INTERSTATE TEHCNOLOGY & REGULATORY COUNCIL

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INTERSTATE TEHCNOLOGY & REGULATORY COUNCIL

Technical/Regulatory Guidance

Decontamination and Decommissioning of Radiologically Contaminated Facilities

January 2008

Prepared by
The Interstate Technology & Regulatory Council
Radionuclides Team

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EXECUTIVE SUMMARY

The decontamination and decommissioning (D&D) of radiologically contaminated facilities present numerous challenges. Many tasks are involved, each of which requires adherence to a complex array of federal and state regulations and policies, attention to health and safety issues for workers and the public, monitoring and management of schedules and costs, and interaction with a potentially large number of stakeholders who have an interest in the present activities and future plans for sites undergoing D&D. Even the terms "decontamination" and "decommissioning" are subject to variations of definition. For the purposes of this document, "decontamination" refers to the removal or reduction of radioactive or other hazardous contamination from facilities, including both structural and nonstructural materials and equipment. The objective is to reduce radiation risk and/or exposure to be protective of public and worker health and safety and the environment. "Decommissioning" refers broadly to actions taken at the end of the life of a facility to retire it from service. The objective is to enable reuse or safe disposition of facilities and equipment. For radiologically contaminated facilities, the decommissioning process generally incorporates some or all of the following activities: the deactivation and safe management of radioactive and other wastes; plant decontamination dismantling, and demolition; and site remediation.

Presently, there are 104 operating nuclear power reactors in the United States, including both pressurized-water and boiling-water types. These plants produced 790 billion kilowatt-hours of electricity in 2004. Since 1960, more than 70 test, demonstration, and power reactors have been retired, most of them relatively small. The first commercial-scale nuclear plant decommissioned was Shippingport (Pennsylvania), in 1989. Since then, 14 nuclear plants, each greater than 100 megawatts, have been shut down and decommissioned. Currently, 16 power reactors and 14 test/research reactors are permanently shut down and undergoing decommissioning (IAEA 2006c). The U.S. Department of Energy (DOE) has also had some recent successes in closing sites. Cleanups at the Rocky Flats Site (Colorado), the Kansas City Plant (Missouri), and the Lawrence Livermore National Laboratory Main Site (California) were all completed in 2006. Cleanups were completed in 2006 at the Ashtabula, Columbus, and Fernald Projects (all in Ohio). Cleanups are scheduled for completion in 2007–2008 at the Miamisburg Environmental Management Projects (Ohio), the Lawrence Berkeley National Laboratory (California), the Inhalation Toxicology Laboratory (New Mexico), the Pantex Plant (Texas), and the Lawrence Livermore National Laboratory Site 300 (California).

The purpose of this document is to compile and make available some of the experience and knowledge acquired in recent years from facilities that have completed a D&D process. It provides guidance on D&D to regulators, the public, project managers, cleanup contractors, technology providers, and others with an interest or a need for information about this topic.

The document introduces D&D by describing the general D&D processes, examining the types of facilities undergoing D&D, and introducing regulatory authorities typically applicable to D&D activities. Subsequent sections further address major elements of the D&D undertaking—the regulatory framework (discussing the decommissioning requirements of the Nuclear Regulatory Commission, the Environmental Protection Agency, and DOE), costs, technologies, and health and safety. The document summarizes case studies of select closure sites, where some of the potential problems and decisions involved in the D&D process are explored. In addition, stakeholder perspectives on the D&D process are included. The document concludes by providing a distillation of lessons learned and factors for success of D&D process that the ITRC Radionuclides Team compiled during the development of this document.

The examples used in this document are by no means comprehensive. Its introductions to technologies are not all-inclusive as new technologies continue to be developed in response to specific needs at facilities undergoing D&D. Further, the case studies it presents are intended to serve as a sampling of the large variety of facilities that may undergo D&D. The greater representation of DOE sites in the case studies presented is reflective of the perspective of the state regulator authors. Further, the majority of the collective experience and knowledge of D&D has come from DOE sites.

It should be noted that D&D is part of the larger process of site closure and should be understood as such. At any given site, any D&D project may present complex overlaps with other regulatory processes, stakeholder concerns, environmental issues, natural resources damage assessments, tribal concerns and treaty issues, monitoring and long-term stewardship, etc. However, the scope of this document is limited to considerations directly related to D&D.

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DECONTAMINATION AND DECOMMISSIONING OF RADIOLOGICALLY CONTAMINATED FACILITIES

1. INTRODUCTION

Decontamination and decommissioning (D&D) is part of the larger process of site closure and should to be understood as such. At any given site, any D&D project may present complex overlaps with other regulatory processes, stakeholder concerns, environmental issues, natural resources damage assessments, tribal concerns and treaty issues, monitoring, and long-term stewardship. D&D of radiologically contaminated facilities can be a challenging task. Each D&D activity requires adherence to a complex array of federal and state regulations and policies, attention to health and safety issues for workers and the public, monitoring and management of schedules and costs, and interaction with a potentially large number of stakeholders during both present activities and future site plans.

This document introduces D&D by describing the general D&D processes, examining the types of facilities undergoing D&D, and introducing regulatory agencies typically applicable to D&D activities. Subsequent sections further address major elements of the D&D undertaking—the regulatory framework (discussing the decommissioning requirements of the Nuclear Regulatory Commission [NRC], the U.S. Environmental Protection Agency [EPA] and the U.S. Department of Energy [DOE]), costs, technologies, and health and safety. Some of the potential problems and decisions involved in the D&D process—explored successes as well as some of the problems associated with the D&D process—are presented through in a set of case studies of sites that have undergone D&D. In addition, a stakeholder perspective on D&D issues is examined. The document concludes by providing a distillation of lessons learned about D&D activities.

Definition of the terms “decontamination” and “decommissioning” vary among different agencies or departments. For the purposes of this document, “decontamination” and “decommissioning” and the main steps of the process are defined as follows.

- “Decontamination” is an activity and refers to the removal or reduction of radioactive and/or other hazardous contamination from facilities, including structural and nonstructural materials and equipment. The decontamination activity can take place at any point in the decommissioning process (see Figure 1-1) and generally occurs more than once. Implicit in the understanding of decontamination is the need to characterize the radioactive hazards both before and after the decontamination process to determine the risks associated with the level of contamination. The objective is to reduce radiation risk and exposure to a level that is protective of public health and safety, worker health and safety, and the environment. Decontamination technologies include chemical, electrochemical, and thermal processes as well as mechanical cleaning, washing, and other techniques. Decontamination methods may include the use of remote techniques that reduce the risk of worker exposure, in situ decontamination methods that reduce the generation of secondary wastes or reduce the requirement for waste handling and processing, and methods for decontaminating inaccessible areas. For example, decontamination can be a stand-alone operation conducted at a facility that is in operation and will remain so after the decontamination is completed.

Figure 1-1. General decision sequence for decommissioning projects keyed to applicable sections in this document.

It can also be an operation closely associated with, and often preceding, decommissioning. It should be noted that some definitions of decommissioning include decontamination. It should also be noted that, in addition to contamination by radiological material, there is frequently contamination by chemicals or other hazardous materials that also must be dealt with, usually in concert with the radiological material. Though this document is focused on radiological decontamination, maintaining awareness of nonradiological, hazardous contaminants that are coextensive with the radiological contaminants is extremely important, especially since removing both types of contaminant in a single waste stream may result in mixed waste (MW), giving rise to serious complications in subsequent management and disposition. Decontamination is often followed by decommissioning.

- "Decommissioning" is a process and refers broadly to actions taken at the end of the life of a facility to retire it from service. The objectives are to enable reuse or safe disposition of facilities and equipment. For radiologically contaminated facilities, the decommissioning process generally incorporates some or all of the following activities: deactivation and safe management of radioactive and other wastes, plant dismantling, demolition, and site remediation. Following successful decommissioning, residual contamination may require monitoring, institutional controls, and maintenance. Depending on the situation, the site may be released for appropriate alternative use.

  The specific actions constituting the decommissioning process vary with the facility and with the particular situation at the facility, but Figure 1-1 nevertheless represents the sequence of steps and links them to the relevant sections of this document.

It should also be noted that the term "D&D" is widely used in the literature to refer to a number of combinations of the "D" terms associated with the general decommissioning process—decommissioning, deactivation, decontamination, demolition, dismantlement, disposition—and has thus become almost a "textual icon" rather than an acronym. Throughout this document the term "D&D" is used to refer to decontamination and the overall process of decommissioning, as defined above.

1.1 Purpose

The purpose of this document is to provide guidance on D&D of radiologically contaminated facilities primarily to state regulators and public stakeholders. This document is also expected to be useful to facility owners, cleanup contractors, technology providers, and others involved in the D&D portion of the cleanup process at these sites.

In addition to explaining the process and regulatory basis, this document provides summary information on a range of technologies and their costs that are applicable throughout the D&D process and describes health and safety measures that should be taken at radionuclide-contaminated sites. Case studies of sites that have undergone D&D are provided to document successes as well as potential problems.

1.2 Types of Facilities Undergoing Decontamination and Decommissioning

The majority of decommissioning activities in the United States occur in two sectors: facilities licensed by the NRC or agreement states and sites that come under the purview of

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), including DOE and Department of Defense (DOD) sites.

During the course of nuclear weapons research and development (R&D) and production activities, the federal government built and used more than 20,000 facilities, including production reactors, research reactors, chemical-processing facilities, uranium-production facilities, plutonium-production facilities, gaseous diffusion plants, hot cells, waste management facilities, and others. Some military bases were also contaminated as these weapons were deployed. Cleaning up the legacy left by nuclear weapons R&D and production is the largest and most expensive environmental project ever undertaken. More than 10,000 facilities are now surplus as the result of changes to the DOE mission and/or facility consolidation and obsolescence. More than 3,000 of these facilities have been decommissioned or are now slated for decommissioning within the DOE Environmental Management Program's life-cycle baseline, including some of the largest, most complex facilities in the world. Many are contaminated with both radioactive and hazardous substances, such as asbestos, beryllium, lead, and polychlorinated biphenyls (PCBs). Through 2006, more than 1,500 facilities had been decommissioned by DOE, including nuclear, radioactive, and industrial facilities. Of particular significance is the recent decommissioning of all the facilities at the Rocky Flats (Colorado) Site and the Fernald (Ohio) Environmental Management Project, both completed in 2006. Many more facilities transitioned from operating status to cleanup status in 2007.

The U.S. nuclear energy industry has considerable experience in decommissioning nuclear reactors. Nuclear energy provided the United States with nearly 21% of its electricity in 2002. These plants produced 790 billion kilowatt-hours of electricity in 2004. Presently, there are 104 operating nuclear power reactors in the United States, including both pressurized-water and boiling-water types. The first commercial-scale nuclear plant decommissioned was Shippingport (Pennsylvania), in 1989. Since then, 14 nuclear plants, each greater than 100 megawatts, have been shut down and decommissioned. Currently, 16 power reactors and 14 test/research reactors are permanently shut down and undergoing decommissioning (IAEA 2006c).

In addition, thousands of commercial facilities (industrial sites, research facilities, medical facilities, etc.) licensed to handle radioactive materials may be required to undergo decommissioning. Since 1960, more than 70 test, demonstration, and power reactors have been retired, most of them relatively small. Approximately 200 NRC materials licenses are terminated each year. NRC Agreement States (states that have entered an agreement with the NRC to regulate certain radioactive materials within their borders) also terminate a substantial number of licenses each year. Most of these license terminations are routine, and the sites require little, if any, remediation to meet the NRC unrestricted-release criteria. However, some present technical and policy challenges that require large expenditures of NRC staff resources, including a few sites that have requested license termination under the restricted-use provisions of NRC regulations.

1.3 Regulatory Agencies and Authorities Relevant to Decontamination and Decommissioning

Radiologically contaminated sites pose unique challenges and risks. A regulatory framework for cleanup of radioactive wastes has evolved in a piecemeal fashion since the late 1940s. This regulatory framework has often focused on the source rather than on inherent radiological properties or risk. Agencies involved in nuclear materials regulation and decommissioning include NRC, DOE, EPA, DOD, the U.S. Department of Transportation (DOT), the Defense Nuclear Facilities Safety Board (DNFSB), and the individual states.

The Atomic Energy Act (AEA) of 1946 gave the federal government control of the production and use of fissionable material and established the Atomic Energy Commission (AEC) to exercise this control. Amendments were made in 1954 to update the act in the light of technological advances, 1959 to include a role for the states, and other subsequent modifications in 1964, 1978, 1984, 1986, and 1988. The Energy Reorganization Act of 1974 abolished AEC, creating instead the Energy Research and Development Administration (which became DOE when the Department of Energy Organization Act passed in 1977) to assume AEC's R&D responsibilities and NRC to assume AEC's licensing and regulatory functions. NRC has the authority to license both commercial nuclear facilities and the possession of nuclear materials. NRC regulates the following:

- commercial nuclear power plants
- research, test, and training reactors
- fuel cycle facilities
- medical, academic, and industrial facilities
- transportation, storage, and disposal of nuclear materials and waste

NRC's mission is to ensure the protection of public health and safety, to promote the common defense and security, and to protect the environment by the safe use of radioactive materials. To these ends, NRC develops regulations for the safe use and remediation of radioactive materials at its licensed sites. Section 2 of this document describes decommissioning requirements at NRC-regulated sites.

The AEA provides for NRC to discontinue authority over certain radioactive materials and for state governments to assume that same authority. Currently, 33 states (see Figure 1-2) have assumed this authority and regulate over 17,000 materials licenses. They are called "Agreement States" since they have a written agreement with NRC. Once an Agreement State has legislation, regulations, and a radiation protection program in place, NRC relinquishes its authority under Section 274 of the AEA, as amended. The AEA requires NRC to periodically review (under its Integrated Materials Performance Evaluation Program) each Agreement State's program and regulations to ensure they continue to protect public health and safety and are compatible with NRC requirements. State radiation control programs can enforce more restrictive limits than NRC's and as a result, many varied state, local, and federal rules and regulations have been developed independently of each other. As a result of the need for consistency, the Council of Radiation Control Program Directors was established in 1968 to promote uniform radiation protection regulations and activities. States do not enforce AEA jurisdiction over federal facilities; however, state regulations can be applied at federal facilities as "applicable or relevant and appropriate requirements" (ARARs) through CERCLA.

