections and would have the lead for development of the cleanup options analysis, working closely with the Operations Section. The NIMS describes the units that make up the Planning Section and allows for additional units to be added depending on site-specific needs. NIMS states that for incidents involving the need to coordinate and manage large amounts of environmental sampling and analytical data from multiple sources, an Environmental Unit may be established within the Planning Section to facilitate interagency environmental data management, monitoring, sampling, analysis, assessment and site cleanup, and waste disposal planning. Radiological incidents would involve the collection of not only large amounts of radiological data, but also data related to other environmental and health and safety hazards and therefore would likely warrant the establishment of an Environmental Unit in the Planning

Section. Planning for FRMAC radiological sampling and monitoring activities will be integrated into the Planning Section and coordinated with other Situation and Environmental Unit data management activities.

The IC/UC may assign the Environmental Unit the responsibility for coordinating the development of the cleanup options analysis. For large incidents requiring more complicated tradeoffs or the evaluation of cleanup goals with broad implications, the IC/UC may choose to establish a separate unit in the Planning Section (e.g., a Cleanup Planning Unit) to coordinate the development of the cleanup options analysis. The IC/UC may then convene a technical working group and a stakeholder working group, managed by the Environmental or Cleanup Planning Unit, to analyze cleanup options and develop recommendations. The Environmental or Cleanup Planning Unit would coordinate working group processes and interactions and report the results of the cleanup options analysis and workgroup efforts to the IC/UC through the Planning Section Chief.

The development and completion of the cleanup options analysis is expected to be an iterative process and for large incidents, the cleanup will likely proceed in phases, (e.g., from the periphery of the contamination toward the most contaminated areas). The extent of the cleanup options analysis and process used to develop it would be tailored to the needs of the specific incident, but the following working groups may be convened by the IC/UC to assist decision-makers in the cleanup options analysis process, particularly for large or complex cleanups.

5.1.6.4 Technical Working Group

A technical working group should be convened as soon as practicable, ideally within days or weeks of the incident. The technical working group would be managed by the Planning Section Unit that is assigned responsibility for the cleanup options analysis. The technical working group may or may not be physically located at the ICP. The group may review data and documents, provide input electronically, and meet with incident management officials. The group may also be asked to participate in meetings with the JFO Unified Coordination Group if needed.

Function: The technical working group provides multi-agency, multi-disciplinary expert input on the cleanup options analysis, including advice on technical issues, analysis of relevant regulatory requirements and guidelines, risk analyses, and development of cleanup options. The technical working group would provide expert technical input to the IC/UC; it would not be a decision-making body.

Makeup: The technical working group should include selected federal, state, local and private sector subject matter experts in such fields as environmental fate and transport modeling, risk analysis, technical remediation options analysis, cost, risk and benefit analysis, health physics and radiation protection, construction remediation practices, and relevant regulatory requirements. The exact selection and balance of subject matter experts is incident-specific. The Advisory Team for Environment, Food and Health is comprised of federal radiological experts in various fields that may warrant representation on the technical working group, therefore, the Team or some of its members may be incorporated into this group as appropriate.

5.1.6.5 Stakeholder Working Group

The stakeholder working group should be convened as soon as practicable, ideally within days or weeks of the incident. The stakeholder working group would be managed by the Planning Section Unit that is assigned responsibility for the cleanup options analysis. The IC/UC may direct the Public Information Officer (PIO) (who would coordinate with the Joint Information Center (JIC)) to work with the group, including establishing a process for the group to report out its recommendations. How and where the stakeholder working group would meet to review information and provide its input would need to be determined in conjunction with the group members. The stakeholder working group may also be asked to participate in meetings with the JFO Unified Coordination Group, if needed.

Function: The function of the stakeholder working group is to provide input to the IC/UC concerning local needs and desires for site recovery, proposed cleanup options, and other recommendations. The group should present local goals for the use of the site, prioritizing current and future potential land uses and functions, such as utilities and infrastructure, light industrial, downtown business and residential land uses. The stakeholder working group would not be a decision-making body.

Makeup: The stakeholder working group should include selected federal, state and local representatives, and local non-governmental representatives as well as local and regional business stakeholders. The exact selection and balance of stakeholders is incident-specific.

5.1.6.6 Activities: Cleanup Planning and Recommendations

The IC/UC directs the management of the cleanup options analysis through the Planning Section. Technical and stakeholder working groups assist in performing analyses and developing cleanup options and provide input to the IC/UC and may be asked to participate in meetings with the JFO Unified Coordination Group. The IC/UC reviews cleanup options analyses and selects a proposed approach for site cleanup in close coordination with federal, state and local officials. Again, depending on the incident size, it may be necessary to conduct the cleanup in phases. Thus, decisions on cleanup approaches may also be made in phases. As appropriate for the magnitude of the cleanup task, the IC/UC would brief relevant federal, state and local government officials on proposed cleanup plans for approval. This may involve the office of the affected mayor and governor. At the federal level, it may involve the JFO Unified Coordination Group and higher-level officials.

5.1.6.7 Public Review of Decision

The IC/UC should work with the PIO and JIC to publish a summary of the process, the options analyzed, and the recommendations for public comments. Public meetings should also be convened at appropriate times. Public comments should be considered and incorporated as appropriate. A reconvening of the stakeholder or technical working group may be useful for resolving particular issues.

