2013

PAG Manual

Protective Action Guides
And Planning Guidance
For Radiological Incidents

U.S. Environmental Protection Agency
Draft for Interim Use and Public Comment
March 2013

This page intentionally left blank.

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, states, or any other federal agency.

This page intentionally left blank.

TABLE OF CONTENTS

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, with the exception of nuclear war.

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;
- acquiring an alternate source of drinking water;
- 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. 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, nonemergency 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 and specifically for radiological incidents, the Nuclear Radiological Incident Annex: http://www.fema.gov/pdf/about/divisions/thd/IncidentNucRad.pdf (FEMA 2008a,b).

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. Or 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.

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;
- 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;
- 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 the U.S. 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 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 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 directed EPA in their Radiological Emergency Planning and Preparedness Regulations 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 "[d]evelop, 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.

1.3.2. 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 1989). 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.

1.3.3. 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, the Department of Homeland Security (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 (DOC), 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.

1.3.4. 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 (DOE 2010a, b),[1] though using other incident-specific dose assessment methodologies is encouraged, where appropriate.

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 decision to lower the PAG for administration of stable iodine to 5 rem (50 millisieverts (mSv)) projected child thyroid dose. Finally, this update removes the intermediate phase relocation PAG of 5 rem (50 mSv) over 50 years to avoid confusion with long-term cleanup. All other PAGs and corresponding protective actions from the 1992 PAG Manual remain unchanged.

[1] See FRMAC Assessment folder at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

Recommended limits of exposure for emergency workers also remain unchanged from the 1992 PAG Manual. The emergency worker guides in this manual are consistent with federal and state regulations. Responsible officials should use judgment when doses may exceed regulatory limits and must advise workers of the risks Table 1-1 presents PAGs with their principal associated protective actions or planning guides.

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.

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 when 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 to relocation areas for specific tasks are suggested and basic planning guidance for late phase cleanup is provided in Chapters 3 and 4.

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 environmental radioactivity and dose models. 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.

Table 1-1. Planning Guidance and Protective Action Guides for Radiological Incidents

Phase	Protective Action Recommendation	Protective Action Guide or Planning Guide
Early (Chapter 2)	Sheltering-in-place or evacuation of the public[a]	1 to 5 rem (10 mSv to 50 mSv) projected dose/4 days[b]
	Administration of prophylactic drugs KI[c]	5 rem (50 mSv) projected child thyroid dose[d] from radioactive iodine
	Limit emergency worker exposure	5 rem (50 mSv)/year (or greater under exceptional circumstances)[e]
Intermediate (Chapter 3)	Relocation of the public	2 rem (20 mSv) projected dose first year[b] Subsequent years, 0.5 rem (5 mSv)/year projected dose
	Food interdiction[f]	0.5 rem (5 mSv)/year projected dose, or 5 rem (50 mSv)/year to any individual organ or tissue, whichever is limiting
	Limit emergency worker exposure	5 rem (50 mSv)/year[b]
	Reentry	Operational Guidelines[g] (Stay times and concentrations) for specific activities (see Section 3.7)
Late (Chapter 4)	Cleanup	Brief description of planning process
	Waste Disposal	Brief description of planning process

[a] 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.

[b] Projected dose- the sum of the effective dose from external radiation exposure (i.e., groundshine and cloudshine) and the committed effective dose from inhaled radioactive material.

[c] Provides thyroid protection from internal exposure to radioactive iodines only. For other information on radiological prophylactics and treatment, refer to http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness/ucm063807.htm http://www.bt.cdc.gov/radiation and www.orau.gov/reacts

[d] Thyroid equivalent dose. For more information, refer to http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness/ucm072265.htm.

[e] 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 2, Section 2.6.

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

[g] 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)

Protective actions may already be designated in existing emergency response plans. Under NRC regulations, large commercial NPPs must maintain detailed radiological response plans for an emergency planning zone (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. Emergency responders should be prepared to select and implement appropriate protective actions when standing response plans are not available or applicable.

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 may be sufficient 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.

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 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 activity. 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 3.3.1 for more details).

Intermediate phase PAGs are based on doses projected in the first and a limited number of subsequent 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), 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 to the removal and disposal of soil and contaminated debris.

Keeping projected doses below the 0.5 rem (5 mSv) PAG for out years – the second year and beyond – 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 relocation area for tasks related to critical infrastructure and key resources, to care for animals and to assess the condition of closed zones. 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.

EPA is not proposing a specific drinking water PAG at this time. EPA has established enforceable drinking water standards for radionuclides under the Safe Drinking Water Act (SDWA). EPA recommends that, to the extent practicable, emergency measures for drinking water be based on the National Primary Drinking Water Regulations (NPDWR) for Radionuclides. The Radionuclides Rule provides states with flexibility when responding to radiological events. If a public water system exceeds the radionuclides standard it must work to get back into compliance as soon as feasible. States have the authority to determine if other corrective actions are needed (e.g. providing alternative water). Guidance on monitoring, notification and protective actions is provided in Chapter 3, along with several online resources for drinking water system operators.

However, in light the Fukushima nuclear power plant accident, in which some Japanese drinking water supplies were impacted, the Agency recognizes a short-term emergency drinking water guide may be useful for public health protection The Agency requests input on the appropriateness of, and possible values for, a drinking water PAG.

While the NPDWR provide for a regulatory standard of 4 mrem/year (beta, photon emitters) based on life-time exposure, international organizations have developed technical approaches and methodologies that have produced a range of emergency guidelines related to drinking water (e.g., the World Health Organization[2], the International Atomic Energy Agency[3]), as have other federal agencies (e.g. the Department of Homeland Security[4], the Food and Drug Administration[5]) and non-federal organizations. EPA is seeking input on an approach and technical rationale for a drinking water PAG designed to help officials select protective actions under emergency conditions when exposures would occur over shorter time periods than those envisioned in the NPDWR.

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 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. 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 U.S. EPA's Superfund program, the U.S. 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 4, 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 and specifically for radiological incidents, the Nuclear Radiological Incident Annex: http://www.fema.gov/pdf/about/divisions/thd/IncidentNucRad.pdf (FEMA 2008a, b).

[2] See: http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/ and http://www.who.int/hac/crises/jpn/faqs/en/index8.html
[3] See: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1467_web.pdf.
[4] See: http://ogcms.energy.gov/73fr45029.pdf and the
[5] See: http://www.fda.gov/downloads/MedicalDevices/.../UCM094513.pdf.

The late phase or cleanup process described in Chapter 4 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 4, the late phase. This guidance addresses both locations that may be identified 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 already 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.

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, 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 4.
- 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

2.1. INTRODUCTION

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 conversion factors (DCFs) and derived response level (DRL) methods referenced in the FRMAC Assessment Manuals (DOE 2010a, b).[6] Other calculation methods to implement PAGs may be appropriate.

2.2. EXPOSURE PATHWAYS DURING THE EARLY PHASE

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 beta and gamma radiation as "groundshine" after the plume has passed causing continued exposure to skin and internal body organs. Similarly, skin and clothes may become contaminated.

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

[6] See FRMAC Assessment folder at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

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 above the contaminated surface provides a direct measurement of 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 3). Exposure pathways that contribute less than ten percent to the total dose incurred need not be considered during the early phase.

2.2.1. The 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[7] at ground level (measured at approximately 1 m 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[8] A and B, y = 2; for stability classes C and D, y = 1.5; and for stability classes E and F, y = 1. Classes A and B (unstable) occur with light winds and strong sunlight and classes E and F (stable) with light winds at night. Classes C and D generally occur with winds stronger than about 10 mph. This method of extrapolation is risky because the measurements available at the reference distance may be unrepresentative, especially if the plume is aloft and has a looping behavior. In the case of an elevated

[7] 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.

[8] 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. The Meteorological Magazine 90, No. 1063, 33-49.

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) 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.

2.3. 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 activity. Sheltering-in-place is the action of staying or going indoors immediately. The administration of KI (stable iodine) 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 primarily to provide protection from beta radiation from radioiodines and particulate materials deposited on the clothing.

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. The basis for the PAGs for the early phase is given in Appendix C of the 1992 PAG Manual, available online as a historical reference at http://www.epa.gov/radiation/rert/pags.html.