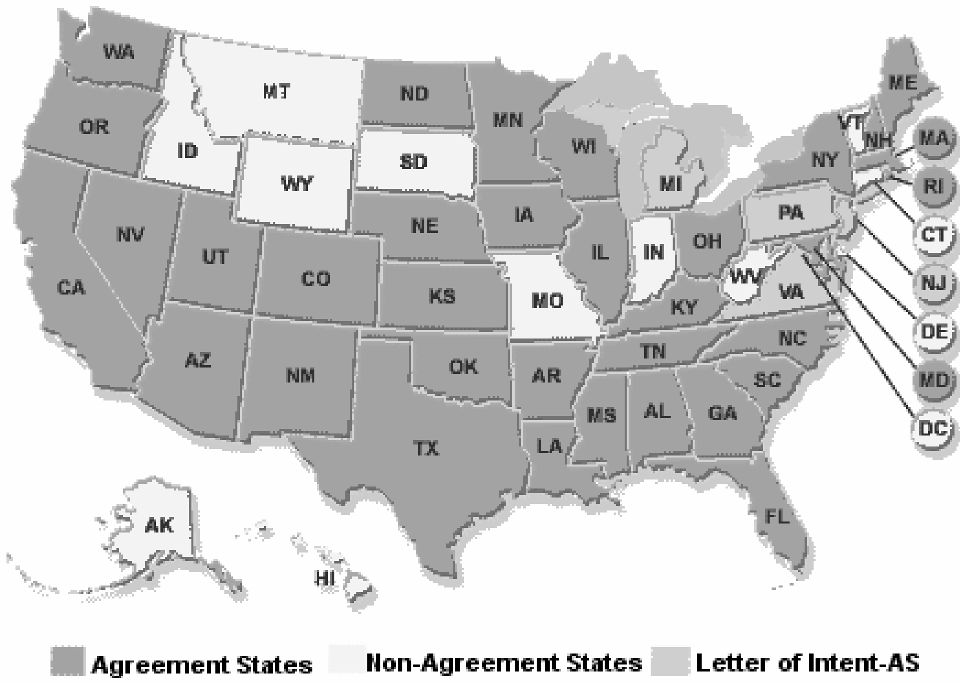

Figure 1-2. Nuclear Regulatory Commission Agreement States.

DOE was formed in 1977 to unify energy organization and planning, including nuclear energy technology, nuclear weapons programs, and environmental cleanup of DOE's contaminated sites. Currently, DOE is responsible for a wide range of energy-, science-, and weapons-related activities, as well as managing low- and high-level radioactive waste generated by past weapons production and research; constructing and maintaining a repository for civilian radioactive waste generated by commercial nuclear reactors; and conducting and overseeing the decommissioning and remediation of DOE facilities. See Section 4 for more information on the decommissioning process at DOE sites.

EPA was created in 1970 to address a growing public demand for protection of human health and natural resources: cleaner water, air, and land. EPA was given authority to improve and preserve the quality of the environment on national and global levels by implementing and enforcing environmental laws, setting environmental guidelines, monitoring pollution, performing research, and promoting pollution prevention. CERCLA, also known as Superfund, was enacted to protect citizens from the dangers posed by abandoned or uncontrolled hazardous waste sites. EPA has broad response authority under CERCLA to address cleanup of radioactive contamination through the National Contingency Plan (NCP). As with all hazardous substances, CERCLA requires cleanup of radionuclides to limit the risk to a specified range, as well as compliance with certain other laws and regulations. See Section 3 for more information. The Superfund program maintains the National Priorities List (NPL) of the most contaminated sites in the United States, and, depending on the terms of the site-specific interagency agreement, EPA is often the lead regulatory agency at DOE NPL sites. If a site-specific interagency agreement is in place, the lead regulatory agency designation may be shared with another agency (e.g., a state agency). EPA also has a memorandum of understanding (MOU) with NRC regarding residual levels of radioactivity at NRC-regulated sites undergoing license termination.

An independent federal agency, DNFSB was established by Congress in 1988. The board's mandate under the AEA is to provide safety oversight of the nuclear weapons complex operated by DOE. DOE activities that fall under the jurisdiction of the DNFSB include maintaining readiness of the nuclear arsenal, dismantling surplus weapons, disposing of excess radioactive materials, cleaning up surplus facilities, and constructing new facilities. The DNFSB is required to ensure that all these activities are carried out by DOE in a manner that adequately protects the public, workers, and the environment.

1.4 Different Decommissioning Approaches at Different Agencies

Since D&D under either AEA or CERCLA involves different regulatory authorities, there are fundamental differences between the regulatory frameworks used to characterize, clean up, or remove a site from regulatory oversight. The processes to determine acceptable exposure limits for workers and the public also differ.

NRC's regulatory process for facility decommissioning first derives cleanup goals (a "derived concentration guideline level," or DCGL) based on an annual radiation dose and then performs any necessary site characterization. A licensee demonstrates compliance by comparing characterization data with DCGLs in a final survey.

EPA's approach to evaluating radioactively contaminated sites considers cumulative excess cancer risk plus total noncancer risk from both radionuclides and chemicals. This approach also includes compliance with standards that are determined to be applicable or relevant and appropriate. Details about various other differences between these two approaches are described in *Determining Cleanups at Radioactively Contaminated Sites: Case Studies* (ITRC 2002). That report found that, "neither approach necessarily leads to more conservative cleanup values than the other." When numerical values for various radionuclides derived using these two different approaches are compared, substantial differences have been noted (Peters, Lively, and Walter 2005).

States' environmental cleanup programs vary, but some states and sites have used a framework that integrates elements of both NRC and EPA approaches. This hybrid approach, sometimes called a "risk-based corrective action" (Peters, Lively, and Walter 2005), compares characterization data with default or site-specific cleanup levels.

1.5 Organization of this Document

This document is organized as follows. Sections 2 and 3 discuss regulatory requirements and processes for D&D under the NRC and CERCLA requirements, respectively. Section 4 outlines DOE decommissioning requirements. Section 5 provides information on the various factors affecting D&D project costs consistent with the major elements of managing a D&D project. Section 6 provides introductory descriptions of several technologies that have been applied in previous D&D activities. Section 7 outlines health and safety considerations at sites that are undergoing D&D. Section 8 provides detailed case studies of D&D actions taken at private and government-owned facilities that are radiologically contaminated. Section 9 provides information on stakeholder perspectives on the D&D process. Section 10 provides a distillation of lessons learned for D&D activities, and Section 11 contains references cited in the text. Appendix A provides additional information resources pertinent to several sections in this document. Appendix B provides information about international agencies involved with D&D in other countries. Appendix C defines terms. Appendix D provides contact information for members of the ITRC Radionuclides Team, and Appendix E provides a list of acronyms used throughout the text.

2. NUCLEAR REGULATORY COMMISSION DECOMMISSIONING REQUIREMENTS

The D&D process comprises a sequence of steps that takes a facility from predecision to closeout, and if necessary, to long-term surveillance and monitoring. This section discusses primary components of the decommissioning process for NRC facilities. Under the AEA, NRC has established a number of regulations related to decommissioning, including regulations that address radiological criteria for decommissioning, requirements for decommissioning plans, timeliness requirements for submittal of decommissioning plans and related documents, and decommissioning funding plans. NRC reviews and approves the decommissioning of nuclear power plants and other NRC-licensed facilities on an individual basis and conducts inspections to ensure compliance with regulations.

For NRC licensees, decommissioning means "removing a nuclear facility from service and reducing residual radioactivity to a level that permits termination of the license." The NRC group that licenses operating nuclear power plants, the Office of Nuclear Reactor Regulation, has responsibilities during the initial stages of decommissioning and has complete responsibility for regulating the decommissioning of research and test reactors. For nuclear power reactors, Office of Nuclear Material Safety and Safeguards (NMSS) Division of Waste Management is responsible for overseeing reactor licensees during final stages of decommissioning, after fuel has been removed from the spent fuel pool, and for approving termination of the license when the decommissioning activities have been completed. The Division of Waste Management also provides technical guidance on decommissioning reviews and support for all nonreactor licensees.

2.1 NRC Decommissioning Processes

The term "nuclear facility" is used to describe those facilities that use radioactive material in amounts that require actions to ensure that the material is managed safely. Sometimes larger facilities, such as reactors and accelerators, are further subdivided into smaller units that may be designated as separate nuclear facilities.

The decision to D&D a nuclear facility is actually preceded by a decision to stop or alter the operational status of that facility. When nuclear facilities attain nonoperational status, they are decommissioned for a variety of reasons. The lead agency or responsible party is generally responsible for determining whether decommissioning of a facility proceeds directly to demolition or if it is deactivated and monitored for an extended period. Extending the life of a facility rather than decommissioning often makes economic sense and involves evaluations of detailed life-cycle cost projections and engineering cost analysis. For example, steam generators in nuclear power plants may require replacement, taking the plant out of service for several years and at a great expense. That decision would be weighed against the lost generation capability if the facility proceeds with decommissioning. As facility operations cease or change, plans and resources must be in place to maintain facility safety and security until a stable end-state is achieved. From a life-cycle perspective, the decision to stop facility operations should pave the way—in terms of both planning and resource availability—for subsequent decisions to achieve final end-state for the facility.

Specification of the end-state depends on which overall decommissioning alternative is chosen. Based on early studies, NRC described three decommissioning options for nuclear power plants: DECON, SAFSTOR, and ENTOMB. Under DECON (immediate dismantlement), soon after the nuclear facility closes, equipment, structures, and portions of the facility containing radioactive contaminants are removed or decontaminated to a level that permits release of the property and termination of the NRC license. Under SAFSTOR, often considered "delayed DECON," a nuclear facility is monitored and maintained in a condition that allows the radioactivity to decay to predetermined levels; afterwards, it is dismantled. Under ENTOMB, radioactive contaminants are encased in a structurally sound material such as concrete and appropriately maintained and monitored until the radioactivity decays to a level permitting release of the property. The facility owner may also choose to adopt a combination of the first two options in which some portions of the facility are dismantled or decontaminated while other parts of the facility are left in SAFSTOR. The decision may be based on factors besides radioactive decay, such as availability of waste disposal sites. The facility end-state decision must consider long-term surveillance and care as well as other responsibilities, the safety of the decommissioning workers, and alternative long-term uses of the site.

D&D actions must be conducted to reduce the potential health and safety impacts of contaminated facilities during the various phases of decommissioning, whether the nuclear facilities are dismantled, encased, or converted to other uses. The probable decommissioning activities and associated costs, as well as available funding profiles for each option, should be evaluated. Many factors must be considered when determining the decommissioning path. Foremost may be the life-cycle cost projections for decommissioning compared with the projected cost(s) of ongoing surveillance and maintenance (S&M) (see Section 5). Factors such as facility hazards (e.g., seismic) and physical condition may also be important. In some cases, part of a facility may remain operational for the foreseeable future; this aspect, as well as the proximity of other contaminated facilities, is important when making decisions that concern the disposition path.

Records of the nuclear facility and its operational history—especially those pertaining to waste management and possible workforce exposure to contaminants—must be both conscientiously maintained and retrievable. Issues may arise between the operating and decommissioning programs regarding the level of information needed to characterize unknown (current and future) conditions of the facility. The operating and decommissioning programs should work closely together to maximize information transfer, which will help minimize costs of implementing the plans.

2.2 Decommissioning Commercial Nuclear Facilities

The D&D of commercial nuclear facilities is regulated by NRC or Agreement States. NRC currently regulates 103 civilian nuclear power reactors and 37 nonpower reactors. While NRC is generally not directly involved in regulating the decommissioning of DOE's nuclear facilities, they regularly cooperate and exchange technical expertise on D&D matters. The public and facility workers are protected by a comprehensive set of federal regulations enforced by NRC.

NRC issued a rule establishing dose-based cleanup standards for all decommissioned facilities under its authority (10 Code of Federal Regulations [CFR] Pt. 20, Subpart E). This rule established criteria for both restricted and unrestricted use of the facility after decommissioning and license termination. NRC uses a performance-based standard that requires demonstration of potential exposures—considering all sources and pathways—to an individual of the public less than 25 millirems in one year. In addition, cleanup is implemented in conjunction with any nonradiological contamination that may be present at the facility. These cleanup standards are implemented by decommissioning facilities in conjunction with other federal and state regulations governing facility closure. NRC conducts inspections to assess cleanups and ensure compliance with regulations.

NRC has developed guidance to assist licensees in complying with the regulations, including standard format and content, standard review plans, and technical guidance in support of the decommissioning process. In 2007, NRC's NMSS updated numerous decommissioning guidance documents into a three-volume NUREG-1757, *Consolidated Decommissioning Guidance: Decommissioning Process for Materials Licensees*. The three volumes establish regulations that address radiological criteria for decommissioning, requirements for and contents of decommissioning plans and related submittals, timeliness requirements for submittal of decommissioning plans and related documents, and decommissioning funding plans. NUREG-1757 describes the risk-informed, performance-based approach for the information needed to support an application for decommissioning a materials license and compliance with the radiological criteria for license termination in 10 CFR Part 20, Subpart E. The approaches to license termination described in this guidance will help to identify the information (subject matter and level of detail) needed to terminate a license by considering the specific circumstances of the wide range of radioactive materials users licensed by NRC. Volume 1 of NUREG-1757 applies to the decommissioning of materials facilities licensed under 10 CFR Parts 30, 40, 70, and 72 and to the ancillary surface facilities that support radioactive waste disposal activities licensed under 10 CFR Parts 60, 61, and 63.

NRC reviews and approves decommissioning of nuclear power plants and other facilities licensed by NRC where radioactive materials are used on a case-by-case basis. (Note: Parts of NUREG-1757 are applicable to reactor licensees.) For power plants, NRC has found that allowing the radioactivity to decay for periods longer than 30 years during SAFSTOR reduces the safety issues for workers, the generation of low-level waste (LLW), and the costs of decommissioning. However, SAFSTOR must be weighed against immediate dismantlement options that would not require an extended S&M program and alternative use(s) for the site.

Decommissioning a nuclear power plant can be characterized as “construction in reverse,” with particular emphasis placed on ensuring industrial safety, which is regulated by the Occupational Safety and Health Administration (OSHA). EPA and appropriate state agencies play a significant role in ensuring the health and safety of the public and workers.