5.1.6.8 Execution of Cleanup and Peer Review

Assuming a Presidential declaration of a major disaster or emergency, FEMA may issue mission assignments to the federal departments and agencies that have the capability to perform the required cleanup, remediation, or debris removal activities. Cleanup activities should commence as quickly as practicable and allow for incremental reoccupation of areas as cleanup proceeds. For significant decontamination efforts, the IC/UC may choose to employ a technical peer review advisory committee to conduct a review of the effectiveness of the cleanup. The technical peer review committee would evaluate pre- and post-decontamination sampling data, the decontamination plan, and any other information key to assessing the effectiveness of the cleanup.

5.2 DISPOSAL OF LARGE VOLUMES OF RADIOLOGICAL WASTE

If a large-scale radiological incident were to occur in the United States, the complexity of radiological waste disposal would depend on the magnitude of the release and the decisions related to site cleanup, both of which will determine the amount and types of waste requiring disposal. Primary responsibility for waste management decisions falls to state and local officials.

This section provides a short introduction to the issue, a summary of the types of available disposal options, a more detailed discussion of each disposal option, including disposal capabilities, and discussion of roles and responsibilities. Although not addressed explicitly in this section, the need to prepare for and conduct safe and environmentally protective storage of waste generated during remediation will also present a significant challenge, as illustrated by the challenges that Japan faced in the aftermath of the Fukushima accident. Many of the considerations for siting disposal facilities will also be applicable to storage sites.

Planners and decision-makers need to view the long-term remediation and recovery as a comprehensive process in which waste management and disposal needs are considered from the earliest stages. For example, the selected decontamination and remediation approach should involve consideration of a number of viable alternatives with regard to potential treatment and disposal options. The precise mix of treatment and disposal options employed would depend on the nature of the specific incident (e.g., location, waste volumes). The suitability of using any individual facility would depend on a number of factors, including but not limited to the toxicity, mobility and volume of radioactively-contaminated wastes (these would be evaluated as part of the characterization process), possible treatment technologies (e.g., volume reduction technologies at the incident location, thermal treatment, neutralization), cost-effectiveness, and existing federal and state (and possibly local) legal requirements governing waste disposal.

5.2.1 General Considerations for Waste Disposal Options and Waste Volumes

As noted above, the complexity of radiological waste disposal decisions would depend on a number of factors, including the magnitude of the release and the decisions related to site cleanup. Consideration of these factors will determine the amount and types of waste requiring disposal. While disposal in a licensed low-level radioactive waste (LLRW) disposal facility may be the preferable first choice, there are a limited number of such facilities and not all states have access to all licensed commercial disposal facilities. If there is a limited radiological incident with relatively small waste volumes, existing capacity is available and may be sufficient to address waste disposal. However, waste resulting from a large-scale radiological incident, such as the event at the 2011 incident at the Fukushima nuclear facility, would likely overwhelm current disposal capacity. For large waste volumes, supplements to existing commercial radioactive waste disposal facilities would need to be considered, such as a combination of hazardous waste landfills, solid waste landfills, DOE disposal facilities, and potentially, the construction of a new disposal facility. Organizational and administrative issues related to federal and state government coordination and preparation are also important.

Discussions of waste disposal options often involve comparisons of estimated waste generation and available disposal capacity. The amount of waste generated is related to the cleanup approach, the selected approach to decontamination and remediation, as well as the long-term cleanup goals, and can affect the volume of waste actually requiring disposal. The projected amounts of wastes for a large-scale radiological incident may range from tens to hundreds of million cubic feet (or several million metric tons). Some of the waste may contain high radioactivity, especially at the incident's origin; however, most of the waste is expected to be only slightly contaminated, though in large quantities. The volume of contaminated soil in Japan resulting from the Fukushima incident is estimated to exceed one billion cubic feet.

As a point of comparison, roughly 28 million cubic feet of LLRW were disposed of at licensed commercial disposal facilities during the period 2002-2011. DOE disposed of approximately twice that volume in commercial facilities during the same period, in which it was involved in significant large-scale site cleanups.[59] Thus, over that ten-year period, an average annual volume of less than ten million cubic feet was disposed of in commercial facilities. Volumes from the non-governmental sector are not expected to increase significantly until the current fleet of NPPs is decommissioned. DOE generated additional waste volumes that were disposed of at DOE sites. For example, from 2000-2010, DOE disposed of approximately 20 million cubic feet of LLRW at the Nevada National Security Site (NNSS, formerly the Nevada Test Site). As it continues site cleanups, DOE projects generation of approximately 150 million cubic feet of LLRW for the period 2010-2015, most of which will be disposed of at the site of origin or other designated DOE sites.

[59] Information on disposal in commercial disposal facilities provided by the Manifest Information Management System (MIMS), operated by the DOE at http://mims.apps.em.doe.gov.

Managing the large volumes of waste resulting from a large-scale radiological incident, such as with the Fukushima accident, would likely overwhelm existing capacity in the U.S. and thus require an overall strategy employing all available types of disposal facilities and integrating federal, state, local and private sector assets. For example, consider the following—

- At the beginning of 2016, more than 150 million cubic feet of capacity was licensed at commercial disposal facilities. An incident could consume all remaining licensed commercial LLRW disposal capacity, which would affect waste generators in the energy, industrial, research and medical sectors for whom the capacity was originally licensed. While there may be remaining property at the facilities that could be developed, there is no guarantee that additional capacity can be licensed or that states will allow all capacity to be consumed.
- Estimated waste volumes are comparable to projected generation from the entire DOE complex over the next several years, which includes DOE's large-scale site cleanups. While DOE is somewhat less constrained than non-DOE disposal sites in adding additional disposal capacity at its sites, displacement of projected DOE disposal with incident-related waste has the potential to interfere with ongoing cleanup activities, leading to extended on-site storage, slower cleanups, and controversial efforts to expand disposal capacity at other DOE sites. Further, there is at present no mechanism to provide access to DOE disposal sites for disposal of incident-related waste.