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

Protective Action Response	PAG (projected dose)	Comments
Sheltering-in-place or evacuation of the public[a]	1 to 5 rem (10 mSv to 50 mSv) over four days[b]	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[c]	5 rem (50 mSv) projected dose to child thyroid from exposure to iodine[d]	KI is most effective if taken prior to exposure. May require approval of state medical officials (or in accordance with established emergency plans).

[a]Should begin at 1 rem (10 mSv) 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.
[b]Calculated dose is the projected sum of the effective dose from external radiation exposure (i.e., groundshine) and the committed effective dose from inhaled radioactive material.
[c]Provides thyroid protection from radioactive iodines only. For other information on radiological prophylactics and treatment, refer to http://www.fda.gov/Drugs/EmergencyPreparedness/BioterrorismandDrugPreparedness, http://www.emergency.cdc.gov/radiation or http://www.orau.gov/reacts.
[d]Thyroid equivalent dose (see Section 2.3.5).

2.3.1. Evacuation vs. Sheltering-in-Place

Evacuation can be 100 percent effective in avoiding dose if completed before plume arrival. Evacuation is appropriate when its risks and secondary effects are less severe than the risk of the projected radiation dose.

Evacuation and sheltering-in-place provide different levels of dose reduction from the principal exposure pathways: direct gamma exposure and inhalation. Both sheltering 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 colocated 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, since vehicles used to transport evacuees provide little protection against exposure (DOE 1990). Evacuation will seldom be justified at less than 1 rem (10 mSv) over the first four days.

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).[9]

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.

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.

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., a fire in the structure or 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 EPZ and on actual conditions at the nuclear facility (see Section 2.3.5). For transportation accidents, RDDs, INDs and other incident

[9] See: http://www.epa.gov/rpdweb00/docs/er/planning-guidance-for-response-to-nuclear-detonation-2-edition-final.pdf

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.

2.3.2. General Guidance for Evacuation and Sheltering-in-Place

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 also appropriate for protection from groundshine in areas with high exposure rates from deposited 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 in 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;
        - 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—
    - 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. Shelters should be opened to vent any airborne radioactivity trapped inside and people should remain sheltered until official notice about leaving high exposure areas as soon as possible to avoid exposure to deposited radioactive material.

2.3.3. Considerations for Evacuation and Sheltering In Place

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 responders.

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.

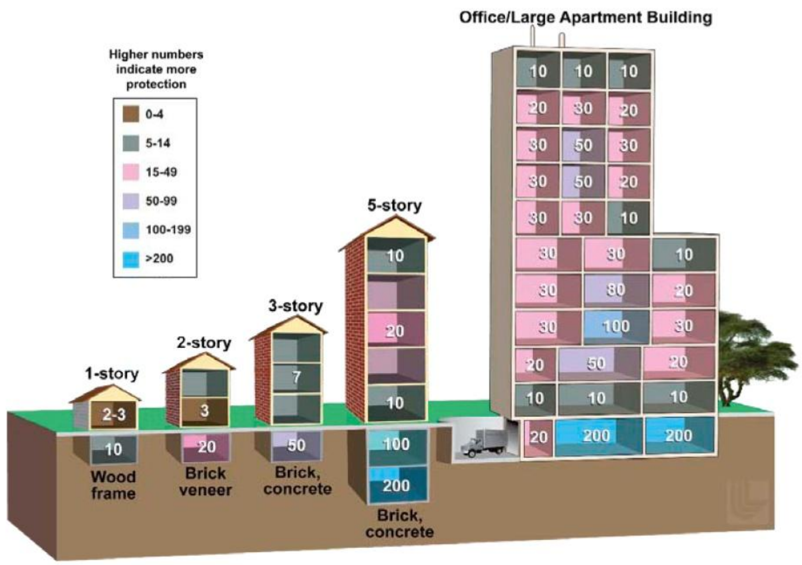
Regardless of size, large or small population groups can be evacuated effectively with minimal risk of injury or death. In the NRC report, only six of the 50 cases studied involved deaths from the hazard and of those six, only one involved death from the evacuation itself (NRC 2005).

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, 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).

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.

2.3.4. Considerations for Potassium Iodide (KI)

FDA updated its guidance on the use of KI as a thyroid blocking agent during radiological emergencies in 2001 (FDA 2001 and FDA 2002). 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).

FDA recommends the following—

- Children 0-18 years of age: Administer KI when the projected radiation dose to the thyroid from exposure to radioiodine is 5 rem (50 mSv) or greater.
- Pregnant and lactating women: Administer KI when the projected radiation dose to the thyroid from exposure to radioiodine is 5 rem (50 mSv) or greater.
- Adults up to 40 years of age: Administer KI when the projected radiation dose to the thyroid from exposure to radioiodine is 10 rem (100 mSv) or greater.
- Adults over 40 years of age: Administer KI when the projected radiation dose to the thyroid from exposure to radioiodine is over 500 rem (5 Sv) in order to prevent hypothyroidism.

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) projected internal thyroid exposure in children) (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 daily until the risk of significant exposure to radioiodine (either by inhalation or ingestion) no longer exists.

It should be noted that adults over 40 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 them to adverse reactions should avoid KI.

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 stable iodine, 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 get their 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 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.

2.3.5. 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 520/1-7-016 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)[10] 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." 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." Because of the relatively limited number and diverse nature of these facilities, the size of the EPZs, is determined, if needed, on a case-by-case basis for reactors with an authorized power level less than 250 MW 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 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,

[10] 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. Therefore, less than about 1% 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.

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.[11] 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.) EPZs are not necessary at those facilities where it is not possible for PAGs to be exceeded off-site.

2.4. 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 (DOE 2010a, b)[12] 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.

2.4.1. 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. 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-

[11] The development of EPZs for nuclear power facilities is discussed in the NUREG 0396.
[12] See FRMAC Assessment folder at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

site officials.[13] 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 monitor 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 3).

2.4.2. 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 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 3.

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

Another factor affecting the estimation of projected dose is the duration of the plume at a particular location. For purposes of calculating projected dose from most pathways, exposure will start at a particular location when the plume arrives and 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

[13] Immediate protective actions based on in-plant conditions are not applicable to naval nuclear propulsion plants. See Footnote 7 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.

duration of a release may range from less than 1 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. Time frames for releases from other facilities will depend on the characteristics of the facility.

2.4.3. Derived Response Levels and Dose Conversion Factors

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. A Dose Conversion Factor (DCF) is any factor used to change an environmental measurement to dose in the units of concern. Depending on the exposure pathway, other factors besides the DCF may be required to convert an environmental measurement into a dose.

The FRMAC Assessment Manuals (DOE 2010a, b)[14] provide guidance in calculating DRLs and DCFs based on the ICRP dosimetry models (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.

2.5. EMERGENCY WORKER PROTECTION

These emergency worker guidelines 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 (Table 2-2) should not be viewed as inflexible limits applicable to the range of early phase emergency actions covered by this guidance. 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. 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 valuable property (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 medical evaluation of emergency workers 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

[14] See FRMAC Assessment folder at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

emergency differ from those in normal operations. Although there are times when implementation of standards or guidelines can cause or enhance other risks, these secondary risks can be controlled. 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, the National Council on Radiation Protection and Measurements (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 2001) 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).

2.6. CONTROLLING OCCUPATIONAL EXPOSURE AND DOSES TO EMERGENCY RESPONDERS

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[15] and NCRP 165[16] for recommendations that support ALARA).

2.6.1. Maintaining the ALARA Principle

To minimize the risks from exposure to ionizing radiation, employers of emergency responders should prepare emergency response plans and protocols in advance to keep worker exposures ALARA, an acronym for "as low as is 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. 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.
- Maintaining the maximum 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.

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

- 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 should include protocols to control worker exposures, establish exposure guidelines in advance and outline procedures for worker protection. Emergency procedures should include provisions for exposure monitoring, worker training commensurate with the hazards involved in response operations and ways to control them and medical monitoring.

2.6.2. Understanding Dose and Risk Relationships

Response 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 document provide a guideline level of 5 rem (50 mSv) for worker protection and alternative response worker guidelines (see Table 2-2) for certain activities where exposures below 5 rem (50 mSv) cannot be maintained. 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 guide 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, exposure control options may be unavailable or insufficient and doses above 5 rem (50 mSv) may be unavoidable.

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 Response Worker Guidelines for life and property saving activities in Table 2-2 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.