Portions of NRC’s authority to regulate the use of reactor-produced isotopes, the source materials uranium and thorium, small quantities of Special Nuclear Material (SNM), uranium mill tailings, and the disposal of LLW have been relinquished to individual states (under Section 274 of the AEA, as amended). States authorized to promulgate regulations on radioactivity (Agreement States, see Section 1.3) are also likely to be concerned about D&D activities at such facilities and will enforce their own regulations which may be equivalent to, or stricter than, NRC requirements. States enforce those regulations at sites undergoing D&D and are consulted as stakeholders on D&D of nuclear facilities in their state that are regulated by NRC.

Other NRC guidance may be useful when planning and executing D&D projects. Applicants for licenses may find the NRC’s environmental review guidance useful—NUREG-1748, *Environmental Review Guidance for Licensing Actions Associated with NMSS Programs*. NUREG 1575 is a consensus document developed jointly by NRC, DOE, DOD, and EPA to provide guidance for planning, implementing, and evaluating facility and environmental radiological surveys conducted to demonstrate compliance with a dose- or risk-based regulation. When issued, NUREG-1575, Supplement 1, *Multi-Agency Radiation Survey and Assessment of Materials and Equipment Manual* (MARSAME), will provide a multiagency approach for planning, performing, and assessing disposition surveys of materials and equipment, while at the same time encouraging an effective use of resources.

2.3 Radioactive Waste Management

In the United States, radioactive waste is generally defined by a combination of processes from which it was generated and its radionuclide content rather than by its radionuclide content alone. This approach—similar to certain classifications of hazardous wastes as defined under the Resource Recovery and Conservation Act (RCRA)—means that knowledge of the process used to generate the waste or the source of the waste can be important to planning for proper disposition. Waste classification is complex; it depends on a number of factors, including how the waste was generated, when it was generated, who generated it, the radionuclides present and their specific activity, whether or not the activity was licensed, whether there are other comingled contaminants, and security considerations. The DOE *Radioactive Waste Management Manual* (DOE M 435.1-1) explains the classification process for radioactive waste types. Because of the many complexities involved, a specialist in this area should be consulted to determine the proper classification of a waste stream as well as the laws and regulations that apply to the waste as a result of the classification. The major classifications of radioactive waste are high-level waste (HLW), transuranic (TRU) waste, LLW, MW, and special-case waste.

2.5.1 High-Level Waste

HLW includes spent (used) fuel from nuclear reactors and waste generated from reprocessing of spent fuel. Spent fuel contains all of the fission and activation products generated by use in the nuclear reactor as well as the remaining uranium. Commercial fresh fuel (fuel ready to enter a reactor) in the United States is essentially 100% uranium oxide. When spent fuel exits a commercial U.S. reactor, its composition is approximately 96% uranium oxide, 1% other actinide elements, and 3% fission products (see Figure 2-1). The TRU elements and fission products drive the hazards present with spent fuel and waste from reprocessing. Spent fuel is ordinarily stored at the site that generated it. The United States does not reprocess spent fuel commercially, although in the past, both commercial as well as DOE reprocessing was allowed.

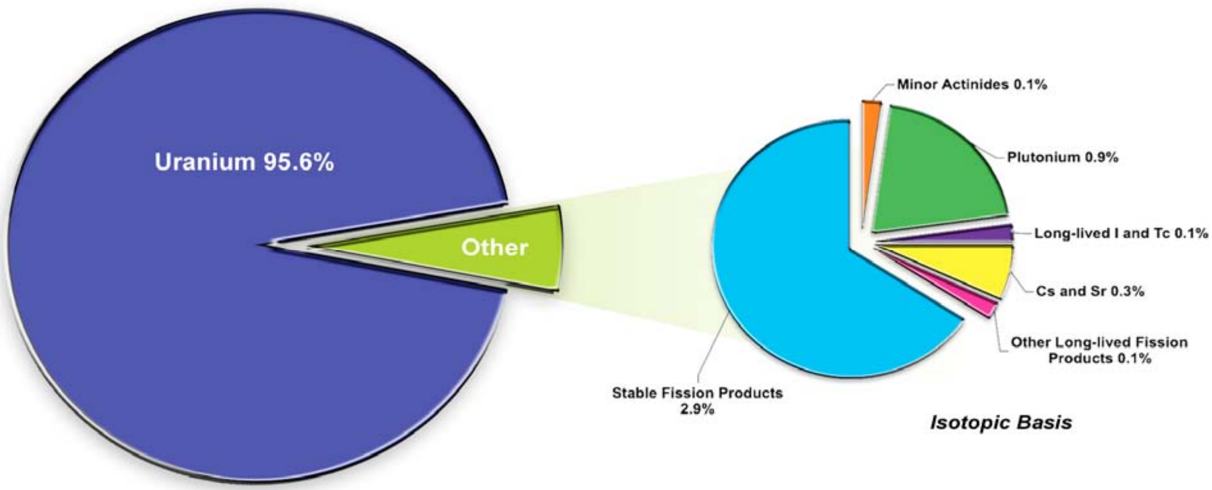

Figure 2-1. Approximate composition of spent fuel, based on DOE data. "Other" actinides include plutonium and minor actinides, and all remaining categories are included in fission products.

HLW from reprocessing generally contains more than 99% of the nonvolatile fission products produced during reactor operation. Most fission products have short half-lives and decay quickly. When initially generated, HLW is a highly radioactive material that generates significant amounts of heat and usually requires special handling. It can be processed into a variety of physical forms (e.g., alkaline or acidic supernatant liquid, sludge, salt cake, or calcine solid), all of which must be stored behind heavy shielding. In the past, HLW often took the form of underground tanks or bins. Most of DOE's inventory of HLW is stored at three facilities: the Hanford Reservation in Washington State, the Savannah River Site (SRS) in South Carolina, and the Idaho National Engineering and Environmental Laboratory (INEEL). It should be noted that, while DOE defines HLW as reprocessing waste only, NRC defines HLW as including both reprocessing waste and spent nuclear fuel (SNF).

SNF is spent nuclear fuel assemblies produced from commercial or government-owned nuclear reactors. SNF that has been discharged from a reactor after irradiation contains fission radionuclides with much higher radioactivity levels than the radionuclides found in other waste forms. Freshly discharged, spent fuel is both physically and radioactively "hot" and must be handled, transported, and stored using heavy shielding and neutron-moderating materials with provisions for appropriate venting due to heat buildup. At nuclear reactor sites, SNF is temporarily stored in pools and/or in aboveground, dry-storage facilities.

Currently, HLW is required to be converted into a solid form—such as borosilicate glass, which is not readily dispersed into the air or leached into the ground or surface water—and then disposed belowground in a geologic repository. The purpose of geologic disposal is to prevent any exposure to the public and to rely on engineered barriers, geologic features, and natural processes to delay and minimize the release of radionuclides to the environment.

In 1987, Congress focused site characterization activities for construction of a geologic repository for spent nuclear fuel and HLW at Yucca Mountain, Nevada; in 2002, based on DOE input, the President recommended and Congress approved the site. The Yucca Mountain project plans to submit a license application to NRC in 2008. HLW may be considered as MW since it contains hazardous components, though its treatment and planned disposal pathway mean that it does not suffer from the management problems that beset other MW (see Section 2.3.4).

2.3.2 Transuranic Waste

TRU waste is defined by DOE Order 435.1, *Radioactive Waste Management* (July, 1999) as radioactive waste containing more than 100 nCi (3700 Bq) of alpha-emitting TRU isotopes (isotopes of elements with an atomic number >92, i.e., that of uranium) per gram of waste. TRU waste is stored either at the waste-generating facility or at a designated DOE facility. Storage methods include retrievable burial, underground bunkers, concrete caissons, aboveground concrete pads, and inside buildings. DOE performs disposal of some TRU waste at the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, the world's first underground repository licensed for disposal of TRU waste generated during nuclear weapons production. Disposal is in bedded salt approximately 700 m below ground surface. WIPP began accepting TRU waste in 1999. As with HLW, TRU waste may be considered as MW, though once again, its treatment and planned disposal pathway mean that it does not suffer from the management problems that beset other MW (see Section 2.3.4).

2.3.3 Low-Level Waste

LLW is defined by the Low-Level Radioactive Waste Policy Amendments Act of 1985 as "radioactive material that: (1) is not high-level radioactive waste, spent nuclear fuel, or by-product material (as defined in section 11e.2 of the AEA of 1954) and; (2) NRC, consistent with existing law and in accordance with paragraph (1), classifies as low-level radioactive waste." LLW is thus defined by what it is not rather than what it is and consequently is the broadest category of waste. It encompasses materials that are slightly above natural radiation background levels to highly radioactive materials, which require extreme caution when handling. LLW is a by-product from the activities involving the generation of nuclear power, biotechnological and nuclear research, performing medical examinations and treatment, producing radioactive chemicals for use in nuclear medicine and research, and quality control of manufacturing processes. Mixed waste is defined as LLW determined to contain both source, special nuclear, or by-product material subject to the AEA of 1954, as amended, and a hazardous component subject to RCRA, as amended.

For purposes of final disposition, NRC recognizes four classes of LLW, in ascending order of hazard: Classes A, B, C, and GTCC (greater than Class C). For Classes A, B, and C, NRC has regulations that set concentration limits for both short- and long-lived radionuclides (see 10 CFR Parts 61 and 72). These limits are based on formulas that reflect both the half-lives and the hazards of the radionuclides in each class and are used to determine appropriate disposal.

Class A LLW is defined to be safe after 100 years, Class B after 300 years, and Class C after 500 years. These LLWs are typically disposed of in shallow land burial sites; however, since it presents a high hazard, GTCC waste is not typically disposed of in shallow land burial sites or commingled with Class A, B, or C LLW. GTCC has concentrations of certain radionuclides above the Class C limits as stated in 10 CFR Part 61.55. Storage of GTCC waste is the responsibility of the generator until the DOE formally accepts ownership, also known as "taking title." DOE is responsible for developing disposal capacity for GTCC waste and takes title at the time of disposal. DOE has initiated environmental studies to analyze alternatives for disposal of this waste.

Typically, DOE disposes of LLW in on-site disposal facilities (for cleanups performed under CERCLA), at other DOE waste facilities, or at commercial facilities. For non-DOE facilities, disposal costs can be significant and can drive decisions about the approach and timing of waste disposal. LLW is disposed in engineered trenches and concrete vaults or by shallow land burial and then covered with a closure cap. Waste is packaged, according to its characteristics, in drums, casks, special boxes, or other sealed containers. Low-activity waste, such as contaminated soil, may be disposed of directly in a cell without a container.

The national policy on LLW disposal was embodied in the Low-Level Radioactive Waste Policy Act of 1980 and its amendments in 1985. The act directs states to secure disposal facilities, either individually or through interstate agreements known as "compacts." Ten such compacts have been negotiated, but currently only three disposal facilities are available for LLW disposal:

- The EnergySolutions facility in Utah currently accepts certain types of Class A radioactive waste only.
- The US Ecology facility in Richland, Washington accepts Class A, B, and C waste, but only from the 11 states in two western compacts.
- The EnergySolutions facility in Barnwell, South Carolina receives Class A, B, and C LLW (scheduled to be closed after June 2008 to waste from all states except the three states that are part of the Atlantic Compact).

A license application for a fourth LLW disposal site, in western Texas, is pending. Given the restricted options for LLW disposal, some industry observers conclude that, "there is a crisis in LLW disposal in the United States" (Zacha 2007).

2.3.4 Mixed Waste

MW is defined as LLW determined to contain both source, special nuclear, or by-product material subject to the AEA of 1954, as amended, and a hazardous component subject to RCRA, as amended. A dual regulatory framework exists for MW, with EPA or authorized states regulating the hazardous waste and NRC, NRC agreement states, or DOE regulating the radioactive waste. NRC and DOE regulate MW under the AEA with regard to radiation safety; EPA regulates MW under RCRA authority with regard to hazardous waste safety. Once waste is determined to be MW, the waste handlers must comply with both AEA and RCRA statutes and regulations, a situation that can cause considerable waste management problems. The requirements of RCRA and AEA are generally consistent and compatible, but provisions in Section 1006(a) of RCRA allow the AEA to take precedence in the event provisions of requirements of the two acts are found to be inconsistent. The radioactive component of most MW is effectively LLW, so strategies often focus on treating the hazardous component of MW and disposing of the remaining LLW.

2.3.5 Special-Case Waste

DOE has identified certain waste as “special-case” waste. Special-case waste is defined as radioactive waste owned or generated by DOE that does not fit into typical management plans developed for the major radioactive waste types such as HLW, LLW, or TRU waste. As an example, special case waste could be LLW that, due to its high radioactivity levels, cannot currently be disposed of at existing DOE LLW disposal facilities without exceeding performance standards or TRU waste that cannot meet geologic disposal acceptance criteria.

2.4 Materials Not Covered by DOE or NRC Standards

Certain materials, such as naturally occurring radioactive material (NORM) and technologically enhanced naturally occurring radioactive material (TENORM), do not fall under NRC or DOE controls. The release of material with radioactive surface contamination from these sources is controlled by individual states.

For volumetrically contaminated material—material in which the radioactive contamination is distributed throughout the entire volume rather than on the surface—there are no release or clearance standards. DOE or NRC may analyze volumetrically contaminated materials from the facilities that they regulate on a case-by-case basis to determine whether the materials are sufficiently clean to be released. Within the DOE complex—where it is estimated that over half a million tons of contaminated scrap metal have been accumulated at various installations—contaminated metal may be melted and reused for controlled uses such as waste containers, caskets, shielding, or construction material. Scrap metal companies should be contacted early in the decommissioning process to verify their requirements for acceptance of the metal. Usually, scrap metal companies will not accept material with any detectable radioactive component even if the metal has contamination below the applicable surface contamination limit or the volumetric concentration limit.

3. EPA DECOMMISSIONING REQUIREMENTS AND PROCESSES UNDER THE COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT

D&D of radiologically contaminated facilities may potentially cause a release or threat of release of a hazardous substance, pollutant, or contaminant into the environment. Such a situation is not addressed by NRC mandates discussed in Section 2; instead, releases or threats of release may be addressed using the broad response authority provided by CERCLA and implemented through the NCP. This section discusses the federal regulatory framework and policies relevant to D&D being addressed under CERCLA. D&D activities may occur under other statutes such as the AEA, as described in Section 2.

3.1 Standards for D&D under CERCLA and the NCP

Under CERCLA, EPA has primary responsibility for implementing a key U.S. law providing broad authority for cleanup of hazardous waste sites. Other federal and state agencies may have the lead for response actions conducted under CERCLA at a particular site. Congress established the Superfund Program in 1980 to, among other things, locate, investigate, and clean up the worst hazardous waste sites nationwide. First published in 1968, the NCP is the federal government's blueprint for responding to both oil spills and hazardous substance releases. It was broadened to cover releases at hazardous waste sites requiring emergency removal actions following the passage of Superfund legislation in 1980.