5.2.2 Existing Disposal Options

An effective response to a large-scale radiological incident will involve consideration of the entire range of potential disposal options. The precise mix of disposal options employed will depend on the nature of the specific incident (e.g., location, waste volumes). The process selected to plan and conduct the long-term decontamination and remediation should identify and make provisions for using the different available disposal options.

Each of these potential disposal alternatives is discussed in more detail below. There may also be some remaining wastes that might require special consideration based on factors such as level of contamination, waste form, lack of access, or capacity or presence of other hazardous or toxic contaminants. These wastes could include those containing both hazardous and toxic constituents (e.g., mercury and PCBs—polychlorinated biphenyls), animal carcasses, or contaminated vehicles (where dismantling the vehicle may represent a greater potential for dispersal of contaminants and exposure of workers).

5.2.2.1 Commercially Licensed LLRW Disposal Facilities

Given that the bulk of the waste resulting from the release of radionuclides from a nuclear facility or a deliberate action will contain radionuclides commonly contained in LLRW, licensed commercial disposal facilities would be the most appropriate and publicly acceptable option for disposal if the volumes of waste from the incident were relatively small. It would be anticipated that the waste would be mostly at the lower end of radionuclide concentrations. Thus, these facilities will be capable of handling all but the most problematic waste types, if the amounts were limited. At present, all commercial LLRW disposal facilities are licensed by states (through agreements with NRC, referred to as "Agreement States").

As described earlier, available capacity and access are significant concerns in relying on commercial LLRW disposal facilities. Further, even if a facility would be generally available to all waste generators and it is found that all but a small portion of the waste would meet that facility's disposal criteria, it is possible that there may be objections to accepting all waste from an incident outside the state, even if the facility's capacity was sufficient.

Access to other facilities generally unavailable to the state(s) affected by the incident might be feasible in an emergency situation under NRC regulations, but it should not be expected that large volumes of waste will be accepted under these provisions. There is also the possibility that the affected state could construct a disposal facility to provide additional capacity. Several states conducted extensive studies of their

geology in anticipation of constructing disposal facilities and these studies may be of use in such situations.

5.2.2.2 Solid and Hazardous Waste Landfills

Most states are authorized by the EPA under the Resource Conservation and Recovery Act (RCRA) to operate their own hazardous waste management programs in lieu of the federal Subtitle C program.[60] Management of non-hazardous solid wastes is governed by RCRA Subtitle D, which is administered largely by the states. Compared to the number of licensed LLRW disposal facilities in the U.S., there are a greater number of commercial landfills operating under Subtitle C and many more operating under Subtitle D of RCRA for disposal of hazardous and solid wastes, respectively. It would not be expected that all of these facilities (particularly those operating under Subtitle D) would be appropriate disposal options. However, some of the hazardous waste landfills have accepted some radioactive material for disposal and a few have received the necessary state approvals to do so on a routine basis. Historically, most of the radiological waste streams accepted by hazardous waste landfills contain naturally-occurring radionuclides not regulated by NRC, such as wastes from the oil and gas or other resource extraction industries, as well as water treatment residuals. However, both NRC and DOE, in coordination with state regulators and facility operators, have approved disposal of radioactive waste in RCRA landfills on a case-by-case basis. Thus, there is reason to believe that one or more hazardous waste landfills could contribute to the disposal capacity for incident-related waste. The use of any particular RCRA facility for the disposal of radioactive contaminants or mixed contamination would require that the unit is well designed and managed appropriately. The uniform design and engineering requirements applicable to hazardous waste landfills would facilitate such an evaluation; by contrast, not all solid waste landfills are constructed to the same specifications. Further, the evaluation would include consideration of the waste characteristics, site characteristics, waste acceptance criteria, and other facility attributes.

RCRA hazardous and solid waste landfills may also offer the advantage of disposal capacity suitable for large volumes of lightly-contaminated material (e.g., soil).[61] In addition, these facilities are more likely to be located near the incident location, which can facilitate their use if deemed appropriate by federal, state and local officials. However, use of these facilities for disposal of radionuclides typically found in low-level radioactive waste, even if it contains very low concentrations of those radionuclides, may generate public concern if the facilities have not been previously approved for this type of disposal. Therefore, additional effort by state and local officials would be necessary to ensure the facility can manage the waste in a protective manner, including technical modification, if appropriate.

5.2.2.3 Potential Use of Federal Properties for New Disposal Capacity

DOE facilities could potentially be a disposal alternative that may be most appropriate for limited volumes of waste for which there is no other disposal outlet (such as high-activity waste, certain mixed wastes, or other problematic waste streams). Waste disposed at DOE sites must meet the waste acceptance criteria for those sites. DOE does not generally accept non-DOE-owned or generated waste for disposal at its sites. In addition, DOE has significant ongoing remediation at a number of sites that will generate large volumes of waste over the coming years. Diverting DOE disposal capacity to incident-related waste may interfere with those efforts. DOE has also utilized commercial LLRW disposal facilities, primarily for bulk waste streams from cleanups, and this potential disposal alternative may also be affected by a large-scale radiological incident.