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 Response Worker Guidelines in Table 2-2 may be unavoidable in responding to such events. Emergency responders undertaking a mission covered under the response worker guidelines should be informed when radiation control measures may not prevent doses from exceeding the 5 rem (50 mSv), general occupational exposure guideline and should be made fully aware of the sub-chronic and chronic risks involved, including numerical estimates of the risk of delayed health effects.

Table 2-2. Response 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 valuable property 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.

[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 response worker guidelines to prevent further loss of life and massive spread of destruction.

The 25 rem (250 mSv) lifesaving response 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) Response Worker Guideline should only be undertaken with an understanding of the potential acute effects of radiation to the exposed responder (see Table 2-3) and only when the benefits of the action clearly exceed the associated risks.

The estimated risk of fatal cancer[17] 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 risk of fatal cancer of 1.5 percent (15 cases per thousand exposed). Because of the latency period of cancer, younger workers face a larger risk of fatal cancer than older workers (for example, 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).[18]

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 have risk factors for specific radionuclides.

Table 2-3. Acute Radiation Syndrome [a]

Feature or Illness	Effects of Whole Body Absorbed Dose from external radiation or internal absorption, by dose range in rad				
	0-100	100-200	200-600	600-800	>800
Nausea, Vomiting	None	5-50%	50-100%	75-100%	90-100%
Time of Onset		3-6 h	2-4 h	1-2 h	<1 h to minutes
Duration		<24 h	<24 h	<48 h	<48 h
Lymphocyte Count	Unaffected	Minimally Decreased	<1000 at 24 h	<500 at 24 h	Decreases within hours
Central Nervous	No	No Impairment	Cognitive	Cognitive	Rapid

[17] Risk per dose of a fatal cancer is assumed to be about 6×10^{-4} per rem (6×10^{-5} per mSv). Cancer incidence is assumed to be about 8×10^{-4} per rem (8×10^{-5} per mSv). (EPA 1999)

[18] The numerical estimate of cancer risk presented above (from Federal Guidance #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)

System Function	Impairment		impairment for 6-20 h	impairment for > 20 h	incapacitation
Mortality	None	Minimal	Low with aggressive therapy	High	Very High: Significant neurological symptoms indicate lethal dose
Source: Medical Management of Radiological Casualties, Second Edition, Armed Forces Radiobiology Research Institute. Bethesda, MD, April 2003. [a] Percentage of people receiving whole-body doses within a few hours expected to experience acute health effects.					

Prior to 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).

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). Incident commanders and responders need a thorough understanding of the worker exposure guidelines for radiological emergency response, including the associated risks and specific worker protection procedures. The FRMAC "Radiological Emergency Response Health and Safety Manual" (FRMAC 2001) provides detailed information. Additional resources for advance planning are available on the Radiological Emergency Medical Management (REMM) web site: http://www.remm.nlm.gov/.

2.6.3. 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).

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.[19] 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 workers in states that do not have occupational health and safety plans.

In addition to the Occupational Safety and Health Act, several federal agencies (DOE, NRC and OSHA) and Agreement States issue occupational radiation safety standards (see Table 2-4). The occupational standards are not guidelines but instead are regulatory limits that cannot be exceeded except under certain

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

conditions. These occupational limits allow workers to receive radiation exposure during the course of performing their jobs.
Federal and state radiation safety standards recognize that it may be necessary to exceed dose limits to take critical lifesaving actions.

Table 2-4. Regulations for Worker Protection

Agency	Statutory Requirement	Title
Occupational Safety and Health Administration[1]	29 CFR 1910.120	Safety and Health-- HAZWOPER
	29 CFR 1910. 1096	Ionizing Radiation
Environmental Protection Agency[1]	40 CFR 311	Occupational Radiation Protection
Nuclear Regulatory Commission[2]	10 CFR 20	Standards for Protection Against Radiation
Department of Energy[3]	10 CFR 835	Radiation Protection Regulations

1. All states are either regulated by federal regulations or by respective state regulations. 40 CFR 311 applies the HAZWOPER standard in states that do not have their own occupational health and safety program.
2. NRC employees are covered by NRC Management Directive 10.131, ''Protection of NRC Employees Against Ionizing Radiation.'' Section VI, Guidance for Emergency Exposure Controls During Rescue and Recovery Activities, deals specifically with radiation exposure control during emergencies
3. 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 835.

2.7. CONTAMINATION LIMITS 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 such people have been evacuated or relocated.

People working in the parts of the restricted areas in which their dose from the residual radioactivity would exceed 2 mrem (20 µSv) in any hour or 100 mrem (1 mSv) in a year should operate under the controlled conditions established for occupational exposure.

Adults may reenter restricted 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.

A contaminated item 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 less than two times (2x) the existing background levels. 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.

2.8. SURFACE CONTAMINATION CONTROL

Surface contamination must be controlled both before and after relocation protective actions are implemented. 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;
- internal dose from absorption of contamination into wounds.

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

It is not practical to set contamination limits 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 event progresses to using lower contamination control 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 events involving fixed nuclear facilities, some evacuation reception centers or shelters will have walk-through portal monitors.

2.8.1. Priorities for Control of Contaminated Areas

The following priorities are recommended—

1. Do not delay urgent medical care for decontamination efforts or for time-consuming protection of attendants, such as donning of additional anti-contamination clothing.
2. In early phase scenarios where it might not be practical or would interfere with other life-saving and public health protection priorities, do not waste effort trying to contain contaminated wash water and be sure to notify sewage treatment plants.
3. Do not allow monitoring and decontamination to delay an ordered evacuation.
4. *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. Gamma exposure rates in such areas should be less than 5 millirem (50 µSv) per hour. 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. Table 2-5 provides guidance on surface contamination levels for use if such centers are needed.
5. Establish monitoring and personnel decontamination (e.g., bathing) facilities at evacuation centers or other locations in low background areas (less than 0.1 millirem (1 µSv) per hour). *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 these centers for monitoring. For more specific considerations on control of contaminated areas refer to "Population Monitoring in Radiation Emergencies: A Guide for State and Local Public Health Planners" (CDC 2007).[20] Table 2-6 provides surface contamination guidance. These screening levels are examples derived primarily on the basis of easily measurable radiation levels using portable instruments.
6. After the relocation 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 limits for the station, they should be sent for further decontamination or for medical or other special attention.

[20] See: http://emergency.cdc.gov/radiation/pdf/population-monitoring-guide.pdf

Table 2-5. Recommended Surface Contamination Screening Levels for Emergency Screening of People and Objects at Monitoring Station in High Background Radiation Areas (0.1 mR/h to 1 mR/h Gamma Exposure Rate)[a]

Condition	Appropriate detection instrument reading	Recommended Action
Before Decontamination	<2x existing background	Unconditional release
	>2x existing background	Decontaminate. Equipment may be stored or disposed of as appropriate.
After Decontamination	<2x existing background	Unconditional release
	>2x existing background	Continue to decontaminate or refer to low background monitoring and decon station. Equipment may be stored for decay or disposed of as appropriate.

[b] Monitoring stations in such high exposure rate areas are for use only during the early phase of an incident involving major atmospheric releases of particulates. Otherwise use Table 2-6.

Table 2-6. Recommended Surface Contamination Screening Levels for People[a] and Objects at Monitoring Stations in Low Background Radiation Areas (<0.1 mR/h Gamma Exposure Rate)[b]

Condition	Appropriate detection instrument reading	Recommended Action
Before decontamination	<2x existing background	Unconditional release
	>2x existing background	Decontaminate
After simple[c] decontamination effort	<2x existing background	Unconditional release
	>2x existing background	Full decontamination
After full[d] decontamination effort	<2x existing background	Unconditional release
	>2x existing background	Continue to decontaminate people Release animals and equipment
After additional full decontamination effort	<2x existing background	Unconditional full release
	>2x existing background	Send people for special evaluation Release animals and equipment

[a] 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.
[b] 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.
[c] Flushing with water and wiping is an example of a simple decontamination effort.
[d] Washing or gentle scrubbing with soap or other mild detergent followed by flushing is an example of a full decontamination effort.

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 activity. 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. Other medical countermeasures are available, as well.
- Dose calculations for PAGs are made using the DCF and 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.
- Response 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.

CHAPTER 3 – INTERMEDIATE PHASE PROTECTIVE ACTION GUIDES

3.1. INTRODUCTION

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 assumed to last for one year for purposes of dose projection.

During the early phase, decisions must be made and implemented quickly by state and local officials before federal assistance is 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 2008 a, b). 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).