Radioactive contamination is generally addressed in the same manner as other hazardous substances at CERCLA sites and normally should follow the same remedy selection process. EPA provides guidance for addressing radiologically contaminated sites that is consistent with its guidance for addressing chemically contaminated sites, taking into account the technical differences between radionuclides and chemicals. The EPA guidance has been developed to facilitate cleanups that are consistent with the NCP at radiologically contaminated CERCLA sites.

DOE-owned and -operated or NRC-licensed facilities are generally subject to those agencies' authorities under the AEA. EPA's involvement under CERCLA in decommissioning facilities normally arises as part of cleanup actions designed to address contamination at a site. The general manner in which sites, including facilities, follow the CERCLA cleanup process is described in this section.

3.2 Cleanup Process under Superfund

Generally, response actions under CERCLA are either removal or remedial actions. Removal actions are generally short-term response actions taken to abate or mitigate imminent and substantial threats to human health and the environment. They may be classified as emergency, time-critical or non-time-critical, and often primarily address surface or soil contamination. In comparison, remedial actions are generally longer term (and hence less time-sensitive), do not pose an imminent threat to human health and the environment, and are usually more costly than removal actions. Further, federally funded remedial actions can be taken only at sites on EPA's

NPL, unless the site is a federal facility. Removal actions may be used to address some threats at remedial sites. The distinction between situations where removal authority applies and situations where remedial authority applies can be difficult, but resources to clarify the problem are available (EPA 1992, 2000). The Superfund remedial cleanup process typically begins with site discovery or notification to EPA of possible releases of hazardous substances, pollutants, or contaminants. Sites may be discovered by various parties, including citizens, state agencies, and EPA Regional offices. Once discovered, sites that are to be addressed by the CERCLA remedial process are entered into the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS), EPA's computer system used to track potential and confirmed hazardous waste sites brought to the attention of the EPA Superfund Program. EPA then typically evaluates a site through steps in the Superfund cleanup process. Other federal and state agencies may have the lead for response actions conducted under CERCLA at a particular site. The steps of the Superfund cleanup process are as follows:

- Preliminary Assessment/Site Inspection (PA/SI)—investigations of site conditions and surrounding area to determine whether a site poses a threat to human health and the environment
- Hazard Ranking System (HRS)—screening mechanism using information obtained by EPA during the PA/SI to determine whether a site should be placed on the NPL
- NPL—list of the most serious sites identified for possible long-term cleanup
- Remedial Investigation/Feasibility Study (RI/FS)—detailed study of the nature and extent of contamination, associated risks to human health and the environment, and cleanup alternatives
- Record of Decision (ROD)—selection of a cleanup alternative to be used at the site
- Remedial Design/Remedial Action (RD/RA)—preparation and implementation of plans and specifications for achieving site cleanup
- Construction Completion—the date on which all components of the remedy are operational and functional
- Post-Construction Completion—long-term stewardship to ensure that Superfund response actions provide for the protection of human health and the environment, which may include Long-Term Response Action, Operation and Maintenance (O&M), Institutional Controls, Five-Year Reviews, Remedy Optimization (RO), and NPL Deletion

EPA generally uses these and other steps to determine and implement the appropriate response to threats posed by releases of hazardous substances, pollutants, and contaminants. Releases that require immediate or short-term response actions are addressed under the Emergency Response program of Superfund.

3.2.1 National Contingency Plan Criteria for Remedial Actions

The NCP sets forth nine criteria for evaluating alternatives when selecting a Superfund remedial alternative. The criteria can be separated into three levels: threshold, balancing, and modifying. The first two criteria are known as "threshold" criteria. They are the minimum requirements that each alternative must meet to be considered for selection as a remedy and a reiteration of the CERCLA mandate that remedies must ensure (1) overall protection of human health and the environment and (2) compliance with ARARs.

In addition to the two threshold criteria, EPA considers the following five "balancing" criteria that help in the assessment of certain trade-offs between alternatives so that the best option can be chosen, given site-specific data and conditions:

- long-term effectiveness and permanence
- reduction of toxicity, mobility, or volume
- short-term effectiveness
- implementability
- cost

The final two criteria are called "modifying" criteria:

- state acceptance
- community acceptance

These two criteria may cause comments from the state or the community to modify the preferred remedial action alternative or cause another alternative to be considered. The NCP addresses how the detailed analysis of alternatives should be performed using these nine criteria (see 55 FR 8719–8723, March 8, 1990).

All remedial actions at CERCLA sites must be protective of human health and the environment and comply with ARARs unless an ARAR is waived. Cleanup levels for response actions under CERCLA are typically developed based on site-specific risk assessments, ARARs, and/or to-be-considered material (TBCs). ARARs are often the determining factor in establishing cleanup levels at CERCLA sites.[1] State standards that are more stringent than federal standards are potential ARARs. However, where ARARs are not available or are not sufficiently protective, EPA generally sets site-specific remediation levels (1) for carcinogens at a level that represents an excess upper-bound lifetime cancer risk to an individual of between 10^{-4} and 10^{-6} and (2) for noncarcinogens such that the cumulative risks from exposure will not result in adverse effects to human populations (including sensitive subpopulations) that may be exposed during a lifetime or part of a lifetime, incorporating an adequate margin of safety [see 40 CFR Pt. 300.430(e)(2)(i)(A)(2)]. The latter approach is used to determine the noncarcinogenic risks of uranium. The specified cleanup levels are designed to account for exposures from all potential pathways and through all media (e.g., soil, groundwater, surface water, sediment, air, structures, and biota).

[1] For a list of federal radiological standards often site-specifically determined to be ARARs, please see Attachment A of *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination* (EPA 1997) which may be found at www.epa.gov/superfund/health/contaminants/radiation/pdfs/radguide.pdf. Lists of other standards that are potential ARARs are provided in both the *CERCLA Compliance with Other Law Manuals*, *Part I* (EPA 1988) and *Part II* (EPA 1989) which may be found at www.epa.gov/superfund/policy/remedy/pdfs/540g-89006-s.pdf and www.epa.gov/superfund/policy/remedy/pdfs/540g-89009-s.pdf.

3.2.2 Site-Specific Remedial Cleanup Levels

Alternatives for achieving a site-specific cleanup are evaluated using the nine criteria specified in Section 300.430(e)(9)(iii) of the NCP. The 10^{-4} to 10^{-6} cancer risk range described in the NCP can be interpreted to mean that an exposed individual may have a 1 in 10,000 to 1 in 1 million increased lifetime chance of developing cancer because of exposure to a site-related carcinogen under the exposure scenarios. A 10^{-6} risk level is used as the point of departure for determining cleanup goals. Some states have adopted single risk goals (e.g., 10^{-6}, 10^{-5}, or 10^{-4}).

While cleanups will generally achieve a risk level within 10^{-4} to 10^{-6} for carcinogenic risk, risks of greater than 1×10^{-4} may be acceptable under appropriate circumstances. CERCLA guidance states that "the upper boundary of the risk range is not a discrete line at 1×10^{-4}, although EPA generally uses 1×10^{-4} in making risk management decisions. A specific risk estimate around 10^{-4} may be considered acceptable if justified based on site-specific conditions" (see p. 4 of the "Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions" (EPA 1991) and p. 5 of the *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination* (EPA 1997)). These documents may be found at www.epa.gov/oswer/riskassessment/pdf/baseline.pdf and www.epa.gov/superfund/health/contaminants/radiation/pdfs/radguide.pdf.

Preliminary Remediation Goals

Generally, Preliminary Remediation Goals (PRGs) under the NCP are developed as risk-based concentrations, usually derived from standardized equations combining exposure information assumptions with EPA toxicity data. Normally, they are considered by EPA to be protective for humans (including most sensitive groups) over a lifetime. However, these risk-based PRGs may not always be used at a particular site.

Generally, PRGs should be established at 1×10^{-6}. PRGs are identified early in the CERCLA process and may be modified as needed at the end of the RI or during the FS based on site-specific information from the baseline risk assessment. Ultimately, a preferred alternative with protective remediation levels should be selected through the use of the nine NCP remedy selection criteria.

PRGs generally can be used to screen sites and as initial cleanup goals in appropriate circumstances. PRGs are not designed to serve as de facto cleanup standards and should not be applied as such. PRGs can be used in site screening to help identify areas, contaminants, and conditions that do not require further federal attention at a particular site. Generally, at sites where contaminant concentrations fall below PRGs, no further action or study is warranted under Superfund so long as the exposure assumptions at a site match those taken into account by the PRG calculations. Chemical concentrations above the PRG do not automatically designate a site as "dirty" or trigger a response action. However, exceeding a PRG suggests that further evaluation of the potential risks that may be posed by site contaminants is appropriate. PRGs are also useful tools for identifying initial cleanup goals at a site. In this role, PRGs can provide long-term targets to use during the analysis of different remedial alternatives. By developing

PRGs early in the decision-making process, project managers may be able to streamline the consideration of remedial alternatives.

A detailed discussion of PRG tools for decommissioning is provided in Section 3.6.

The Hazard Index

To help assess the potential for cumulative noncarcinogenic effects posed by multiple contaminants, EPA has developed a hazard index (HI). Generally, the HI is derived by adding the noncancer risks for site contaminants with the same target organ or mechanism of toxicity. When the HI exceeds 1.0, there may be concern for adverse health effects due to exposure to multiple contaminants.

Combining Radionuclide and Chemical Risk

Excess cancer risk from both radionuclides and chemical carcinogens should be summed to provide an estimate of the combined risk presented by all carcinogens. Exceptions would be cases in which a person cannot reasonably be exposed to both chemical and radiological carcinogens. Similarly, the chemical toxicity from uranium should be combined with that of other site-related contaminants in calculating the HI.

There are generally several differences between cancer slope factors (the cancer risk [i.e., proportion affected] per unit of dose used in EPA's Integrated Risk Information System chemical files) for radionuclides and chemicals. However, similar differences also occur between different chemical slope factors. In the absence of additional information, it is reasonable to assume that excess cancer risks are additive for purposes of evaluating the total incremental cancer risk associated with a contaminated site.

"To Be Considered" Materials

TBCs generally include criteria, advisories, guidance, and proposed standards that are not legally enforceable but contain information that may be helpful in determining the level of protectiveness in the remedy selection and implementation process. Because TBCs are not ARARs, their identification and use are not mandatory.

Guidance Outside the Risk Range

Guidance that provides for cleanups outside the risk range (greater than 10^{-4}) is generally not consistent with CERCLA and the NCP and should not be used to establish cleanup levels. Thus, dose-based guidance for developing cleanup levels generally is inconsistent with CERCLA and the NCP's risk range approach for reasons that include the facts that (1) estimates of risk from a given dose estimate may vary by an order of magnitude or more for a particular radionuclide and (2) dose-based guidance generally begins an analysis for determining a site-specific cleanup level at a minimally acceptable risk level rather than the 10^{-6} point of departure set forth in the NCP. Where radiological and nonradiological (chemical) contaminants are present at a CERCLA site, they should both be addressed using the risk range approach regarding risk from carcinogens. For further information see pp. 11 and 13 of *Radiation Risk Assessment at CERCLA Sites: Q & A* (EPA 1999) which may be found at www.epa.gov/superfund/health/contaminants/radiation/pdfs/riskqa.pdf.

3.2.3 Removal Actions

Removal actions are generally short-term responses taken to abate or mitigate imminent substantial threats to human health and the environment related to releases of hazardous substances. EPA divides removal actions into three categories (emergency, time-critical, and non-time-critical) based on the type of situation, the urgency and threat of the release or potential release, and the subsequent time frame in which the action must be initiated. This section focuses on non-time-critical removals since most D&D activities under CERCLA at DOE sites are conducted as non-time-critical removals. Non-time-critical removal actions are those where the lead agency determines, based on the site evaluation, that a removal action is appropriate but a planning period of more than six months is available before on-site activities must begin. Non-time-critical removal actions typically involve a secure site, no nearby population center, storage containers in stable condition, and a dangerous concentration of chronic toxic substances. Because non-time-critical removal actions can address priority risks, they provide an important method of moving sites more quickly through the Superfund process.

Section 300.415(b)(4)(i) of the NCP requires an Engineering Evaluation/Cost Analysis (EE/CA) for all non-time-critical removal actions. An EE/CA is intended to accomplish the following:

- satisfy environmental review requirements for removal actions
- satisfy administrative record requirements for documentation of removal action selection
- provide a framework for evaluating and selecting alternative technologies

The EE/CA identifies the objectives of the removal action and analyzes the effectiveness, implementability, and cost of various alternatives that may satisfy these objectives. Thus, an EE/CA serves an analogous function to, but is more streamlined than, the RI/FS conducted for remedial actions. The non-time-critical removal should be conducted to ensure that all risk assessment activities are consistent with any future remedial action that may occur to achieve consistent risk goals. The results of the EE/CA and EPA's response decision are summarized in an Action Memorandum (AM). For further information see *Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA* (OSWER Directive 9360.0-32) at www.oscreadiness.org/cec_courses/removal.htm#mod7.

3.3 Background Radiation in Facility Cleanup

Background radiation should be considered when developing remediation goals. Background and site-related levels of radiation are generally addressed as for other contaminants at CERCLA sites. For risk-based (10^{-4} to 10^{-6} or HI) cleanup levels, background levels of the contaminant typically are included in the risk estimate. If background levels of a contaminant exceed the acceptable risk goal (e.g., 10^{-4}, HI of 1), then background is generally used as the cleanup level. In general, CERCLA cleanups do not go below background.

It should be noted that certain ARARs specifically address how to factor background into cleanup levels. For example, some radiation ARAR levels are established as increments above background concentrations. In these circumstances, background normally should be addressed in the manner prescribed by the ARAR where that approach leads to a protective cleanup level. For further information see EPA's guidance *Role of Background in the CERCLA Cleanup Program* (EPA 2002) at www.epa.gov/oswer/riskassessment/pdf/role.pdf.

Additional information on radioactive materials present in building materials can be found in "Radioactivity Measurements on Glazed Ceramic Surfaces" (Hobbs 2000) at http://nvl.nist.gov/pub/nistpubs/jres/105/2/j52hob.pdf.