[60] Alaska, Iowa, Puerto Rico, the Virgin Islands, American Samoa and the Trust Territories and Northern Marianas Islands do not have authorized RCRA programs as of the date of this publication.

[61] EPA reports that about 132 million tons of municipal solid waste were landfilled in 2009, comparable to the rate over the past two decades. The 2009 figure represents about 54 percent of total generation. (EPA 2010a)

DOE's primary disposal site serving the DOE complex is the NNSS. DOE/NNSS continues to excavate additional disposal capacity as needed and estimates that significant additional capacity could be developed at NNSS.

DOE's other designated site for complex-wide disposal is Hanford, WA; however, DOE has an agreement with the State of Washington that it will not bring waste from other sites until certain remediation milestones have been met. Overall, DOE anticipates that most of its waste generated in the coming years will be disposed at the site of generation. Sites other than NNSS and Hanford are designated for disposal of waste generated at those sites, although exceptional situations may allow for disposal of waste generated off-site and development of some additional disposal capacity. Additional disposal capacity would likely be dependent upon agreement from the state in which the facility is located.

In order to provide cleanup managers the use of all potential disposal capacity there are some issues that would need to be addressed, such as waste acceptance criteria for waste sites that have not been evaluated for radioactive material disposal. However, based on an understanding of the types of waste involved and the capabilities of existing disposal facilities, a generalized discussion of the attributes of the different disposal options, with qualifiers, can be developed and these attributes are discussed below.

COMPARISON OF ATTRIBUTES OF EXISTING DISPOSAL OPTIONS

- Licensed Commercial LLRW Disposal Facilities—
  - Can manage most anticipated waste types within license conditions.
  - Highest degree of public acceptance.
  - Significant bulk disposal volume possible.
  - Access restrictions may require special approval for waste from certain states.
  - Management of mixed radioactive and hazardous waste will need to ensure proper disposal and long-term groundwater monitoring.
- Solid and Hazardous Waste Landfills—
  - May offer local disposal option for expected large volumes with limited contamination.
  - May offer a disposal option at hazardous waste landfills for mixed wastes (mixtures of hazardous and radioactive wastes); hazardous waste landfills have specified construction and engineering requirements.
  - Need to consider the location of the units in proximity to large or sensitive populations, sensitive ecosystems, and sole source aquifers.
  - May require design modifications to ensure that the waste can be managed protectively over time.
  - Difficulty in obtaining public acceptance, although some hazardous waste landfills have accepted waste with limited radionuclide content with state approval.
  - Requires additional demonstration of suitability to ensure protectiveness for radiological material (e.g., groundwater monitoring, additional engineering controls); many solid waste landfills have not been evaluated for disposal of radioactive material and may not be suitable for radiological material.
  - May require longer-term/special monitoring, as well as institutional controls.
- DOE Disposal Sites—
  - Could potentially handle high-activity waste if insufficient commercial access or capacity.
  - May be suitable for some problematic waste types (e.g., whole vehicles).
  - DOE disposal facilities generally accept only DOE-owned or DOE-generated waste. Disposal of non-DOE waste requires additional review and agreements involving the host state, consistent with DOE's authorities, particularly where existing agreements limit DOE's waste disposal activities.

5.2.3 Planning and Coordination among Federal and State Entities for Disposal Options

A number of federal and state agencies may have important roles to play in making decisions on final disposal, depending on the extent of the waste. A framework for coordination with these various federal and state agencies should be an element of the process selected for long-term decontamination and remediation.

States should be intimately involved ahead of time in planning for a large-scale radiological incident and the resulting waste disposal. The following authorities regarding waste disposal may exist within affected states—

- All existing commercial LLRW disposal facilities are licensed by Agreement States.
- Many, but not all, states have formed regional compacts (as authorized by Congress) to site and operate LLRW disposal facilities; compacts control access to these sites.
- Although statutorily required[62] to provide disposal capacity for low-level waste generated within the compact boundaries (with certain exceptions), states are under no obligation to accept waste from outside their compacts. States that are not members of compacts do not have the statutory protection to prohibit disposal of out-of-compact waste.
- Many DOE disposal sites have agreements with the host State regarding the extent of long-term disposal or acceptance of off-site waste. States hosting DOE disposal sites should participate in planning for the potential disposal of incident-related off-site waste at DOE sites.
- States regulate hazardous waste landfills (when authorized by EPA) and solid waste landfills that may be used for disposal of waste with very low concentrations of radioactivity (see Section 5.2.2.2). In planning for disposal of incident-related waste, states should take into account any restrictions placed on the disposal of radionuclides in these facilities.
- It is anticipated that on-site disposal at a location affected by the incident, where appropriate, will be one location of choice and that an affected state could approve construction of a new disposal facility for that purpose.

Depending on the circumstances, coordination with numerous federal agencies would be necessary. Of particular note:

- EPA is the coordinating agency for long-term remediation and cleanup, as designated by the National Response Framework (FEMA 2008a) and has federal authority for hazardous waste disposal;
- DOE is "owner" of federal sites that may be used for waste disposal;
- NRC is the federal authority for commercial LLRW disposal; and
- USDA provides technical assistance for agricultural materials contaminated by the release, including animal carcasses.