3.2. EXPOSURE PATHWAYS DURING THE INTERMEDIATE PHASE

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

- **exposure of the whole body** to external gamma radiation from deposited radioactive materials (groundshine). External gamma radiation is the expected dominant pathway for reactor accidents and incidents involving RDDs and INDs;
- **internal exposure** from the inhalation of resuspended materials;
- **internal exposure** from the ingestion of food and water.

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

3.3. 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;
- 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 3-1. The basis for these values is presented in detail in Chapters 4 and 7 and Appendix E of the 1992 PAG Manual, available online as a historical reference at http://www.epa.gov/radiation/rert/pags.html. 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 the second year PAG (0.5 rem (5 mSv) in a year) will be exceeded.

Avoiding exceedance of the relocation PAGs may not be easy 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 whole-body and internal exposure from inhalation of resuspended contamination. Food and milk ingestion dose should be considered separately with decisions based on the FDA PAGs.[21]

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.

[21] Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies, FDA 1998, available online: http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM094513.pdf

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 3-1. Protective Action Guides for Exposure to Deposited Radioactivity during the Intermediate Phase of a Radiological Incident

Protective Action Recommendation	PAG (Projected Dose)[a]	Comments
Relocate the general population[b]	≥ 2 rem (20 mSv) in the first year, 0.5 rem (5 mSv)/year in the second and subsequent years	Projected dose over one year
Apply simple dose reduction techniques[c]	< 2 rem (20 mSv)	These protective actions should be taken to reduce doses to as low as practicable levels

[a]Projected dose refers to the dose that would be received in the absence of shielding from structures or the application of dose reduction techniques. These PAGs may not provide adequate protection from some long-lived radionuclides (see Section 3.7).

[b]People previously evacuated from areas outside the relocation zone 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]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.

3.3.1. 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.

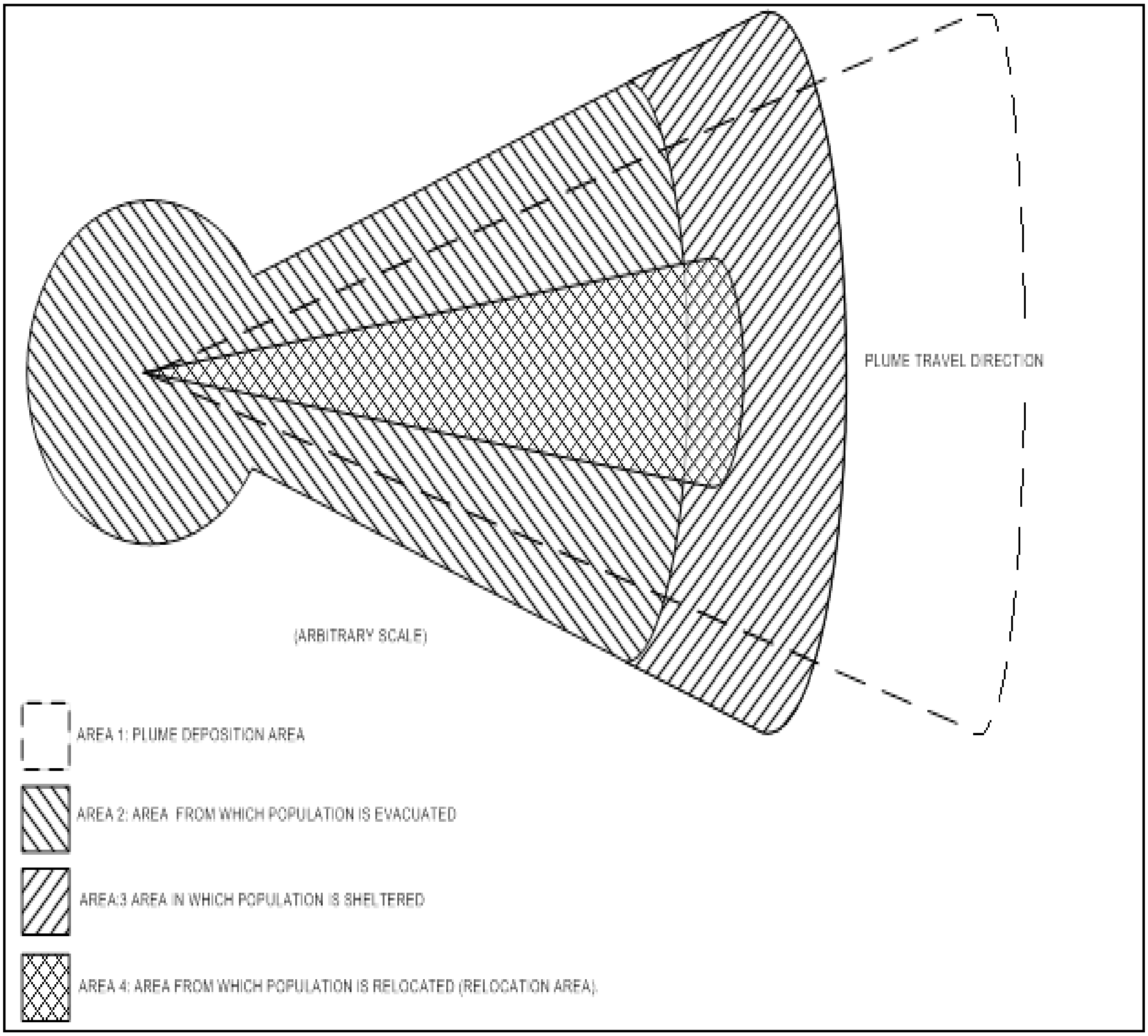


Figure 3-1. Generalized Protective Action Areas for NPP Incident

3.3.2. Areas Involved

Figure 3-1 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 3-1 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 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 gradual 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 dose objectives addressed in Section 3.6.

The relocation PAG applies 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.

3.3.3. 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.

3.4. 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 for people in the highest exposure rate areas.
2. Allow previously evacuated people to return as quickly as possible to areas where field gamma 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 3.4.1), 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 food 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.

3.4.1. 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 one meter (39 inches) 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 where runoff settles. In general, where exposure rates vary within designated areas, dose projections should be estimated using an appropriate average exposure rate.

3.4.2. Dose Projection

The FRMAC Assessment Manuals[22] provide detailed guidance for dose projection and calculating DRLs and DCFs (DOE 2010a, b). The FRMAC Assessment Manuals incorporate the ICRP dosimetry models (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, anytime 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 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 2008 a, b).

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

[22] See FRMAC Assessment folder at http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

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.

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 should 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.[23]

Keeping below the 0.5 rem (5 mSv) PAG for "out-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 4).

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.

3.4.3. Projected External Gamma Dose

Projected whole body external gamma doses at 1 meter height at particular locations during the first year and second year after the incident are the parameters of interest (DOE 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 m 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. DCFs are therefore needed to convert environmental measurements to projected dose during the first year and second year following the incident (See FRMAC Assessment Manuals). 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.

[23] The 1992 PAG Manual is available as a historical reference on line at: <http://www.epa.gov/radiation/rert/pags.html>

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 can be considered.

3.4.4. 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 1987). 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 emergency relocation area should operate under the controlled conditions established for occupational exposure (EPA 1987). The 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.

3.5. 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 is not proposing a specific drinking water PAG at this time. EPA has established enforceable drinking water standards for radionuclides under the Safe Drinking Water Act (SDWA). EPA recommends that to the extent practicable, emergency measures for drinking water be based on the National Primary Drinking Water Regulations (NPDWR) for Radionuclides. The Radionuclides Rule provides states with flexibility when responding to radiological events. If a public water system exceeds the radionuclides standard it must work to get back into compliance as soon as feasible. States have the authority to determine if other corrective actions are needed (e.g. providing alternative water).

However, the Agency recognizes a short-term emergency drinking water guide may be useful for public health protection in light of the Fukushima nuclear power plant accident, which impacted some Japanese drinking water supplies. Input on the appropriateness of, and possible values for, an intermediate phase emergency drinking water PAG is being sought during the public review of this Manual.