3.4 CERCLA Response Actions at Sites with Contamination inside Buildings

Under certain specific circumstances, CERCLA response authority can be used to address releases of hazardous substances, pollutants, or contaminants that are found within buildings. OSWER Directive 9360.3-12, issued August 12, 1993, provides useful guidance on this subject. See www.epa.gov/superfund/policy/remedy/pdfs/93-60312-s.pdf. (Figure 3-1 is a flow chart of recommended steps for action in this guidance.)

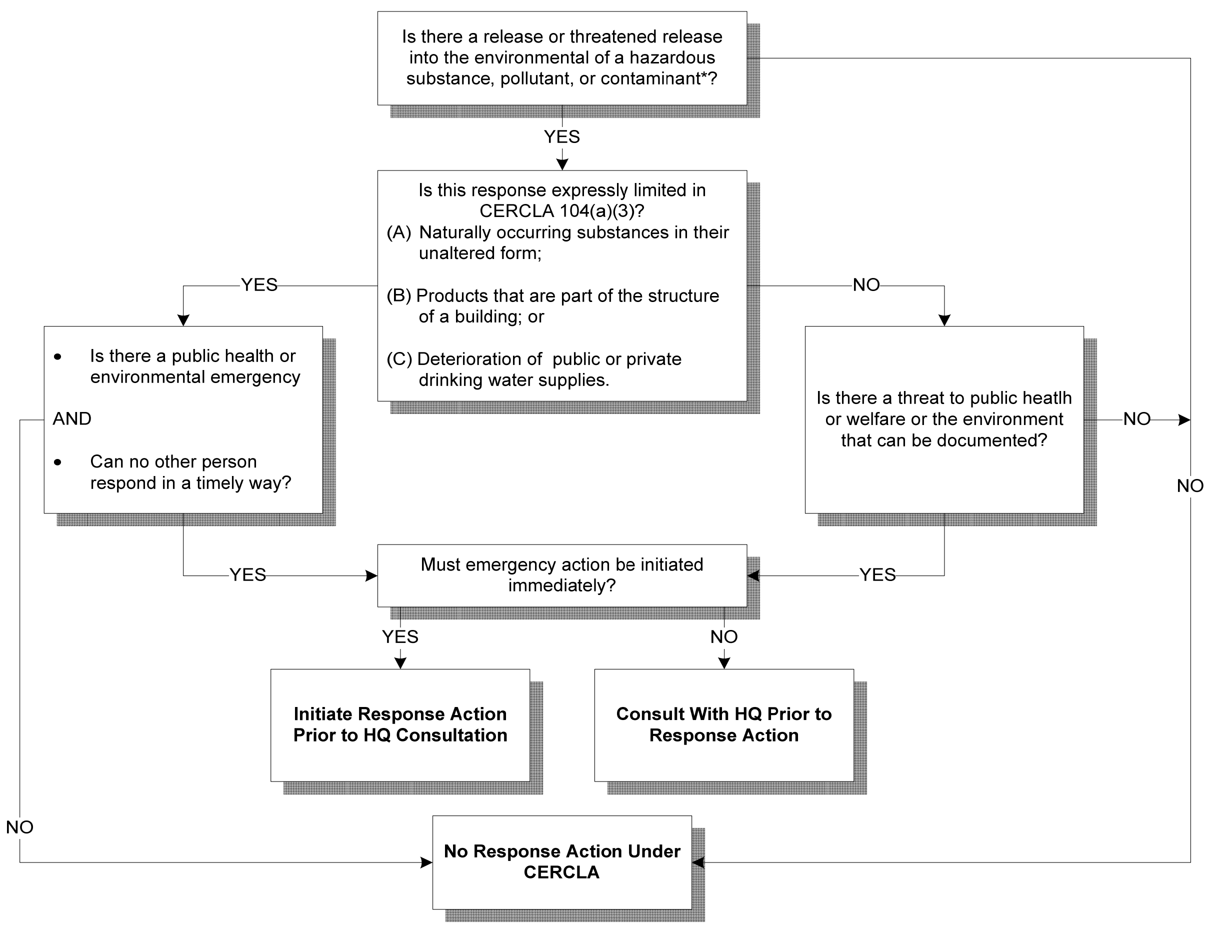

Figure 3-1. Indoor contamination: Steps for action.

3.4.1 Release or Threat of Release

CERCLA authorizes response to a release or threatened release into the environment of a hazardous substance, pollutant, or contaminant. The authority to respond to a release of a pollutant or contaminant applies to situations where there may be an imminent and substantial danger to the public health or welfare. The terms "hazardous substance" and "pollutant or contaminant" are defined very specifically in CERCLA (see 42 U.S. Code 9601). In general, a release or threat of release from a building may exist if at least one person or the environment outside of the building may be exposed to the release. For example, if the hazardous substance, pollutant, or contaminant can migrate through a window or through the foundation or building structure into the soil, creating exposures to persons or hazards to the environment, a sufficient basis may exist to show that there is a threat of release into the environment that may justify the cleanup of the interior of the building. A release or threat of release of a hazardous substance, pollutant, or contaminant may also exist where contaminated articles, clothing, or even parts of the structure itself may inadvertently be removed from the building.

Indoor contamination also may be the direct result of a release into the environment from a nonnatural source that migrates into a building or structure. For example, contamination in a yard may be transported into a building on the feet of the residents or workers or may migrate into the building through an open window or basement walls. In this situation, a release into the environment may be occurring and can cause a building to become contaminated with the hazardous substance, pollutant, or contaminant.

3.4.2 Limited vs. Nonlimited Authority

If a release or threat of release is present, the next step generally is to determine whether the qualified limitation on response authority provided for in CERCLA Section 104(a)(3) is triggered; this determination corresponds to the uppermost "YES" decision in Figure 3-1. In brief, this provision may limit the authority to respond under CERCLA for a release or threat of release

- "of a naturally occurring substance in its unaltered form, or altered solely through naturally occurring processes or phenomena, from a location where it is naturally found;
- "from products which are part of the structure of, and result in exposure within, residential buildings or business or community structures; or
- "into public or private drinking water supplies due to deterioration of the system through ordinary use."

CERCLA Section 104(a)(4) provides exceptions to this limitation of response authority.

Under these three circumstances, a CERCLA response action may be appropriate if there is a "public health or environmental emergency, and no other person with the authority and capability to respond" in a timely way is available. When these three circumstances are not present, CERCLA Section 104 response authority is not affected.

3.5 Land Use/Institutional Controls under CERCLA

The concentration levels for various media that correspond to the acceptable risk level established for cleanup typically depend in part on land use at the site, in particular the reasonably anticipated future land use of the facility undergoing D&D (e.g., demolished and taken down, reused for some industrial/commercial purpose). Land uses that will be available following completion of an RA may depend on the remedy that has been selected (considering the reasonably anticipated future land use, along with other remedy selection factors).

EPA's policies for how to consider reasonably anticipated future land use in the CERCLA remedy selection process are discussed in *Land Use in the CERCLA Remedy Selection Process* (EPA 1995), which may be found at www.epa.gov/superfund/community/relocation/landuse.pdf.

In certain cases, in spite of the acceptable land use scenarios and due to other limitations, an interim D&D process could be in place until those limitations are eliminated over time.

Generally, institutional controls may be included as a supplemental component to the remedy selected at a CERCLA site, not as a substitute for treatment, containment, or other remedial action. Institutional controls typically are nonengineering measures—usually legal controls—intended to affect human activities in a way that prevents or reduces exposure to hazardous substances. Institutional controls usually restrict land use to prevent unanticipated changes in use that could result in unacceptable exposures from residual contamination. At a minimum, institutional controls are normally intended to alert future users to the residual risks and the need to monitor the site in light of potential changes in land use. Engineering controls may be employed with institutional controls. Inside buildings, different methods have been employed to shield contamination from occupants, such as shielding or distance regulations.

EPA's CERCLA policy states that if a site cannot be cleaned up to a protective level (i.e., generally within the 10^{-4}–10^{-6} risk range) for the "reasonably anticipated future land use" because it is not cost-effective or practicable, then a more restricted land use should be chosen that will meet that protective level (EPA 1995, p. 9).

When waste is left on site at levels that do not allow unlimited and unrestricted use, CERCLA requires that reviews be conducted at least every five years to ensure the remedy remains protective; monitoring the site for any changes in land use can be part of the Five-Year Review process. Such reviews usually analyze the implementation and effectiveness of the remedy, including any institutional controls where they are relied upon. Should land use change in spite of the institutional controls, it may be necessary to evaluate the implications of that change for the selected remedy and whether the remedy remains protective.

3.6 Preliminary Remediation Goal Tools for Decommissioning

EPA recently developed two risk assessment tools that can be particularly relevant to decommissioning activities conducted under CERCLA authority: the Preliminary Remediation Goals for Radionuclides in Buildings (BPRG) for radionuclides electronic calculator and the Preliminary Remediation Goals for Radionuclides in Surfaces (SPRG) electronic calculator.

EPA developed the BPRG calculator to help standardize the evaluation and cleanup of radiologically contaminated buildings at which risk is being assessed for occupancy. BPRGs are radionuclide concentrations in dust, air, and building materials that correspond to a specified level of human cancer risk. The BPRG calculator recommends assessing contamination in building materials both on the surface and volumetrically. The BPRG calculator includes two standard default land-use scenarios—residential and indoor worker. The BPRG calculator is available at http://epa-prgs.ornl.gov/radionuclides/.

The intent of SPRG calculator is to address hard, outside surfaces such as building slabs, outside building walls, sidewalks, and roads. SPRGs are typically radionuclide concentrations in dust and hard, outside-surface materials. The SPRG calculator recommends assessing contamination in hard, outside-surface materials both on the surface and volumetrically. The SPRG calculator includes three standard default land use exposure scenarios—residential, indoor worker, and outdoor worker. The SPRG calculator will be available at www.epa.gov/superfund/health/contaminants/radiation/radrisk.htm.

Tables are provided with both the BPRG and SPRG calculators to show generic PRG concentrations. Both calculators are designed to help provide the ability to modify the standard default BPRG/SPRG exposure parameters to calculate site-specific BPRGs/SPRGs. However, to set radionuclide-specific BPRGs/SPRGs in a site-specific context, assessors should answer fundamental questions about the site. Information on the radionuclides present on site, the specific contaminated media, land-use assumptions, and the exposure assumptions behind pathways of individual exposure is generally necessary to develop site-specific BPRGs/SPRGs.

To facilitate compliance with dose-based ARARs while conducting decommissioning activities under CERCLA, EPA is developing two electronic calculators. These are the Radionuclide Building Dose Cleanup Concentrations (BDCC) and the Radionuclide Outside Hard Surfaces Dose Cleanup Concentrations (SDCC) electronic calculators. Both of these ARAR dose calculators are set up in a manner similar to the BPRG and SPRG calculators. They include the same exposure scenarios. Also, the equations in the scenarios are essentially the same except the ARAR dose calculators use dose conversion factors instead of slope factors and a year of peak dose instead of risk over a period of exposure such as 30 years.

4. DECOMMISSIONING REQUIREMENTS AT DEPARTMENT OF ENERGY SITES

DOE-owned facilities are subject to DOE's AEA authority. Radionuclides are defined as CERCLA hazardous substances and in most cases, DOE facilities and sites are currently decommissioned under CERCLA. Exceptions include any DOE facilities licensed by the NRC and processing sites designated under the Uranium Mill Tailings Radiation Control Act (UMTRCA). If a facility is being decommissioned under a RCRA permit or order, EPA or the state may have RCRA corrective action authority over decommissioning actions. Even if a facility does not have a RCRA permit, RCRA requirements may be ARARs.

Requirements of CERCLA, RCRA, and other ARARs may be combined and integrated in an interagency agreement (IAG) that establishes the roles of DOE, EPA, and the state in completing remedial actions. Remedial actions at a site covered by an interagency agreement often include decommissioning of facilities.

4.1 EPA-DOE Joint Policy on Decommissioning DOE Facilities under CERCLA

On May 22, 1995, EPA and DOE issued a joint "Policy on Decommissioning of Department of Energy Facilities Under Comprehensive Environmental Response, Compensation, and Liability Act" (http://homer.ornl.gov/oepa/guidance/cercla/d&d.pdf) to ensure the following:

- protection of human health and the environment
- consistency with CERCLA
- provision for stakeholder involvement
- achievement of risk reduction without unnecessary delay

This policy addresses all decommissioning projects conducted by DOE regardless of NPL status. Under the policy, decommissioning activities normally should be conducted as non-time-critical removal actions when using CERCLA response authority, unless the circumstances at the facility make it inappropriate. Under the authority delegated by Executive Order 12580, DOE normally is the lead agency. Oversight is provided by EPA with state and stakeholder participation. The role of the state may include oversight responsibilities and be further formalized when it is a signatory to a site-specific Federal Facility Agreement (FFA).

Decommissioning activities must comply with all applicable requirements established by any existing IAGs or FFAs, Site Treatment Plans required under the Federal Facility Compliance Act, permits and orders issued pursuant to authorized state or federal programs, and other applicable requirements. Decommissioning activities also should meet or waive ARARs as discussed in the NCP. Decommissioning activities should be conducted in full compliance with the community relations and public participation requirements established by CERCLA, the NCP, and DOE policies. Where applicable, a formal Community Relations Plan (CRP) should be prepared, specifying the community relations activities to be conducted during the removal. The CRP should be prepared prior to completion of the analysis of removal alternatives. In addition, stakeholders normally will be provided with notice and an opportunity to submit comments on the analysis of removal alternatives. Written responses to public comments should be prepared. For further information see Tab 36 of the "Superfund Community Involvement Toolkit" at www.epa.gov/superfund/community/toolkit.htm.

The policy also addresses sites under RCRA. States authorized by EPA to administer state hazardous waste programs have authority under such programs to enforce requirements applicable to decommissioning activities. These requirements may involve waste management, corrective action, and closure; the requirements may be established or enforced through regulations, permits, orders, or agreements. The degree to which state hazardous waste and other requirements may affect decommissioning projects normally depends on a number of site-specific factors, including the scope of the state's authorized program and whether the facility to be decommissioned is included within a RCRA-permitted facility or is otherwise subject to RCRA requirements.

A removal action is not necessarily the final response action and may be followed by a remedial action if necessary. Removal actions under CERCLA should, to the extent practicable, contribute to the efficient performance of any long-term remedial action conducted at the site.