5.2.4 Considerations for Modified Use of Existing Disposal Options

Depending on the circumstances, it may be appropriate to create additional disposal capacity. This decision would most likely need to involve extensive discussion between the federal government and the affected state(s) where an incident occurred. Generally, there are two options for additional disposal capacity—

- **On-site disposal.** As a result of evaluating available options, it may be advantageous to develop disposal capacity on-site (e.g., build a large disposal facility within the property boundaries where the facility causing the release is located), if the site is suitable.

[62] Pursuant to the Low-Level Radioactive Waste Policy Act of 1980 (LLRWPA) and the 1985 LLRWP Amendments Act of 1985.

- **Off-site disposal.** An additional option would be for a state or the federal government to build a disposal site on suitable public lands. The federal or state government could use the provisions of eminent domain to condemn property contaminated by a radiological incident and subsequently, then use it for waste disposal.

If it is determined that constructing a new disposal facility is the appropriate action, the proposed site(s) should be evaluated for suitability. Although the contemplated disposal actions would be taken in event of a national emergency, every effort should be made to ensure the protection of public health and the environment. Appropriate regulatory standards should be considered in developing a specific disposal plan. The disposal plan and site suitability should take into account the radiological characteristics of the waste. As discussed above, some slightly radioactive materials may be disposed in hazardous waste landfills if they are permitted for it. More radioactive materials may be sent to sites licensed as LLRW disposal facilities, though less contaminated materials may also be sent to LLRW disposal facilities. A small amount of waste from a radiological incident may have concentrated radioactivity, but most of the waste generated in a large-scale radiological incident would likely be contaminated with low levels of radioactivity. The different radiological characteristics of the waste would have a bearing on the stringency of containment required of a waste disposal facility. All waste sites would need to have appropriate controls to protect public health and the environment for any level of radioactive contamination, but more highly radioactive materials would need more robust controls than slightly contaminated material.

The physical/geographic characteristics of the site and the availability of land will be important in determining the appropriateness of a potential disposal site. Sites with limited rainfall, high evapotranspiration, deep water tables, and soil characteristics that limit migration of radionuclides have been found to be best suited for disposal of radioactive waste, although waste management and engineering can be applied to improve performance at sites with less favorable characteristics (e.g., controls on the waste form or level of allowable radioactivity, addition of liners, cover requirements, or through construction of concrete bunkers or vaults). Other characteristics, such as location in a high risk area (e.g., flood plain or seismic zone) or sensitive ecologic area, should also be considered. A disposal cell for 1 million cubic feet of waste will occupy 1 acre or more of surface area, assuming disposal to a depth of about 30 feet (9 meters). Large-scale disposal operations may also require extensive surface facilities.

Additional factors to evaluate the advantages and disadvantages among potentially suitable sites may include:

- Proximity to the incident: it may be useful to consider sites in different regions of the country to limit transportation demands;
- Proximity to residential areas or commercial districts: the potential for disposal activities to affect nearby populations or commercial activities, whether located within the site boundaries or on adjacent property, should be considered;
- Proximity to transportation: access to timely and direct transportation that can accommodate large shipments is desirable—action to facilitate: construction of transportation infrastructure (e.g., direct rail lines);
- Experience in waste disposal: waste disposal sites will have infrastructure, procedures and trained personnel that can make most efficient use of the site—action to facilitate: development of infrastructure, training, construction of disposal cells and engineered containment (e.g., vaults or bunkers); and
- Level of existing contamination: areas that are unlikely to be remediated in the near future or unlikely to be released for public use may be more acceptable for disposal.

5.2.5 Potential Federal Properties to Develop New Disposal Capacity

In addition to criteria for siting new disposal facilities, the federal government has control of a large amount of land throughout the U.S. that could be repurposed, or could offer assistance to support state governments in developing new facilities.

5.2.5.1 DOE Sites

DOE has decades of experience in radioactive waste management. In considering the primary selection criteria described above, DOE sites in the western U.S. generally have more favorable characteristics and readily available property compared to those in the eastern U.S. However, DOE has successfully implemented disposal at the eastern sites, often with some engineering enhancements. DOE has several categories of sites for consideration, beginning with the most suitable—

- Active disposal or cleanup sites in the western U.S.
- Active disposal or cleanup sites in the eastern U.S.
- Closed sites with disposal areas.
- Closed uranium milling sites.
- Other long-term stewardship sites.

Considerations: Some DOE sites have agreements with states or other stakeholders regarding further disposal or cleanup activities. Current disposal sites have waste acceptance criteria governed by DOE policy or statute. Closed and long-term stewardship sites may not have large amounts of additional property available for disposal.

5.2.5.2 DoD Installations

DoD maintains some installations with large land areas, primarily in the western U.S. Many of these sites have been contaminated through extensive training or other activities. DoD likely has more sites in the eastern U.S. than does DOE. Categories of sites that could be considered suitable include:

- Bombing and firing ranges;
- Chemical weapons demilitarization and storage sites;
- Ammunition plants and arsenals; and
- Surplus properties (e.g., BRAC – base realignment and closure, FUDS – formerly used defense site).