While the NPDWR provide for a regulatory standard of 4 mrem/year (beta, photon emitters) based on life-time exposure, international organizations have developed technical approaches and methodologies that have produced a range of emergency guidelines related to drinking water (e.g., the World Health Organization[24], the International Atomic Energy Agency[25]) as have other federal agencies (e.g., the Department of Homeland Security[26], the Food and Drug Administration[27]) and non-federal organizations. EPA is seeking input on an approach and technical rationale for a drinking water PAG designed to help

[24] See: http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/ and http://www.who.int/hac/crises/jpn/faqs/en/index8.html.
[25] See: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1467_web.pdf.
[26] See: http://ogcms.energy.gov/73fr45029.pdf
[27] See: http://www.fda.gov/downloads/MedicalDevices/.../UCM094513.pdf

officials select protective actions under emergency conditions when exposures would occur over shorter time periods than those envisioned in the NPDWR.

3.5.1. Monitoring & Characterization of Contaminants

The Radionuclides Rule requires community water systems (CWS) to monitor at each entry point to the distribution system to ensure that every customer's water does not exceed the maximum contaminant levels (MCLs) for radionuclides. All CWS are required to monitor for gross alpha, radium-226/228 and uranium. In addition, CWS designated by the state as "vulnerable" or if they use waters contaminated by effluents from nuclear facilities must also conduct monitoring for beta particle and photon radioactivity.

In the event of a radiological event the state, at its own discretion, may exercise regulatory flexibility and require systems to collect samples for radionuclides, including beta particle and photon activity (40 CFR 141.26(c)). For more information about monitoring requirements for the Radionuclides Rule see the "Radionuclides Rule: A Quick Reference Guide" (EPA816-F-01-003, June 2001)[28] or "Implementation Guidance for Radionuclides" (EPA 816-F-00-002, March 2002).[29]

To determine if there is radiological contamination of drinking water sources and the extent to which such contamination is occurring, systems sampling for radionuclides must use approved EPA methods.[30]

3.5.2. Public Notification

If water sample monitoring indicates that contamination levels exceed the MCL for any radionuclide, water systems are required to issue a Tier 2 Public Notification (i.e., within 30 days).

States have the flexibility to elevate the notification if warranted to a Tier 1 Public Notification (i.e., within 24 hours) (40 CFR 141.201(a)(3) Special public notices: Occurrence of a waterborne disease outbreak or other waterborne emergency.

During a radiological event, water systems may be dealing with a number of requirements and operating procedures and may not be prepared to issue public notification. The state may issue public notification on behalf of the water system (40 CFR 141.210(a)). This would allow the state to develop and deliver a consistent message to all affected customers and also allows the system to concentrate its efforts on returning the system to operation and/or returning to compliance in the event of a radionuclides MCL violation. For more information see the Revised Public Notification Handbook (EPA 816-R-09-013, March 2010).[31]

3.5.3. Corrective Actions to Reduce Levels of Contamination

Water distribution systems all incorporate reserve and storage capacity. During the early phase of an incident it is unlikely that contamination could affect water which is directly available for consumption through distribution systems. It would take some time for radionuclides to be deposited from the plume into the supply system water source and then subsequently be distributed. During the early phase, recommendations to the public (i.e., about drinking tap water) should reflect these considerations. The public should be advised that the water is safe to drink unless otherwise informed by state officials. Some

[28] See: http://www.epa.gov/ogwdw/radionuclides/pdfs/qrg_radionuclides.pdf

[29] See: http://water.epa.gov/lawsregs/rulesregs/sdwa/radionuclides/upload/2009_04_16_radionuclides_guide_radionuclides_stateimplementation.pdf

[30] A list of EPA approved analytical methods for Radionuclides is available at: http://www.epa.gov/ogwdw/methods/pdfs/methods/methods_radionuclides.pdf

[31] See: http://water.epa.gov/lawsregs/rulesregs/sdwa/publicnotification/upload/PNrevisedPNHandbookMarch2010.pdf.

useful and practical actions water systems can take during the intermediate phase to provide drinking water to customers are described below.

Wait for Flow-By

If radionuclides are deposited over a river, a section of the water can become contaminated and can be repeatedly contaminated as rain re-deposits radioactive particles. As this section flows down the river, this section of contaminated water is called a plume. This action calls for closing down any source intake valves along the path of the plume of contaminated water. While the intake valve is closed, no contaminated water can enter the water supply system; therefore the contaminated water is allowed to flow by the system. During this time, the system's existing storage capacity can be depended upon. If the stored water supplies could be depleted before the affected valves can be reopened, treatment of the contaminated water while using available stored water supplies should be considered. This assumes that the treatment technology will be in place or readily accessible. In the event of no other option, contaminated water could be temporarily replaced with large quantities of purchased uncontaminated water.

Treat Contaminated Water

Various treatment options exist for reducing or eliminating the contamination of drinking water by man-made radionuclides. Only a small percentage of all water systems treat specifically for radionuclides. However, typical technologies used to treat water for other contaminants can reduce the concentration of radioactivity. These technologies include coagulation/filtration, ion exchange, lime softening and reverse osmosis. Their actual removal efficiency depends on the radionuclide and the type of treatment.[32]

Activate Existing Connections to Neighboring Systems

If the water supply system is part of a larger, regional supply system, activation of existing connections to a neighboring area could be considered. Most large water systems can establish connections with other large systems for emergency purposes. As in many cases, this option may have already been considered during emergency planning. If this option is implemented, steps must be taken to ensure that the "clean" systems do not become contaminated from water backflow.

Smaller water supply systems (i.e., that serve between 10,000 and 75,000 people), or sparsely populated or rural areas, may not be connected to a neighboring system. In this case, regionalization may be a part of emergency planning to explore. This involves connecting smaller systems to larger systems, thus forming a regional water supply system. This is obviously a long-term proposition, but it does have the added advantage of reducing system vulnerability to water shortages or water quality problems other than those resulting from a radiological incident.

Establish Pipeline Connections to Closest Sources/Systems

Running a pipeline from a "clean" water supply system to various distribution centers located throughout the affected community is a routine means of providing clean water. For example, when water mains must be repaired or cleaned of debris, community water needs have been met through the assembly of temporary pipes and hoses. This is a relatively simple procedure, requiring very little construction and technical expertise. For medium- to long-term emergencies, the construction of a temporary pipeline could be cost-effective. PVC pipe, fire hoses and steel pipe have been used to provide emergency drinking water for periods of up to 2 months when service has been disrupted by earthquakes, drought, or bacterial contamination.

[32] Additional information about treatment options and compliance guidance is available at the following website: http://water.epa.gov/lawsregs/rulesregs/sdwa/radionuclides/compliancehelp.cfm.

Import Water in Tanker Trucks
If an uncontaminated source of water is close to the affected area, it may be more efficient to arrange to transport water from that source by truck, rail, or barge to distribution centers located throughout the community. The most significant obstacle for the use of this option is the cleanliness and availability of transport vehicles. State and local laws may also affect this option.

Import Bottled Water
Importing bottled water into the affected community is another possible option. The water may come from a nearby water supply 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 merit long-term action, such as the construction of a temporary pipeline.

Ration Clean Water Supplies
Rationing uncontaminated water is also a possibility. This is particularly true if water reserves can provide each individual in the community with 1 L (0.264G, about 1 qt) of water per day until the contaminated plume has passed, the contaminated water is treated, or the water supply system has returned to normal operating conditions. If this option is chosen, it is important that efficient methods for rationing are in place. Rationing water might also be required if water treatment capabilities are limited. Consider a scheme to ration water as part of emergency planning efforts.

3.6. 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 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.

Based on the relocation PAGs, reentry guidance can be found in the Reentry Matrix in Section 3.8, as well as in the Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident, Group C (DOE 2009). After the population has been protected in accordance with the PAGs for relocation, return for occupancy of the relocation areas should be governed on the basis of cleanup criteria and late phase cleanup activities should proceed.

3.7. REENTRY DURING THE EARLY AND INTERMEDIATE PHASES

3.7.1. Assumptions and Definitions

The term reentry is used for emergency workers and members of the public going into radiologically contaminated areas temporarily under controlled conditions.

The incident response is divided into three activity planning phases. Early Phase begins with the incident and may last from hours to days. Intermediate Phase begins with control and characterization of the release; it may overlap early and late phase activity and last from weeks to months. Late Phase begins when recovery actions to reduce radiation in the environment begin and ends when all recovery actions are complete. The matrix below only addresses Early and Intermediate Phase activity.

3.7.2. Approach and Discussion

Interagency guidance informed this section, including—

- "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents" (EPA, 1992)[33].
- "Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident" (DOE 2009)[34].
- FRMAC Assessment Manual (Sandia National Lab, 2010)[35].