4.2 DOE Decommissioning Framework

Practices and procedures for decommissioning facilities at DOE sites are described in detail in DOE's *Decommissioning Handbook* (DOE 2000b), which is based on the decommissioning framework defined in the *Decommissioning Implementation Guide* (DOE 1995c). That framework is summarized in Figure 4-1 and is discussed below. The decommissioning framework follows the process for conducting non-time-critical removal actions under CERCLA described in Section 4.1 but is flexible enough to be implemented at facilities not governed by CERCLA. It should be noted that decommissioning may be only one aspect of ongoing environmental remediation at a site; at some sites remediation projects may not involve decommissioning any facilities. Once a facility is determined to be surplus and approaches the end of its life cycle, it goes through three general phases: transition, disposition, and post-decommissioning.

4.2.1 Transition/Planning Phase

Before formal decommissioning begins, a facility determined to be surplus goes through a transition phase where its status is evaluated and decisions about its ultimate fate are made. Understanding the set of conditions defining the final disposition of a facility, its wastes, and the planned future land use (its end-state) is essential to the engineering-planning process and resource allocation for decommissioning activities. Identification of the end-state is usually done in collaboration with regulators, local community planners, tribal governments, and various stakeholder groups.

Decommissioning Project Scoping Document (Baseline)

Once a decision has been made to proceed with decommissioning, a decommissioning project scoping document must be prepared to define the ultimate decommissioning objective (e.g., demolition) and end-points and to establish conceptual initial estimates of technical scope, cost, and schedule for the project. All decommissioning projects are expected to establish technical, schedule, and cost baselines in the decommissioning project scoping document and subsequently update them in the decommissioning project plan.

Project Baseline Definitions (DOE 2000c)

Technical baseline—Documented technical requirements/scope of the effort needed to achieve the project objectives.

Schedule baseline—Documented logic sequence of activities with durations and milestones that defines the project's path from beginning to completion.

Cost baseline—Documented estimate of cost to complete all the scheduled activities, including direct and indirect work scope for the project, time-phased with the project's schedule.

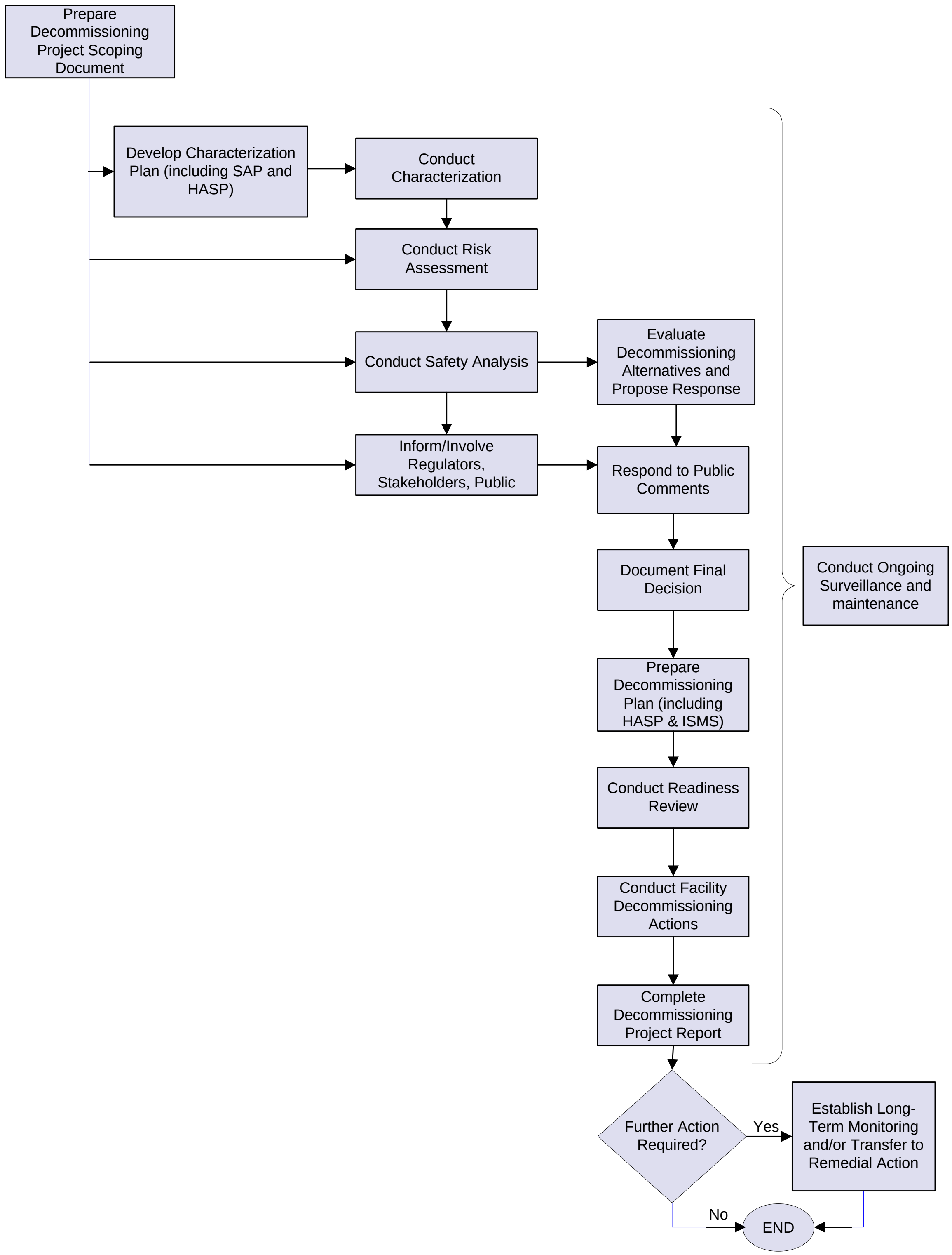

Figure 4-1. DOE decommissioning framework. Adapted from DOE 2000c.

Decommissioning end-points are the detailed specification of conditions to be achieved for a facility's spaces, systems, and major equipment. Identifying the end-points is an integral part of deriving the project work breakdown structure, schedule and budget. Specifying and achieving end-points is a systematic engineering method for progressing from an existing condition to a final end-state condition. An end-point method is a way to translate broad mission statements into explicit goals that can be readily understood and applied by personnel who will perform the work. Development of the facility end-points should use a graded approach to differentiate between complex facilities with process systems and significant hazards and those with relatively simple buildings that are not substantially contaminated. In this way, the project will apply an appropriate level of detail and effort for different facility types and for facilities with different hazard categories.

The decommissioning objective and end-points stated in the decommissioning project scoping document provide the basis for identifying decommissioning alternatives. Decommissioning alternatives capable of achieving the decommissioning objective and reaching decommissioning end-points should be formulated. Each decommissioning alternative may consist of one or more specific actions. Included among these activities and studies are site characterization, risk assessment, safety analysis, and stakeholder participation. Ultimately, a ROD or other suitable decision document is produced identifying the most appropriate decommissioning alternative.

The appropriate facility disposition option used as the basis for project planning can be selected using hazard information, activities, cost, and other constraints, combined with national priorities and strategies. Disposition options are generally decontamination and/or dismantling, then release, demolition, or entombment.

Characterization Plan

To determine which of the decommissioning alternatives is most appropriate, it will be necessary to have data that reliably characterize the nature and extent of contamination at the facility. To evaluate whether existing data characterize the facility well enough to plan decommissioning, the data quality objective (DQO) process should be used. Additional characterization activities should be considered if there is insufficient knowledge of hazards to understand the hazardous substance types, quantities, forms, potential exposures, and locations. Besides their use in helping to choose among decommissioning alternatives, characterization data are used for assessments of nature and extent of contamination, in risk assessments, when developing emergency response management, S&M plans, sampling and analysis plans (SAPs), and health and safety plans (HASPs).

Risk Assessment

In parallel with characterizing the facility to be decommissioned, an assessment must be prepared of the environmental risks posed by the facility and by the decommissioning activities. The risk assessment should be designed to evaluate existing and potential risks to human health and the environment in the absence of decommissioning and to present information on the potential impacts from the decommissioning alternatives. The graded approach mentioned earlier should be applied in determining the appropriate complexity level for the risk assessment. Regardless of the legal authority under which decommissioning is conducted at a facility for which DOE has responsibility, an assessment of the environmental risks posed by the facility in the absence of decommissioning, and the potential impacts from activities associated with the decommissioning alternatives is needed. In some circumstances, a qualitative assessment of environmental risks is adequate, while in other circumstances, more sophisticated methods could be warranted. Risk assessments generate data that can be used to produce site-specific, risk-based action levels or preliminary remediation goals, to develop site conceptual exposure models, and to compare contaminant concentration levels in the environment at the facility with applicable or relevant and appropriate, risk-based and chemical-specific standards.

Safety Analysis

The hazards analysis should evaluate radiological, chemical, biological, and physical hazards at the facility to be decommissioned. Documentation of the hazards analysis should provide a formal record of all identified hazards at the facility—both those posed to the public as well as those that workers may encounter during decommissioning work activities. A single safety document maximizes efficiency and allows for a quick response in critical situations.

Public Involvement

It is DOE's policy to involve stakeholders in the program operations, planning activities, and decision making. Stakeholders (the "public") may be any affected or interested party, which may include representatives of state, tribal, and local governments, Congress, other federal agencies, external review bodies, community groups, environmental and other interest groups, business, labor, academia, professional and technical organizations, educational organizations, DOE employees and contractors, and members of the general public. Additionally, the legal authorities under which decommissioning may be conducted mandate specific public participation activities.

Document Final Decision

The final selection of a decommissioning alternative must be made, taking into consideration all available information, including public comments. Selection of the final decommissioning action must be documented in an AM or similar decision document.

4.2.2 Disposition Phase

The disposition phase of a facility's life-cycle usually includes deactivation, decommissioning, and S&M activities. Major tasks in this phase include preparing a Decommissioning Plan, conducting a Readiness Review, and completing a Decommissioning Project Report.

Decommissioning Project Plan

The scope and detail of the decommissioning project plan should be commensurate with the scope and complexity of the decommissioning project. The decommissioning project plan should incorporate the measures necessary to protect the health and safety of workers and the public and to prevent the spread of contamination during decommissioning operations (see Section 5.1 for further information). The decommissioning project plan should provide for change control, unless change control management is addressed on a sitewide basis. When approved, the decommissioning project plan will replace the decommissioning project scoping document and will contain the new technical, cost, and schedule baselines for the project.

Decommissioning Project Plan—Suggested Contents (DOE 2000c)

- Facility Description and History
- Scope and Objectives of the Decommissioning Action
- Summary of Characterization
- Technical Approach
  - Alternatives considered
  - General decommissioning approach
  - Activity specifications
  - Technical baselines and assumptions
- Project Management
  - Management approach
  - Organization
  - Training
  - Quality assurance
  - Cost
  - Schedule
- Worker and Environmental Protection
  - HASP and ISMS
  - ALARA program
  - Occupational exposure estimates
  - Emergency preparedness and response program
  - Environmental compliance program
  - Safety analysis and review of decommissioning activities
- Waste Management
  - Waste minimization
  - Waste handling, packaging, transport and disposal
  - Waste estimates
- Final Site Survey
  - Plans and criteria
  - Independent verification

Two critical elements of the Decommissioning Project Plan pertain to worker protection. The HASP addresses matters such as assessment of hazards, training, personal protective equipment, monitoring, site control, etc (see Section 7.2 for further information). The Integrated Safety Management System (ISMS) systematically incorporates safety considerations into management and work practices at all levels (see Section 7.3 for further information). Policy and guidance for these safety elements of the Decommissioning Project Plan are listed in the resources for Section 4 included in Appendix A.

Readiness Review

It is DOE's policy that program work (such as decommissioning) should not be started or resumed in nuclear facilities until they have been brought to a state of readiness to safely conduct that program work and that the state of readiness to operate has been verified. Based upon the complexity of the planned activity, there are two different reviews that can be used to determine that conditions are satisfactory for the activity to proceed: a management assessment or an Operational Readiness Review (ORR). The purpose of either review is to minimize work stoppages caused by incomplete planning and preparation and to ensure safety to the workforce and the public. It is possible that a project may require more than one management or readiness review to cover portions of a project separated by time (e.g., transition review; decommissioning readiness review).

The ORR is an activity to verify that management has brought the facility to a state of readiness to commence or resume program work. In some circumstances, an ORR will be conducted by both DOE and the responsible contractor to provide the verification. The management effort may include management self-assessment activities in preparation for the ORR. Once management concludes that readiness has been achieved, this state of readiness is independently verified by the contractor ORR and confirmed by the DOE ORR. Only then is the nuclear facility authorized to begin or resume decommissioning-related work. The ORR includes the minimum core requirements provided in DOE 5480.31. The depth of the evaluation of core requirements is determined according to the situations associated with the shutdown and subsequent outage, magnitude of hazard, and level of complexity associated with the proposed facility operating mode by using a graded approach.

The management assessment is a shortened version of the ORR and is used for small-scale projects or for projects having very little risk and few hazards. This review can usually be accomplished in a short period of time and verifies that all hazards have been identified, appropriate safety and health requirements have been met, and safety systems and controls are in place and functioning.

Deactivation

Following operational shutdown, the first activity is typically to deactivate the facility. Deactivation places a facility in a safe shutdown condition that is economical to monitor and maintain until the eventual decommissioning of the facility can occur. The deactivation process removes the facility from active service and places it in a safe and stable condition to ensure adequate protection of the worker, public health and safety, and the environment. Actions typically include removal of readily removable hazardous and radioactive materials, removal of fuel, draining and/or deenergizing nonessential systems, and related activities. Deactivation is designed to place the facility in a low-risk state with minimum S&M requirements (frequently referred to as “cold and dark”), sometimes for an extended period of time until decommissioning decisions can be made. The disposition of a large facility such as a reactor can be affected by factors such as the technical and financial resources available, the impact to utilities needed by other facilities on the site, and by political considerations. In some cases, however, deactivation may be immediately followed by full decommissioning. For example, in a small facility with low contamination levels, deactivation and decommissioning may proceed seamlessly as a single project and the facility can released or demolished relatively quickly.

Decommissioning

During decommissioning, the facility may be decontaminated and/or dismantled, and then released, demolished, or entombed. Radiological decontamination involves ensuring that all radioactive components are removed, all surfaces are cleaned, and radioactive waste is properly packaged and sent to an appropriate disposal facility. For example, pipes that were used to transport radioactive fluids may need to have contamination removed or fixed in place and be sized (cut) and packaged. Concrete that may have been in contact with radioactive particles should be characterized to determine whether contamination exists and be decontaminated as is appropriate and cost-effective.