Considerations: Section 2692 of title 10, United States Code, "Storage, Treatment and Disposal of NonDefense Toxic and Hazardous Materials," generally states that the Secretary of Defense may not permit the use of an installation of the DoD for the storage, treatment, or disposal of any material that is a toxic or hazardous material and that is not owned either by the DoD or by a member of the armed forces (or by a dependent of the member) assigned to or provided military housing on the installation. Radiological waste resulting from either a nuclear accident or a terrorist attack may fall under this prohibition. The Secretary of Defense may grant exceptions to this restriction when "essential to protect the health and safety of the public from imminent danger." A determination of whether or not radiological waste meets the "imminent danger" threshold would be required.

Additionally, some DoD properties, including ranges in the western U.S., are on "withdrawn" lands, which are part of the public domain supervised by the Bureau of Land Management (BLM). Withdrawn land statutes permit DoD to use the property for specific military mission needs. The use of withdrawn lands to manage radiological waste would violate those statutes.

5.2.5.3 Other Federal Properties

Agencies such as the Department of Interior or USDA own large properties that could be considered suitable for disposal, many of which are in the western U.S. These properties may be administered by discrete entities within the cabinet-level departments, such as the National Park Service, BLM, or Forest Service. Some properties may be in proximity to DOE or DoD lands.

Considerations: Properties may be designated for public use or for protection (e.g., wilderness areas or preserves). Many properties are also in rugged terrain with difficult access or border tribal lands.

KEY POINTS IN CHAPTER 5 – LATE PHASE

- Numeric PAGs will not be used to guide restoration and recovery of areas impacted by a radiological incident; rather, planning activities should include a process to involve stakeholders in setting priorities and determining actions. Such a process should be flexible to adapt to a variety of situations.
- Planning considerations for worst case scenarios are provided. Smaller radiological incidents may be well addressed by existing emergency response and environmental cleanup programs at local, state, tribal and federal levels.
- Reoccupying households and businesses should be considered in balance with progress made in reducing radiation risks through decontamination, radioactive decay, and managing contaminated waste.
- Exposure limits that lead to excess lifetime cancer incidence in a range of one in a population of ten thousand (10^{-4}) to one in a population of one million (10^{-6}) are generally considered protective, though this may not be achievable after a large-scale radiological incident. In making decisions about cleanup goals and strategies for a particular event, decision-makers must balance the acceptable level of excess lifetime cancer incidence with the extent of the measures that would be necessary to achieve it.
- Incidents that result in large volumes of waste from a large-scale radiological incident would likely overwhelm existing radioactive waste disposal capacity in the U.S.
- Following a nuclear accident, the states bear primary responsibility to identify and provide waste management options, including disposal capacity; in the event of a terrorist attack, the federal government can offer a range of assistance to states to identify and implement waste management options.
- Safely managing and disposing of radioactive waste will require advance planning at all levels of government and careful coordination with stakeholders at all stages of the decision-making process.

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APPENDIX B – GLOSSARY

Acute health effects: Health problems caused by high radiation doses received in a short period of time. Examples of acute effects include erythema (reddening of skin), blistering, epilation (hair loss), and vomiting.

ALARA: Acronym for "as low as reasonably achievable" means making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practical consistent with the purpose for which the activity is undertaken.

Alpha radiation: Alpha radiation comes from the ejection of alpha particles from the nuclei of some unstable atoms. An alpha particle is identical to a helium nucleus and consists of two protons and two neutrons. Alpha particles are highly energetic, but can only travel a few centimeters in air. They have low penetrating power and can be stopped by a sheet of paper. Alpha particles generally cannot even penetrate the layer of dead cells on the skin, but can pose a health risk when inhaled or ingested.

Avoided dose: The radiation dose saved by implementing a protective action.

Best Available Technologies (BAT): BATs are treatment technologies, treatment techniques, or other means that the U.S. EPA administrator determines to be available, after examination for efficacy under field conditions and not solely under laboratory conditions (taking cost into consideration).

Beta radiation: Beta radiation comes from the emission of beta particles during radioactive decay. Beta particles are highly energetic and fast-moving. They carry a positive or negative charge and can be stopped by a layer of clothing or few millimeters of a solid material. Beta particles can penetrate the skin and cause skin burns, but tissue damage is limited by their small size. Beta particles are most hazardous when inhaled or ingested.

Centigray (cGy): One cGy is equal to one hundredth of a gray (0.01Gy). See Gray. One cGy is equivalent to one rad. See Rad.

Cloudshine: Gamma radiation emitted from an airborne plume overhead.

Committed effective dose: The sum of the committed equivalent doses following intake (inhalation or ingestion) of a radionuclide to each organ multiplied by a tissue weighting factor.

Community Water Systems (CWS): A public water system that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

Contamination: Radionuclides on a surface or in the environment as a result of an accidental release.

Concentration: Radionuclide activity per unit of mass.

Chronic effects: Health problems caused by radiation doses delivered over a long period. Examples of chronic effects include cancer and genetic mutations.

Derived Intervention Level (DIL): Concentration derived from the intervention level of dose at which introduction of protective measures should be considered. (FDA 1998)

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

Dose: The amount of radiation exposure a person has received, calculated considering the effectiveness of the radiation type (alpha, beta, gamma), the timeframe of the exposure, and the sensitivity of the person or individual organs.

Dose parameter (DP): Any factor that is used to change an environmental measurement to dose in the units of concern.

Dose projection: A calculated future dose that an individual might receive; also the process of making these calculations.