The Operational Guidelines include detailed numeric guidance, developed by a multi-agency working group as a follow-up to the RDD/IND Planning Guidance. 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. Food and agriculture guides use FRMAC assessment methods 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 the NPP radionuclides.

---

[33] PAGs Manual online at http://www.epa.gov/rpdweb00/rert/pags.html.

[34] The Operational Guidelines were developed by federal agencies and published in draft form by DOE in February 2009 with DOE reference number DOE/HS-0001; ANL/EVS/TM/09-1, on-line at http://ogcms.energy.gov/review.html.

[35] FRMAC Assessment Manual, Overview and Methods online at: http://www.nv.doe.gov/nationalsecurity/homelandsecurity/frmac/manuals.aspx.

3.8. REENTRY MATRIX FOLLOWING A RADIOLOGICAL INCIDENT OR ACCIDENT

PHASE	ACTIVITY	SUGGESTED LEVELS	CLEANUP ACTIONS
Early Phase (first 4 days)	**Sheltering or Evacuation for the Public** **Emergency Worker Protection**	**Public**: 1,000-5,000 mrem (10-50 mSv) projected over four days (See Ch. 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. **Emergency Responders**: 5,000/10,000/25,000 mrem (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). Responder 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.	It is too early for organized cleanup, due to chaos of the situation and higher priorities such as life-saving 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 (1st 4 days). Once evacuation is completed, there are simple actions cities can implement themselves: rinsing roofs and streets, street sweeping. The objective of these efforts 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.
Intermediate Phase (first 30 days and up to a year)	**Relocation for the Public**	**Public**: 2,000 mrem (20 mSv) projected first year, 500 mrem (5 mSv) per year projected in subsequent years (See Ch. 3). 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 guides 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 large amount of waste. Having addressed the removable part of the contamination, later efforts can focus on fixed contamination. Paved surface

Intermediate Phase (first 30 days and up to a year)	**Reentry** **For Use of Critical Infrastructure**	**Public**: 2,000 mrem (20 mSv) in first year (Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident, *Operational Guidelines Group C*). Dosimeters could be considered for the public.	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.
	Radiation Worker Protection	**Radiation Worker Protection**: (dose not to exceed) 5,000 mrem (50 mSv) per year ((*Radiation Protection Guidance to Federal Agencies for Occupational Exposure*, EPA 1987). Radiation workers have knowledge of the risks associated with radiation exposure, training to protect themselves and dosimeters to track their doses. During an incident response, workers (police, waste handlers) needed in contaminated areas could be trained and given dosimeters. The guidance for Radiation Workers applies throughout the response.	
	Reentry For Use of Roads and Walkways	**Public**: 2,000 mrem (20 mSv) first year, 500 mrem (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.	
	Reentry For Access to the Relocation Zone	**Public**: 500 mrem (5 mSv) over one year for temporary access with stay times dependent on reentry tasks and site-specific conditions (*Operational Guidelines, Group D*). '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 characteristics such as indoor or outdoor work, sensitive populations and level of radioactivity. 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 Figure 7.5 and Table 7.8). For example, if the maximum surface street	

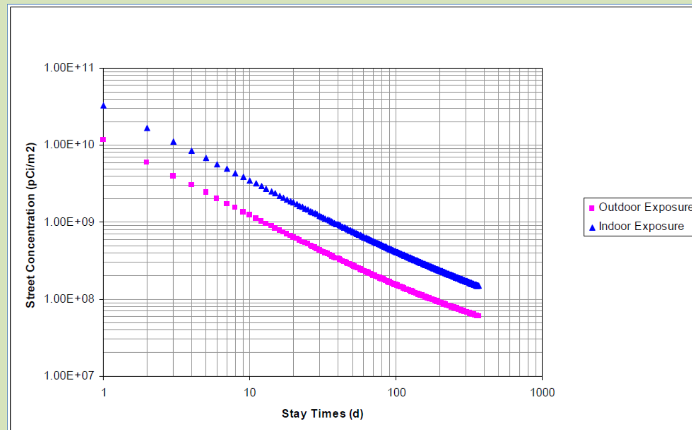


FIGURE 7.5 Limiting Concentrations of Cs-137 for Access to Business

concentration of Cesium-137 is 3.00E+09 pCi/m^2 (1.11E+08 Bq/m^2), people limited to 500 mrem (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.

Table 7.8 Scenario D2-2 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 outdoors 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 keep radiation exposure 'ALARA' below the Operational Guideline.

KEY POINTS IN CHAPTER 3 – 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 PAG and site-specific geographical features such as rivers, mountains or roadways.
- 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).
- EPA has established enforceable drinking water standards for radionuclides under the SDWA. EPA recommends that to the extent practicable, emergency measures for drinking water be based on the NPDWR for radionuclides. The Radionuclides Rule provides states with flexibility when responding to radiological events. Input on the appropriateness of, and possible values for, an intermediate phase emergency drinking water PAG is being sought during the public review of this Manual.
- To inform temporary reentry into relocation areas, use the Operational Guidelines (DOE 2009).

CHAPTER 4 – GUIDANCE FOR THE LATE PHASE

4.1. CLEANUP PROCESS

This section describes the remediation cleanup process for the late phase of a nationally significant radiological incident, like 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. 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 and specifically for radiological incidents, the Nuclear Radiological Incident Annex: http://www.fema.gov/pdf/about/divisions/thd/IncidentNucRad.pdf (FEMA 2008a, b).

4.1.1. 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 living conditions. 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. There will be opportunities to involve key stakeholders in providing sound, cost-effective cleanup recommendations. Generally, 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 must 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 U.S. EPA's Superfund program, the U.S. 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, 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, 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.[36]

4.1.2. 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 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.

4.1.3. 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 must 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, what the costs and benefits are and how the process of reducing exposures and risks can improve human and ecological health.

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

- The types of contamination; the technical feasibility, cost, timeliness and effectiveness of decontamination measures; and the availability and cost of options for the disposal of wastes.

[36] 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.

- 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, 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 areas. In making decisions about cleanup goals and strategies for a particular event, decision makers must balance the desired level of exposure reduction with the extent of the measures that would be necessary to achieve it, in order 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 must be made on a site-specific basis and should reflect the interim risks that are reasonable and acceptable to the affected community as 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;
- the 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;
- the success or effectiveness of the cleanup or remediation as the cleanup progresses (contaminant removal);
- the 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;
- the impacts of alternative levels of clean up 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 clean up levels have been reached);
- preservation or destruction of places of historical, national, or regional significance;

- the technical and administrative feasibility of the remedy, including the availability of materials and services needed to implement each component of the option in question;
- the 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;
- community support for the remedy.

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

4.1.4. 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 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, 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.

4.1.5. 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 must 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.

4.1.6. Cleanup Process Implementation and Organization: An Example

This example, reprinted 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.

a) <u>Cleanup Implementation</u>

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). 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 site 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.

b) 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 responders under the IC/UC. On-scene actions include incident stabilization, lifesaving activities, dose reduction actions for members of the public and emergency responders, access control and security, emergency decontamination of persons 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 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 jointly by federal, state and local officials.

Under the NRF and NDRF, 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 as follows:

c) 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 NRF 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 in accordance with NIMS principles regarding jurisdictional authorities, functional responsibilities and resources provided. For a wide-area radiological incident, multiple Incident Command Posts (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 process will be managed by the IC/UC, who ultimately determines the structure and organization of the Incident Command Post, but the discussion below provides one recommended approach for managing the cleanup process within a NIMS ICS response structure. The Incident Command Post 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 (for example, 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, most likely from the "outside in" toward the most contaminated areas. The extent of the 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 process, particularly for large or complex cleanups.

d) 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.

e) 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, local non-governmental representatives as well as local and regional business stakeholders. The exact selection and balance of stakeholders is incident specific.

f) 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 analysis 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.

g) 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.

h) 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.

4.2. 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. If there is a limited radiological incident with relatively small waste volumes, existing licensed radioactive waste capacity is available and may be sufficient to address waste disposal. However, in a situation involving a more significant release and certainly in an event such as the 2011 incident at the Fukushima nuclear facility, the waste resulting from such an incident would likely overwhelm current disposal capacity. When waste volumes exceed existing capacity, options available for consideration include supplements to existing commercial licensed radioactive waste disposal facilities, such as a combination of hazardous waste landfills, solid waste landfills, DOE facilities and construction of one or more new disposal facilities. New disposal capacity could be located at the site where the radionuclide release originated, elsewhere within the contaminated area, or away from the affected area altogether.