The type and extent of radioactive contamination depend on the function of the facility. For example, the major source of contamination in an accelerator facility is likely to be in the form of activated metals and concrete, whereas the principal concern in a fuel-processing facility is likely to be surface contamination. In most cases, the identities of the major contaminants can be deduced from the operational histories of nuclear facilities, though actual magnitudes and distribution must be determined through characterization. Characterization includes identifying the location and magnitude of radioactive, chemical, and physical hazards. Characterization will also lead to an estimation of the type and amount of radioactive waste that will require management. Continuing S&M throughout decommissioning also ensures that any contamination is adequately contained and that potential hazards to the public, workers, and the environment are minimized.

Dismantlement is the removal of equipment, fixtures, fittings, etc. from a structure followed by the controlled breaking of the structure into pieces and removal of the pieces from the facility. Demolition is the controlled tearing-down of a structure, usually without the sequential breaking involved in dismantlement. Dismantlement and demolition of structures may take place after decontamination. Certain structures (e.g., stand-alone administration buildings) may not require demolition. After all radioactive substances are removed or fixed in-place, dismantlement and demolition follow standard industry practices. Both demolition and dismantlement activities create waste that may be reduced and may have value when recycled.

Surveillance and Maintenance

As shown in Figure 4.1, S&M activities continue throughout the decommissioning process until the facility can be released for unrestricted use. Surveillance includes any activity at a facility that involves the periodic inspection of a facility, equipment, or structure to demonstrate compliance, identify problem areas requiring corrective action, and determine the facility's present environmental, radiological, and physical condition. Maintenance includes any activity performed at a facility on a day-to-day basis that is required to sustain property in a condition suitable for the property to be used for its designated purpose. It includes preventative, predictive, and corrective maintenance.

When a facility enters the disposition phase with its condition and/or operating history unknown, baseline data must be collected and evaluated to determine the status and condition of the facility. Then throughout deactivation and decommissioning stages in particular, S&M activities are performed to maintain the facility safety envelope. Development and implementation of an S&M program is an iterative process in which the S&M program is frequently reevaluated and updated to reflect changes in facility conditions and activities. S&M may also be conducted as a separate, stand-alone activity between the deactivation and decommissioning activities, if these activities are separated by a substantial length of time. The degree of S&M activities can be influenced by the decommissioning option selected. For example, entombing a facility could significantly reduce the level of security required.

Decommissioning Project Report

To release a decommissioned facility or site for use with or without radiological restrictions, it is necessary to verify, and in some cases certify, that the decontamination has been completed in accordance with DOE-approved criteria established for the project. In addition, several documents should be prepared, including the final project report, the record of completion, certification docket, and the project data package. The ultimate goal of any decommissioning action is to ensure that resulting radiological and chemical conditions at the facility or site comply with established criteria, standards, or guidelines, and that the public and environment are thereby protected. To ensure that this goal is met, a process of verification, with appropriate close-out surveys, should be performed for all decommissioning projects.

4.2.3 Post-Decommissioning Phase

Where long-term monitoring and/or remedial action is required to comply with overall site plans and regulatory requirements, the facility life-cycle will include a post-decommissioning phase.

Long-Term Monitoring

S&M activities that continue throughout the life of the decommissioning project are converted to long-term S&M following decommissioning. The post-decommissioning S&M plan should be customized to provide for physical safety and security of the specific facility and to ensure compliance with restrictions (e.g., institutional controls) established for that facility.

Remedial Action Program

Sites may be transferred to remedial action for final cleanup of adjacent soil or groundwater in accordance with environmental regulatory requirements and future land and facility uses.

Final Project Report Elements

1. Background, including facility history and project purpose
2. Facility description, including buildings and systems and predecommissioning status
3. Decommissioning and remedial action objectives including work
4. Work performed, including—
   - Project management
   - Project engineering
   - Site characterization
   - Alternatives assessment
   - Site preparation
   - Decommissioning operations
   - Waste disposal
   - Post-decommissioning final radiological and chemical surveys
5. Costs and schedules
6. Waste volumes generated
7. Occupational exposure to personnel
8. Final facility or site condition
9. Lessons learned, conclusions, and recommendations

5. PROJECT MANAGEMENT AND COST ELEMENTS

This section examines various factors that affect D&D project costs that are consistent with the major elements of managing a D&D project. The more detailed elements involved in estimating costs of decommissioning are not included in this section but have been evaluated and documented in numerous studies. NRC prepared a three-volume regulatory guide for their licensees (NUREG 1757) that addresses the decommissioning process (Vol. 1, NRC 2006a); characterization, survey, and determination of radiological criteria (Vol. 2, NRC 2006b); and financial assurance, recordkeeping, and timeliness (Vol. 3, NRC 2003). These documents include the development of detailed decommissioning procedures and of unit cost factors that form the basis for a cost estimate. These documents also address the use of a contingency factor that addresses uncertainty in developing a cost estimate. Additionally, DOE published a comprehensive handbook on decommissioning (DOE 1995c) that addresses decommissioning processes and costs as well as other facets of decommissioning. Due to the comprehensive nature of these previous documents, this section is intended to address only the major cost elements and considerations of concern when developing a budget and is not intended as a guide for developing a site-specific cost estimate.

The Remedial Action Cost Engineering and Requirements (RACER) system is the primary tool for preparing cost estimates for environmental remediation and is used by multiple federal agencies that have environmental liabilities. This program is updated periodically and is maintained under contract to the Air Force Civil Engineer Support Agency.

There are six major cost elements to consider in a D&D project (DOE 1995c):

- D&D Plan development
- the removal of materials and equipment from land and structures
- construction and operation of support facilities
- decontamination and/or removal of empty structures
- waste management
- contracting and project management

These elements are discussed in the following subsections.

5.1 Decontamination and Decommissioning Plan Development

Prior to D&D actions occurring, detailed planning and the order of events must be set up in a D&D Plan and/or documents, such as the following:

- AM
- EE/CA
- RA work plans
- waste-handling plan
- RA report
- phased construction completion report
- standard operating protocols
- sampling plans

Planning for DOE D&D actions should be formed in accordance with DOE Order 413.3 (see Section 2.2) and DOE Order 430.1B, establishing a corporate, holistic, and performance-based approach to real property life-cycle asset management that links real property asset planning, programming, budgeting, and evaluation to program mission projections and performance outcomes. Furthermore, it accomplishes this objective by identifying requirements and establishing reporting mechanisms and responsibilities for real property asset management.

Document development can often account for 30% of total project costs (National Research Council 1996). The cost of documentation can be minimized by gathering as much knowledge about the site as practical in advance; planning for unknowns; planning for flexibility, including decision points throughout the process; and developing a team (regulatory and technical management) early. This approach will minimize potential work stoppage during D&D.

Prior to development of a D&D Plan or other planning documents, the responsible party needs to know how much money will be required and whether sufficient funding will be available throughout the project. However, prior to development of the plan, this knowledge may not always be available at the appropriate uncertainty level. State statutes may require proof of financial assurance; federal properties, however, are exempt from such state requirements. FFAs (e.g., tri-party agreements at DOE sites) typically require the site-managing agency to request funding in budgets submitted to Congress that is sufficient to complete milestones identified in the agreement. Since the costs for decommissioning a nuclear plant are in the $500 million range, NRC requires that its licensees demonstrate financial assurance for decommissioning by one or more of the following (NRC 2007):

- Prepayment—a deposit by the licensee at the start of operation in a separate account such as a trust fund
- Surety, insurance, or parent company guarantee method—assurance that the cost of decommissioning will be paid by another party should the licensee default
- External sinking fund—a separate account outside the licensee's control to accumulate decommissioning funds over time if the reactor licensee recovers the cost of decommissioning through ratemaking regulation or nonbypassable charges

A well-developed D&D Plan requires input from several interested parties. The responsible party, in agreement with regulators and stakeholders, should analyze risks, costs, and social values (including future land use). The health and safety of the general workforce, as well as potential impacts to the local community and environment, need to be addressed. This process leads to wider public acceptance, which may minimize future costly delays. Numerous regulations and jurisdictions can lead to an agglomeration of requirements that must be clarified early on. Guidelines published by NRC, DOE, and EPA provide assistance, regulatory coordination and compliance.

During the planning stage, the potential hazards of the various facilities should be identified and evaluated so that they can be prioritized according to their relative hazards. More hazardous facilities should generally be removed/mitigated first to lower maintenance costs and risks posed to workers, the public, and the environment. In some cases, factors such as availability of waste disposal sites, the location or physical relationship of facilities to one another, and continuing building usefulness may dictate remediating facilities in an order other than the hazard ranking. Likewise, maintenance and security expenses can be minimized by removing high-security features quickly, eliminating nonessential security activity. Personnel with lower clearance levels will be able to accomplish tasks without the need for escorts. This approach removes a layer of sometimes burdensome security. Finally, manpower needs can be reduced when high-maintenance areas are addressed early.

The D&D Plan should consider previous D&D experience at the site or at other sites with similar problems. Taking time to compile process knowledge and to apply lessons learned can result in tremendous cost savings.

Clearly defining the future use of a facility is critical for estimating costs and developing a D&D Plan. As an example, cost estimates were developed for seven major plutonium buildings at the Rocky Flats Plant for attaining standby, restricted use, and unrestricted use conditions. A comparison of these estimates shows that the costs for performing the tasks required for a restricted use are about 4–5½ times the cost of a standby condition. For an incrementally small additional amount (approximately 10%) over the cost of a restricted use condition, an unrestricted use could be achieved (Rockwell International Energy Systems Group 1981).

5.2 Removal of Equipment and Materials from Structures

An active S&M program must exist at any radiologically contaminated structure until the contamination is controlled or contained. These expenditures can be saved with expedited equipment removal actions, done in a safe and orderly manner. Decisions must be made whether and how to segregate and decontaminate the removed equipment and whether or not any of it can be recycled. The large amount of equipment from D&D structures can potentially result in large amounts of LLW. Section 6 further discusses techniques and experiences that deal with the removal and disposal of equipment.

When economical, equipment and materials can be decontaminated for reuse. However, economics alone do not often justify the cost of decontamination. If items are not releasable to the public, they may still find a purpose on a controlled DOE site. Since the public and the regulatory community have a significant interest in how materials and equipment are disposed of or reused, effective communication greatly increases the likelihood of success. Further, as these communications can take a considerable amount of time, the process should be started early. Free-release standards should also be discussed with the regulatory community at an early stage to avoid any misinterpretations.

5.3 Construction and Operation of Support Facilities

If at all possible, it is best to use existing buildings as support facilities for personnel and operations such as decontamination, waste segregation, waste packaging, etc. This approach may be impractical due to contamination or building logistics. In such cases, the construction of small, dedicated shops is preferred over the construction of large, multipurpose facilities. It is important to remember that the future cost of demolishing or decontaminating these newly constructed facilities must be considered in the total cost.

5.4 Removal or Reuse of Empty Structures

The question of whether or not to decontaminate and reuse or remove empty structures is an important decision point. If the planned future use is industrial, decontamination and reuse of existing facilities is a viable option. Costs must be weighed between the decontamination and handling of waste streams from the building or the demolition and removal of the structure. Sections 6 and 8 contain further information on technologies involved with these processes and on case studies.

5.5 Waste Management

Large quantities of LLW, hazardous waste, and MW are generated during D&D. Waste management covers safe and economic disposal, including collection, separation, treatment, packaging, and transportation of the products generated from the D&D process. Costs can vary considerably depending on how efficiently a site's waste management strategy addresses each of these elements. A major decision at most sites is whether all wastes will be transported to an off-site disposal facility or if some wastes can be disposed of in facilities constructed on site. Section 2.3 describes classification of radiological waste. Examples of waste management strategies are described in the case studies in Section 8.

Characterization (tailored or graded within the context of DQO considerations) of hazardous substances to determine their identities, forms, amounts, and locations is essential before, during, and after D&D operations. Sampling allows wastes to be segregated, determining how various waste streams need to be dispositioned. It is sometimes more cost-effective and safer to assume a whole structure or part of a structure is contaminated and dispose of it as such in an acceptable landfill rather than attempt to segregate the waste into component streams. Historical knowledge of the contaminated structure (to assist characterization), available landfill space, and disposal costs need to be considered.

If classified wastes are encountered, the site must be secure enough to handle, maintain, and protect those specific wastes. The facility must then incur the added cost of security (guards, fencing, and personnel security clearance) to handle classified waste on site or ship it off site to a secure facility.

An aggressive waste minimization effort applied to personal protective equipment (PPE), clothing, tools, chemicals, and supplies helps reduce waste disposal costs. The generation of MW in particular should be kept to a minimum due to the expense and difficulty of locating an acceptable location for its disposal. Waste treatment sometimes allows less costly disposal; e.g., the cost of treating MW might be warranted if it could be disposed of as LLW at a significant cost savings. Caution must be used to ensure all requirements are met for LLW.

Wastes are subject to several handling steps before they are disposed on site or shipped off site. This materials handling often blends the waste so that the portions with elevated concentrations are reduced. Under certain circumstances, regulatory agencies may approve adding less contaminated soil to waste containers to reduce the average radiation levels to below regulatory criteria.

One means of reducing the quantity of waste produced is to decontaminate radioactive materials—primarily metals—to a level sufficient to permit sale to the commercial market. In addition to reducing wastes, this step produces revenue for the project. Recycling metals commonly found at radiologically contaminated sites (such as steel, stainless steel, nickel, copper, aluminum, mercury, and depleted uranium) can recoup costs, but release standards must still be met. Potentially recyclable products should be segregated into clean scrap, contaminated scrap that can be decontaminated economically, and contaminated scrap that cannot be decontaminated economically. A choice must sometimes be made between disposal costs and reducing volume. A great deal of consideration must be given to the cost and benefit of decontaminating materials to recycle and reuse since decontamination produces a waste stream that must be addressed. The cost of recycling is more than just a monetary issue since valuable space in landfills can be freed up if the choice is made to decontaminate or recycle materials.