Dose reduction factor: A factor by which a decontamination technique or protective action reduces the radiation dose to a person.

Dosimetry: The system for assessing radiation doses from external radiation exposures and from intakes of radionuclides using biokinetic models and dosimetric quantities developed by the ICRP and the International Commission on Radiation Units and Measurements (ICRU).

Early phase: The beginning of a radiological incident for which immediate decisions for effective use of protective actions are required and must therefore be based primarily on the status of the radiological incident and the prognosis for worsening conditions. This phase may last from hours to days.

Effective dose: The sum of organ equivalent doses weighted by ICRP organ weighting factors.

Emergency Planning Zone: A designated zone around a commercial nuclear power plant for which radiological response plans must be maintained under Nuclear Regulatory Commission regulations.

Emergency worker: Anyone with a role in responding to the incident whether a radiation worker previously or not, who should be protected from radiation exposure.

Evacuation: The urgent removal of people from an area to avoid or reduce high-level, short-term exposure, from the plume or from deposited radioactivity. Evacuation may be a preemptive action taken in response to a facility condition rather than an actual release.

Gamma radiation: Gamma radiation comes from the emission of high-energy, weightless, chargeless photons during radioactive decay. Gamma photons are pure electromagnetic energy and highly penetrating—several inches of lead or a few feet of concrete may be required to attenuate them. External exposure to gamma rays poses a health threat to the entire body. Inhalation and ingestion of gamma emitters also poses a health threat.

Graves' disease: An autoimmune disorder that leads to the over activity of the thyroid.

Gray (Gy): International unit of absorbed radiation dose. One Gy is equivalent to 100 rad. See Rad.

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

Half-life: The time required for half the atoms of a given radioisotope to transform by radioactive decay.

Hashimoto's thyroiditis: An autoimmune disorder that leads to underactive thyroid with bouts of over activity.

Improvised Nuclear Device (IND): A crude, yield-producing nuclear weapon fabricated from diverted fissile material.

Intermediate phase: The period beginning after the source and releases have been brought under control (has not necessarily stopped but is no longer growing) and reliable environmental measurements are available for use as a basis for decisions on protective actions and extending until these additional protective actions are no longer needed. This phase may overlap the early phase and late phase and may last from weeks to months.

Isodose-rate line: A contour line that is used to connect points of equal radiation dose rates.

Late phase: The period beginning when recovery actions designed to reduce radiation levels in the environment to acceptable levels are commenced and ending when all recovery actions have been completed. This phase may extend from months to years. A PAG level, or dose to avoid, is not appropriate for long-term cleanup.

Latency period, cancer: The time elapsed between radiation exposure and the onset of cancer.

Maximum Contaminant Level (MCL): An enforceable standard established to protect the public against consumption of drinking water contaminants that present a risk to human health. A MCL is the maximum allowable amount of a contaminant in drinking water that is delivered to the consumer.

Microsievert (μSv): One millionth of a Sievert. See Sievert. One ten-thousandth of a rem. See Rem. (1 μSv = 0.1 mrem (millirem))

Millirem (mrem): One thousandth of a rem. See Rem.
(1 mrem = 0.00001 Sv (sievert) = 0.01 mSv (millisievert) = 10 μSv (microsievert))

Millisievert (**mSv):** One thousandth of a sievert. See Sievert.
(1 mSv = 100 mrem (millirem) = 0.1 rem)

Noble gases: A group of elemental gases that are tasteless, odorless, and that do not undergo chemical reactions under natural conditions. The noble gases consist of Helium (He), Neon (Ne), Argon (Ar), Krypton (Kr), Xenon (Xe), and Radon (Rn).

Off-site: Areas outside the controlled border of a facility, such as a nuclear power plant. For an incident not involving a facility, this term may also be used to refer to areas impacted by contamination.

On-site: Areas inside the controlled border of a facility, such as a nuclear power plant. For an incident not involving a facility, this term may refer to areas controlled during a response.

Potassium iodide: A salt of stable, non-radioactive iodine in medicine form. The administration of potassium iodide saturates the thyroid with non-radioactive iodine, so it does not absorb radioactive iodine released into the environment from a radiological incident.

Projected dose: The prediction of the dose that a population or individual could receive.

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

Protective Action Guide (PAG): The projected dose to an individual, resulting from a radiological incident at which a specific protective action to reduce or avoid that dose is warranted.

Prophylactic: A treatment or medication designed to prevent exposure to radiation.

Rad (radiation absorbed dose)**:** A basic unit of absorbed radiation dose. It is being replaced by the "gray," which is equivalent to 100 rad. One rad equals the dose delivered to an object of 100 ergs of energy, per gram of material.

Radioactive: Quality of a material that emits alpha particles, beta particles, gamma rays, or neutrons.

Radiological dispersal device (RDD): A device or mechanism that is intended to spread radioactive material from the detonation of conventional explosives or other means. An RDD is commonly known as a "dirty bomb."

Radiopharmaceutical: A radioactive chemical used for diagnosis, cure, treatment, or prevention of diseases.

Recovery: The phase after response when efforts focus on remediation, or the process of reducing radiation exposure rates and concentrations of radioactive material in the environment to levels acceptable for unconditional occupancy or use.

Reentry: Workers or members of the public going into relocation or radiological contaminated areas on a temporary basis under controlled conditions.

Release: Uncontrolled distribution of radioactive material to the environment.

Relocation: The removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. Not to be confused with *evacuation*.