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.

4.2.1. Potential Waste Volumes and Existing Waste Disposal Options

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 incident 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.

a) Waste Volume

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, as the selected approach to decontamination and remediation, as well as the long-term cleanup goals, 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.[37] 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 at the site of origin or other designated DOE sites.

b) Capacity Issues

Managing the large volumes of waste resulting from a wide-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 that:

- At the beginning of 2012, less than 100 million cubic feet of disposal 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 include large-scale 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.

4.2.2. Integrated 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. 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 are discussed below.

- Licensed Commercial LLRW Disposal Facilities—
  - Can manage most anticipated waste types within license conditions.
  - Highest degree of public acceptance.
  - Significant bulk disposal volume possible.

[37] 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/.

  - 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 radiological 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 eco-systems, 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 control.
- DOE Disposal Sites—
  - Could potentially handle higher-activity waste if insufficient commercial access/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.

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), animal carcasses or contaminated vehicles (where dismantling the vehicle may represent a greater potential for dispersal of contaminants and exposure of workers).

a) <u>Commercially Licensed LLRW Disposal Facilities</u>
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.

b) 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.[38] Management of nonhazardous 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)[39]. 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.

c) DOE Disposal Sites
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

[38] Alaska, Iowa, Puerto Rico, the Virgin Islands, American Samoa and the Trust Territories and Northern Marianas Islands do not have authorized RCRA programs.

[39] 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% of total generation. "Municipal Solid Waste in the United States: 2009 Facts and Figures," EPA530-R-10-012, December 2010.

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 low-level radioactive disposal, primarily for bulk waste streams from cleanups and this potential disposal alternative may also be affected by a wide-scale incident.

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.

4.2.3. Planning and Coordination Among Federal and State Entities

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.

a) State Roles and Responsibilities

States must be intimately involved ahead of time in planning for a large-scale radiological incident and the resulting waste disposal.

- 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[40] 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.
- All DOE disposal sites are located within states, many of which have agreements 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 (when authorized by EPA) and solid waste landfills that may be used for disposal of waste with very low concentrations of radioactivity; 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.

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

b) Federal Agencies
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 might be used for waste disposal;
- NRC is the federal authority for commercial LLRW disposal;
- USDA provides technical assistance for agricultural materials contaminated by the release, including animal carcasses.

4.2.4. Other Potential Options and Considerations

a) Potential Federal Actions to Increase Preparedness

- Develop criteria under which access to DOE disposal sites is acceptable and identify issues to be resolved.
- Facilitate agreements among regional LLRW compacts and states to address situations in which access to compact sites can be assured for all states.
- Identify geographically strategic federal sites that can be used for staging and interim storage of large waste volumes.
- Identify federal sites that can be characterized in advance for construction of disposal capacity for incident-related waste, should the need arise.
- Clarify federal authorities that can be used in exceptional circumstances for acquisition of property for use as disposal or long-term storage capacity and indemnification of private sector service providers.
- Assist state and local officials in planning for and making decisions to use local disposal options (solid and hazardous waste landfills) for waste that contains relatively low concentrations of radionuclides, including:
  - developing criteria for case-by-case alternate disposal evaluations, such as those employed by NRC, EPA and DOE for limited volumes of waste;
  - establishing generally applicable criteria for disposal of radionuclides in solid and hazardous waste landfills;
  - supporting federal research into behavior of radionuclides and decontamination residuals in solid and hazardous waste landfills;
  - providing technical assistance and streamlined regulatory review (e.g., permitting) for states to evaluate existing sites and identify new sites for incident-related waste disposal capacity; and,
  - developing and disseminating tools to support planning and decision-making regarding incident-related waste management.

b) Detailed Guidance
It may be appropriate for the federal government to develop detailed guidance to address factors such as waste acceptance criteria needed for waste disposal at RCRA disposal facilities, safety evaluation of existing disposal facilities, or siting, development and regulatory approval of new disposal facilities.

c) Adding Additional Disposal Capacity

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.

- On-site disposal. As a result of looking at the different choices, 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.
- 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 power of eminent domain to condemn property contaminated by a radiological incident and use it for waste disposal.

d) Site Selection Criteria

If it is determined that constructing a new disposal facility is the appropriate action, the proposed site(s) should be studied 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 path and site suitability must take into account the radiological characteristics of the waste. As discussed above, some slightly radioactive materials are disposed in hazardous waste landfills if they are permitted for it. More radioactive materials are sent to sites licensed as LLRW disposal sites, though less contaminated materials are also sent to LLRW disposal sites. 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.

e) Site Characteristics

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 to 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. Large-scale disposal operations may also require extensive surface facilities.

f) Other Important Considerations

Additional considerations can also be applied to make finer distinctions among potentially suitable sites. These criteria 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);
- 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.

4.2.5. Potential Federal Actions 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.

a) 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 by DOE policy or statute. Closed and long-term stewardship sites may not have large amounts of additional property available for disposal.

b) 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;
- surplus properties (e.g., base realignment and closure (BRAC), formerly used defense site (FUDS)).

Considerations: Section 2692 of title 10, United States Code, "Storage, Treatment and Disposal of NonDefense Toxic and Hazardous Materials," generally provides 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 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.

c) Other Federal Properties

Agencies such as the Department of Interior (DOI) 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 (NPS), BLM, or Forest Service. Some properties may be in proximity to DOE or DoD lands.

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

KEY POINTS IN CHAPTER 4 –LATE PHASE

- PAGs will not be used to guide restoration and recovery of areas impacted by a radiological incident; rather, planning activities should include developing a process to involve stakeholders in setting priorities and determining actions. Such a process should be flexible enough 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 in a range of one in a population of ten thousand (10^{-4}) to one in a population of one million (10^{-6}) excess lifetime cancer incidence outcomes are generally considered protective, though this may not be achievable after a large radiological incident. In making decisions about cleanup goals and strategies for a particular event, decision makers must balance the desired level of exposure reduction with the extent of the measures that would be necessary to achieve it, in order to maximize overall human welfare.
- Incidents that create large volumes of waste from a wide-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 state governments to identify and implement waste management options.
- Safely managing and disposing of radioactive waste will require pre-planning at all levels of government and careful coordination with stakeholders at all stages of the decision-making process.

APPENDIX A – REFERENCES

Aaberg 1989	Aaberg, R. Evaluation of Skin and Ingestion Exposure Pathways. EPA 520/1-89-016. U.S. Environmental Protection Agency, Washington, D.C., (1989).
CDC 2007	Centers for Disease Control and Prevention, Department of Health and Human Services (US)[CDC/HHS]. Population monitoring in radiation emergencies: A guide for state and local public health planners. Centers for Disease Control and Prevention, Department of Health and Human Services. Atlanta, GA, (2007).
DHS 2008	Federal Emergency Management Agency, Department of Homeland Security (US)[FEMA/DHS]. Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents. Federal Register, 70, 45029; August 1, 2008.
DOE 1988	Department of Energy (US)[DOE]. External Dose-Rate Conversion Factors for Calculation of Dose to the Public. DOEIEH-0070, U.S. Department of Energy, Washington, D.C., (1988).
DOE 1990	Department of Energy (US)[DOE]. Effectiveness of Sheltering-in-place in Buildings and Vehicles for Plutonium. DOE/EH-0 159, U.S. Department of Energy, Washington, D.C., (1990).
DOE 2001	Department of Energy (US)[DOE]. Radiological Emergency Response Health and Safety Manual. DOE/NV/11718--440, Federal Radiological Monitoring and Assessment Center, U.S. Department of Energy, Washington, D.C., (2010).
DOE 2009	Department of Energy (US)[DOE]. Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident. DOE/HS-0001; ANL/EVS/TM/09-1. U.S. Department of Energy, Washington, D.C. (2009).
DOE 2010a	Department of Energy (US)[DOE]. Federal Radiological Monitoring and Assessment Center (FRMAC) Assessment Manual, Volume 1: Overview and Methods. SAND2010-1405P, Federal Radiological Monitoring and Assessment Center, U.S. Department of Energy, Washington, D.C., (2010).
DOE 2010b	Department of Energy (US)[DOE]. Federal Radiological Monitoring and Assessment Center (FRMAC) Assessment Manual, Volume 2: Pre-Assessed Default Scenarios. SAND2010-2575P, Federal Radiological Monitoring and Assessment Center, U.S. Department of Energy, Washington, D.C., (2010).
DOD 2003	Military Medical Operations, Armed Forces Radiobiology Research Institute (US)[AFRRI/DOD]. Medical Management of Radiological Casualties, Second Edition. Armed Forces Radiobiology Research Institute, Department of Defense. Bethesda, MD, (2003).