Reoccupancy: The return of households and communities to relocation areas during the cleanup process, at radiation levels acceptable to the community.

Rem (roentgen equivalent man): The product of the absorbed dose in rads and a weighting factor which accounts for the effectiveness of the radiation to cause biological damage; a conventional unit for equivalent dose. One rem equals 0.01 Sv.

Release rate: The measure of the amount of radioactive material dispersed per unit of time.

Return: Permanent resettlement in evacuation or relocation areas with no restrictions, based on acceptable environmental and public health conditions.

Roentgen (R): A conventional unit for exposure. For x-ray and gamma radiation, Rad ~ rem ~ Roentgen (R). A handheld survey meter that reads in R/hr can be used to measure exposure rates.

Shelter-in-place: The action of staying or going indoors immediately.

Sievert (Sv): International unit of equivalent dose. One sievert equals 100 rem.
(1 Sv = 1,000 mSv (millisieverts) = 1,000,000 μSv (microsieverts) = 100 rem = 100,000 mrem (millirem))

Small System Compliance Technologies (SSCT): Treatment technologies that achieve compliance with Maximum Contaminant Levels and which have been identified by EPA as being affordable for small drinking water systems serving fewer than 10,000 persons.

Source term: The amount of a contaminant available in a scenario or actually released to the environment.

Stay time: Term of art used in the radiation safety field. Stay times are the amount of time a person may access the contaminated area. These times vary based upon site-specific factors or incident characteristics such as indoor or outdoor work, sensitive populations, and level of radioactivity.

Total Effective Dose (TED): The sum of the effective dose (for external exposures) and the committed effective dose; also referred to in this Manual as whole body dose. See Section 2.3.

Whole Body Dose: See Total Effective Dose.

APPENDIX C – LIST OF ACRONYMS

AEA	Atomic Energy Act
ALARA	As Low as Reasonably Achievable
ANS	American Nuclear Society
BAT	Best Available Technology
BEIR	Committee on the Biological Effects of Ionizing Radiation (BEIR) of the National Academy of Sciences
BLM	Bureau of Land Management
Bq	Becquerel (measurement unit)
CDC	Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
cGy	Centigray (measurement unit)
Ci	Curie (measurement unit)
cpm	Counts per minute (measurement unit)
CRARM	Presidential/Congressional Commission on Risk Assessment and Risk Management
CWS	Community Water System
DCF	Dose Conversion Factor
DHS	Department of Homeland Security
DIL	Derived Intervention Levels
DoD	Department of Defense
DOE	Department of Energy
DOL	Department of Labor
DP	Dose Parameter
DRL	Derived Response Level
DTPA	Diethylenetriaminepentaacetic acid or Pentetic acid
EAL	Emergency Action Level
EPA	Environmental Protection Agency
EPZ	Emergency Planning Zone
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FRC	Federal Radiation Council
FRMAC	Federal Radiological Monitoring and Assessment Center
FRPCC	Federal Radiological Preparedness Coordination Committee
hr	Hour
Gy	Gray (measurement unit)

HAZWOPER	Hazardous Waste Operations and Emergency Response
HHS	Department of Health and Human Services
HPS	Health Physics Society
IAEA	International Atomic Energy Agency
ICP	Incident Command Post
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
IC/UC	Incident Command/Unified Command
ICS	Incident Command System
IND	Improvised Nuclear Device
JFO	Joint Field Office
JIC	Joint Information Center
KI	Potassium Iodide
km	Kilometer
L	Liter
LLRW	Low-level radioactive waste
LLRWPA	Low-Level Radioactive Waste Policy Act
MCL	Maximum Contaminant Level
mg	Milligram (measurement unit)
MIMS	Manifest Information Management System
mL	Milliliter (measurement unit)
µR	Microroentgen (measurement unit)
µSv	Microsievert (measurement unit)
mSv	Millisievert (measurement unit)
mrem	Millirem (measurement unit)
mR	Milliroentgen (measurement unit)
NAS	National Academy of Sciences
NCP	National Contingency Plan
NCRP	National Council on Radiation Protection and Measurements
NIMS	National Incident Management System
NNPP	Naval Nuclear Propulsion Program
NNSS	Nevada National Security Site
NPDWR	National Primary Drinking Water Regulation
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRF	National Response Framework
NDRF	National Disaster Recovery Framework

NSS	National Security Staff
NUREG	NRC technical report designation (Nuclear Regulatory Commission)
OSHA	Occupational Safety and Health Administration
PAG	Protective Action Guide
pCi	Picocurie (measurement unit)
PIO	Public Information Officer
PPE	Personal Protective Equipment
R	Roentgen (measurement unit)
RASCAL	Radiological Assessment System for Consequence Analysis
Rem	Roentgen equivalent man (measurement unit)
REMM	Radiation Emergency Medical Management
RESRAD	RESidual RADioactivity (computer code developed by Argonne National Laboratory)
RCRA	Resource Conservation and Recovery Act
RDD	Radiological Dispersal Device
SDWA	Safe Drinking Water Act
SSCT	Small System Compliance Technology
SNL	Sandia National Laboratories
Sv	Sievert (measurement unit)
TED	Total Effective Dose
USDA	United States Department of Agriculture

United States
Environmental Protection Agency

Office of Air and Radiation
1200 Pennsylvania Avenue, N.W. (6101A)
Washington, DC 20460

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