DOT 2004	Department of Transportation (US)[DOT]. Traffic Safety Facts 2004: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System. DOT HS 809 919. U.S. Department of Transportation, National Highway Traffic Safety Administration. Washington, D.C. (2004).
EPA 1978a	Environmental Protection Agency (US)[EPA]. Protective Action Evaluation Part I: The Effectiveness of Sheltering-in-Place as a Protective Action Against Nuclear Accidents Involving Gaseous Releases. EPA 520/1-78-001A, U.S. Environmental Protection Agency, Washington, D.C., (1978).
EPA 1978b	Environmental Protection Agency (US)[EPA]. Protective Action Evaluation Part II -Evacuation and Sheltering-in-place as Protective Actions Against Nuclear Accidents Involving Gaseous Releases. 52011-78-00lB, U.S. Environmental Protection Agency, Washington, D.C., (1978).
EPA 1987	Environmental Protection Agency (US)[EPA]. Radiation Protection Guidance to Federal Agencies for Occupational Exposure. Federal Register, 52, 2822-2834; 1987.
EPA 1992a	Environmental Protection Agency (US)[EPA]. Implementing Protective Actions for Radiological Incidents at Other Than Nuclear Power Reactors. EPA 402-R-92-001. U.S. Environmental Protection Agency, Washington, D.C., (1992).
EPA 1992b	Environmental Protection Agency (US)[EPA]. Manual of Protective Action Guides and Protective Actions for Nuclear Incidents. EPA 400-R-92-001 U.S. Environmental Protection Agency, Washington, D.C., (1992).
EPA 1999	Environmental Protection Agency (US)[EPA]. Cancer Risk Coefficients for Environmental Exposure to Radionuclides, Federal Guidance Report #13. EPA 402-R-99-001. U.S. Environmental Protection Agency, Office of Air and Radiation, Washington, D.C., (1999).
FEMA 2008a	Federal Emergency Management Agency (US) [FEMA]. National Response Framework. U.S. Federal Emergency Management Agency, Washington, D.C., (2008)
FEMA 2008b	Federal Emergency Management Agency (US) [FEMA]. National Response Framework, Nuclear/Radiological Incident Annex. U.S. Federal Emergency Management Agency, Washington, D.C., (2008)
FDA 1998	Food and Drug Administration (US)[FDA]. Accidental Radioactive Contamination of Human Food and Animal Feeds: Recommendations for State and Local Agencies. U.S. Food and Drug Administration, Center for Devices and Radiological Health. Rockville, MD, (1998).
FDA 2001	Food and Drug Administration (US)[FDA]. Notice: Guidance Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies. Federal Register, 66, 64046; 2001.

FDA 2002 Food and Drug Administration (US)[FDA]. Guidance for Industry - KI in Radiation Emergencies - Questions and Answers. Food and Drug Administration, Center for Drug Evaluation and Research. Procedural, Revision 1. Rockville, MD, (2002).

Hans et al. 1975 Hans, J.M. Jr. and Sell, T.C. Evacuation Risks -An Evaluation. EPA-520/6-74-002, U.S. Environmental Protection Agency, Washington, D.C., (1975).

IAEA 1989 International Atomic Energy Agency. Principles for Establishing Intervention Levels for the Protection of the Public in the Event of a Nuclear Accident or Radiological Emergency. Safety Series No. 72, Revision 1, International Atomic Energy Agency, Vienna, Austria, (1991).

ICRP l991 International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Annals of the ICRP 21(1-3), Pergamon Press, Oxford (1991).

NCRP 2001 National Council on Radiation Protection and Measurements. Management of Terrorist Events Involving Radioactive Material, NCRP Report No. 138. National Council on Radiation Protection and Measurements, Bethesda, MD, (2001).

NCRP 2010 National Council on Radiation Protection and Measurements. Responding to a Radiological or Nuclear Terrorism Incident: A Guide for Decision Makers, NCRP Report No. 165, National Council on Radiation Protection and Measurements, Bethesda, MD, (2010).

NRC 1975 Nuclear Regulatory Commission (US)[NRC]. Reactor Safety Study. An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants. WASH-1400, NUREG-751014, U.S. Nuclear Regulatory Commission, Washington, D.C., (1975).

NRC 1980 Nuclear Regulatory Commission (US)[NRC]. Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants. NUREG-0654, FEMA-REP-1, Rev.l., U.S. Nuclear Regulatory Commission, Washington, D.C., (1980).

NRC 1988 Nuclear Regulatory Commission (US)[NRC]. A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Material Licensees. NUREG-1140, U.S. Nuclear Regulatory Commission, Washington, D.C., (1988).

NRC and EPA 1978 Nuclear Regulatory Commission (US)[NRC] and Environmental Protection Agency (US)[EPA]. Task Force Report. Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants. NUREG-0396 or EPA-52011-78-016, U.S. Environmental Protection Agency, Washington D.C., (1978).

NRC 2005	Nuclear Regulatory Commission (US)[NRC]. Identification and Analysis of Factors Affecting Emergency Evacuations. NUREG/CR-6864. U.S. Nuclear Regulatory Commission, Washington, D.C., (2005).
NRC 2008	Nuclear Regulatory Commission (US)[NRC]. Assessment of Emergency Response Planning and Implementation for Large Scale Evacuations. NUREG/CR-6981. U.S. Nuclear Regulatory Commission, Washington, D.C., (2008).
NSS 2010	National Security Staff, Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats. Planning Guidance for Response to a Nuclear Detonation. Second Edition. Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats, Washington, D.C., (2010).
Pasquill, 1961	Pasquill,F. The estimation of the dispersion of windborne material. Meteorology Magazine. 90, 33-49, (1961).
SNL 1982	Sandia National Laboratory. Technical Guidance for Siting Criteria Development. NUREG/CR-2239. U.S. Nuclear Regulatory Commission, Washington, D.C., (1982).

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 is 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. (ICRP 1991b)

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.

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.

Contamination: Radionuclides on 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 conversion factor (DCF): 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).

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.

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

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.

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

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

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

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

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

Microsievert: One ten-thousandth of a rem. See Rem.

Millirem: One thousandth of a rem. See Rem.

Millisievert: One thousandth of a Sievert. See Sievert.

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, Neon, Argon, Krypton, Xenon and Radon.

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, nonradioactive iodine in medicine form. The administration of potassium iodine 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 dispersion 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 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 dispersed per unit of time.

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

Sievert (Sv): International unit of equivalent dose.

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

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 2.4.

Yield-producing improvised nuclear device: A crude weapon fabricated from diverted fissile material that produces a nuclear explosion.

APPENDIX C – LIST OF ACRONYMS

ALARA	As Low as Reasonably Achievable
ANS	American Nuclear Society
BLM	Bureau of Land Management
BRAC	Base Realignment and Closure
CDC	Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CWS	Community Water System
DCF	Dose Conversion Factor
DHS	Department of Homeland Security
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOL	Department of Labor
DOT	Department of Transportation
DRL	Derived Response Level
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
FUDS	Formerly Used Defense Site
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
IC/UC	Incident Command/Unified Command
IND	Improvised Nuclear Device

JFO	Joint Field Office
JIC	Joint Information Center
KI	Potassium Iodide
LLRW	Low-level radioactive waste
LLRWPA	Low-Level Radioactive Waste Policy Act
MCL	Maximum Contaminant Level
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 Regulations
NPP	Nuclear Power Plant
NPS	National Park Service
NRC	Nuclear Regulatory Commission
NRF	National Response Framework
NDRF	National Disaster Recovery Framework
NSS	National Security Staff
OSHA	Occupational Safety and Health Administration
PAG	Protective Action Guide
PIO	Public Information Officer
PPE	Personal Protective Equipment
RASCAL	Radiological Assessment System for Consequence Analysis
RCRA	Resource Conservation and Recovery Act
RDD	Radiological Dispersal Device
SDWA	Safe Drinking Water Act
SNL	Sandia National Laboratories
TED	Total Effective Dose
USDA	United States Department of Agriculture