A number of components of the waste shipment process are capable of creating bottlenecks for the entire D&D process. Careful consideration and planning can reduce the potential for significant delays. Sufficient on-site storage capacity must be available, along with staging areas for loading waste containers. Containers must be compatible with transportation vehicles and unloading equipment at disposal facilities. Optimizing container size and purchasing containers in quantity can often yield significant discounts and reduce delays. The work required to reduce the size of large pieces of contaminated equipment to fit standard waste containers can be expensive and time-consuming and must be performed within rigorous safety analysis and control envelopes. Innovative options for size-reduction are discussed in Section 6. A review of off-site disposal and transportation options needs to include opposition to transportation routes. Besides coordination with the disposal facility, regulators in the receiving and trans-shipping states need to be aware of, approve, and sometimes inspect shipments. It is advantageous for the contractor to have a transportation coordinator who tracks railcars on a daily basis using the rail carrier tracking system.

5.6 Project Management Considerations

Cost-effective management requires a management structure that is streamlined, orderly, responsive, and focused on safety and cost containment. Management layers need to be minimized using an integrating contractor or a single, independent contractor where possible. Multiple layers of management lead to added cost and a high ratio of management and professional services to cost of execution of the physical decommissioning.

The contractor should be given adequate responsibility and accountability in performing the operations. Fixed-price contracts with incentives for cost and schedule reduction should be used where possible. The roles of the contractor and any subcontractors should be well-defined. However, details about contracting are not a subject of this document.

Experience from various D&D projects has led to some general principles that are useful for contractors/project managers to consider:

- D&D planning should include the following:
  - project schedules with associated management details
  - a precleanup survey, including both radiological measurements and thorough documentation of the previous uses of the facility must be made to assist in planning
  - administrative activities for procurement
  - establishing equipment removal sequences for each area, taking into account the effects on building exhaust, air-supply, power, and communication systems
  - scheduling and supervision of work assignments for specific D&D tasks
  - allotment of sufficient storage space for equipment and materials awaiting disposition
- The early stages of D&D planning should incorporate environmental considerations along with technical and economic issues in decision making.
- Selection of suitable disposal or storage sites for contaminated materials is a critical step.
- Choosing personnel experienced in D&D processes will increase the efficiency of any task.
- D&D projects are labor-intensive; final costs are therefore very sensitive to changes in labor rates.
- Applying lessons learned from previous projects and from other sites makes a project more efficient and less costly.
- Early and frequent input from stakeholders will more likely result in a project that gains and maintains critical support from local governments and politicians.

- Consulting with regulatory agencies before and during D&D efforts will save time and effort in the long run.
- Close coordination with regulators can allow decisions to be made in the field.
- Resources are used more efficiently when similar remediation tasks are done simultaneously.
- Plans need to be open to ideas and scrutiny throughout the entire D&D process.
- Environmental efforts must be evaluated to ensure that soils and groundwater are not recontaminated during the process (e.g., contaminated soil should not be staged in an area already remediated).
- Delays in the waste shipment process are capable of creating bottlenecks for the entire D&D process.
- Optimize the use of automation and robotics in repetitive operations, taking into consideration factors such as reliability, decontamination needs, additional waste generation, etc. Robotics minimizes the potential exposure and radiation dose to the worker, in turn reducing the amount of person hours and health and safety monitoring as well.
- Optimize the use of heavy equipment for similar operations. The high cost of leasing heavy equipment dictates its prudent use. Leased equipment must be decontaminated or purchased if the equipment cannot be cleaned for free release.
- Focused demonstrations are necessary to determine which technology is best suited for a particular site and particular project. Major R&D programs usually are not beneficial at this stage.
- Sacrificing attention to health and safety requirements may result in costly delays if incidents lead to violations and work stoppages.
- Removing classified or high-security items early in the process minimizes the need for specialized security monitoring.
- Waste-reduction efforts can result in tremendous cost savings.
- All D&D operations from initial cleanup to the final radiological certification survey must be thoroughly documented.
- Mock-ups should be used as decommissioning trials to account for missed procedures or deficiencies in the procedures.

6. TECHNOLOGY FOR DECONTAMINATION AND DECOMMISSIONING

This section introduces and provides overviews of various technologies that have been used at D&D sites. A summary of these technologies is presented at the end of the section. Their inclusion in this document does not mean that they are the only ones that are available or applicable to a specific site. The following types of technologies are introduced in this section:

6.1 Site Characterization and Verification Sampling
6.2 Decontamination
6.3 Contamination Control
6.4 Cutting and Sizing
6.5 Solids Removal
6.6 Liquids Removal
6.7 Robotics

6.8 Large Structure Demolition
6.9 Waste Sampling for Disposition
6.10 Packaging and Transportation
6.11 Work Monitoring

Examples in the sections below highlight technologies that have been applied during D&D projects. The examples used in this document are by no means comprehensive, nor does it constitute endorsement of those technologies by ITRC. Its introductions to technologies are not all-inclusive as new technologies continue to be developed in response to specific needs at facilities undergoing D&D. Further, the case studies presented here are intended to serve as a sampling of the large variety of facilities that may undergo D&D. The greater representation of DOE sites in the case studies presented is reflective of the perspective of the state regulator authors. Further, the majority of the collective experience and knowledge of D&D has come from DOE sites.

6.1 Site Characterization and Verification Sampling

Characterization sampling is intended to provide an understanding of the nature and extent of contamination sufficient to assess potential risks to human health and the environment. Verification sampling is conducted following D&D activities to demonstrate that specific remediation goals or waste acceptance criteria have been met.

There are a wide range of tools available for characterization and verification sampling. How these tools are applied is also important to the quality of the characterization and verification process. Strategies such as Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) provide recognized approaches for determining which data need to be gathered, selecting what level of detail is required, and guiding the analysis and interpretation of the data.

The horizontal directional drilling (HDD) and environmental measurement while drilling (EMWD) provides an example of the one of the tools available. These two technologies were brought together to meet the need of remotely characterizing subsurface soil contamination under structures. Demonstrations performed by Sandia National Laboratories at nuclear weapons facilities (e.g., Hanford and SRS) successfully characterized subsurface contamination using HDD/EMWD. The technology provides immediate data on what contamination may be present and where it is likely located. These combined technologies were brought to Rocky Flats, where 31 buildings with known or suspected under-building contamination required characterization due to known spills, leaks, or building processes during years of production (DOE 2006b).

The EMWD gamma ray spectrometer (GRS) with position location capability system represents an innovative blend of new and existing technology that produces real-time environmental and drill bit data during drilling operations. Down-hole components of the EMWD-GRS system include a gamma ray spectrometer; the up-hole system consists of a personal computer, a battery pack/coil, a pickup coil, and a receiver. The EMWD-GRS system is compatible with a variety of directional drilling techniques that include systems that push soils to the side and use minimal drilling fluids generating little or no secondary waste and mud systems using rotary drilling or mud motor.

Figure 6-1. Environmental sampling using HDD at Building 865 at Rocky Flats.

The foundation of HDD technology is a drill head that can be steered toward the area that is to be characterized. As applied at Rocky Flats (Figure 6-1), the HDD system's primary equipment consisted of a hammer drill that pushed a casing containing a drill bit through the soil. This method was selected because it used no drilling fluid. A 900-pound pneumatic hammer mounted on a 20-foot steel frame simultaneously drove the drill bit and a 4-inch exterior steel casing to create the borehole. To avoid subjecting the EMWD tool to shock, the casing was hammered to the sampling point with the pneumatic hammer without the EMWD. The hammer was then pulled out, the EMWD was pushed in, and the hole was logged as the EMWD tool was withdrawn.

Experience indicates that deployment of HDD/EMWD has resulted in a significant increase in personnel safety, a significant decrease in environmental hazards, and cost savings of some $150,000 to more than $200,000 for each building with a footprint in the 10,000-20,000 square foot range.

6.2 Surface Decontamination

Several technologies have been successfully used on radiologically contaminated surfaces. These include both wet and dry methods of physically removing surface layers. Other methods, such as chemical peeling and chemical applications, can work well on steel surfaces but are limited on porous surfaces such as concrete. EPA's *Technology Reference Guide for Radiologically Contaminated Surfaces* (EPA 2006) provides a comprehensive listing of available decontamination technologies and describes several. The information in that document is not repeated here.

6.2.1 Chemical Decontamination of Gloveboxes and Tanks

Cerium nitrate [$Ce(NO_3)_3$] was used with great success at Rocky Flats to decontaminate surfaces. An earlier decontamination process applied a complex blend of acids and other chemicals to equipment surfaces in a three-step process. Cerium nitrate is injected with steam into tanks and other equipment, or diluted solutions of cerium nitrate are simply applied to interior surfaces, which are then wiped and rinsed with a neutralizer (Figure 6-2). The extraction solution uses microemulsification and chemical ion exchange to bind itself to contaminants. After 24 hours, surfaces are surveyed to determine whether DOT criteria have been achieved.

Chemical decontamination technologies became a viable alternative to size-reducing gloveboxes and tanks when new DOT regulations allowed gloveboxes that met surface-contaminated object (SCO) criteria to be dispositioned as whole LLW. The life-cycle estimates for using chemical decontamination technology on TRU waste in projects involving hundreds of contaminated gloveboxes and tanks destined for more hazardous and costly size-reduction were reduced by nearly 30%. The most significant benefit of chemical decontamination was thousands of hours of avoided worker exposure to high airborne radioactivity, exertion, and several industrial hazards that result from size-reduction.

Figure 6-2. A scrub brush is used during the second step of the chemical decontamination process.

6.2.2 Hydrolasing Radiologically Contaminated Surfaces

Hydrolasing uses ultrahigh-pressure water jets to scabble or "scarify" a thin layer of contamination from the outermost surfaces of the concrete walls or floors. Hydrolasing systems can blast away paint and the initial layer of surface material, capture the resulting water and debris, and filter this mixture to separate the water from leftover sludge for analysis and treatment or disposal. The hydrolasing system significantly reduces the potential for airborne contamination, minimizes waste, and contains any floor or wall contamination as it is removed.

Hydrolasing systems consist of four basic components: a pump, the hydrolasing unit, a filter, and water-collection tanks. The hydrolasing unit is capable of operating on floor surfaces or suspended from a boom for walls. The hydrolaser itself is a compact, track-driven sled resembling a lawn mower base without wheels. Underneath the base is a round, rotating nine-inch head with six high-pressure jets capable of spray pressures up to 36,000 pounds per square inch (psi). Offset to one side of the spray head is a port that connects to a vacuum line to remove water and debris and pump it back to a filtering unit.

An underwater hydrolasing technology was successfully demonstrated in real conditions in the Hanford K East Basin in 2003. A robotic arm allows deployment of the technology in 17 feet of water in a highly radiological environment. A hydrolaser was to be installed in the K East Basin in 2007 to scrub contamination from the walls and floor, which have absorbed radioactivity from the basin water (DOE 2007b).

The hydrolaser performs extremely well for stripping paint and underlying contaminated material in the majority of cases. Thicknesses of up to ¾-inch of paint and ⅛-inch of solid concrete can be removed in one pass. On masonry walls the effect is even greater, with mortar joints completely removed in some instances. In comparison with conventional scrabbling or sandblasting methods, the hydrolasing system dramatically increases worker safety while also dramatically decreasing waste.

Some conventional hydrolasing systems can generate large quantities of wastewater. However, in comparison with dry decontamination methods, such as scabbling, shaving, or sandblasting, the hydrolasing system used at Rocky Flats was shown to dramatically increase worker safety while also dramatically decreasing waste volume (DOE 2006b). The only limitation of the system is the inability to strip thick buildup of paint in corners and cracks or voids in the walls and floors; however, this is a common problem shared by all current removal systems, both wet and dry.

6.3 Contamination Control

Contamination control minimizes the uncontrolled distribution of radioactive material in a given environment. For highly radioactively contaminated rooms, a two-step process has been used to remove the contamination from the air and then seal it in place on the floor and walls of the room. An aerosol sugar fog is first dispersed with a machine that uses sound waves to make very small droplets (Figure 6-3). After the radioactive particles in the air are fixed to the surfaces by the fog as it settles, up to a ¼-inch layer of polyurea coating is sprayed on its surface to permanently seal the contamination in place. Passive aerosol-generating equipment used for sugar-fogging large rooms uses ultrasonic parabolic transducers to create the encapsulating aerosol. The aerosol fog consists of sugar, glycerin, and water with an added fluorescent tracer to track potentially contaminated fog residues that might adhere to workers' clothing and equipment.

Figure 6-3. Use of the aerosol fogging equipment is intended to downgrade the personal protective equipment requirements for room entry from supplied-air suits to standard powered air-purifying respirators.

The continued success of room fogging has resulted in avoiding countless hours of potential worker exposure to airborne radioactive particles. In many applications, entry requirements could be downgraded to standard air-purifying respirators after the fixative was applied, resulting in a cost savings. A lower derived air concentration also eliminated the need for multiple entries in expensive and cumbersome supplied air suits.

6.4 Cutting and Sizing

6.4.1 Plasma-Arc Cutting Technology

Plasma cutters function by sending an electric arc through a gas as it passes through a constricted opening. The gas can be compressed air, nitrogen, argon, oxygen, etc. The arc elevates the temperature of the gas to the point where it enters the fourth state of matter called "plasma." The electrical conductivity of the plasma causes the arc to transfer to the metal, while the high current causes the metal to melt. The nozzle's restricted opening causes the gas to squeeze by at a high rate of speed and cut through molten metal. The gas is also directed around the perimeter of the cutting area to shield the cut.

Figure 6-4. Plasma-arc cutting torch.

Plasma-arc cutting units can be equipped with remote-control arms (Figure 6-4), providing additional protection to workers. One arm is capable of holding the torch and cutting while a worker manipulates the arm with a joystick. A second arm grips the pieces to be cut and loads the cut pieces into an appropriate container for shipping and disposal. Consequently, workers are kept at a distance from contaminated materials, reducing the potential for exposure. From an ergonomic perspective, using cutting technologies such as plasma arc in combination with remote/robotic platforms greatly decreases physical demands on workers.

6.4.2 Ultrahigh-Pressure Water Jet

An ultrahigh-pressure, abrasive water-jet cutting system uses a 50 hp intensifier pump to generate 55,000 psi output pressure. The pump supplies water to an abrasive cutting head that is configured on a 14-foot aluminum track to guide the cutting unit for a desired cut. Direction of cut, drive motor start and stop, travel speed, and abrasive delivery rate are all controlled from a remote panel. A fluidized system delivers garnet, the abrasive material used in sandpaper. The unit is capable of cutting ¼-inch stainless steel at a rate of 24 inches per minute.

Innovative for cutting contaminated equipment, the use of water keeps contaminants suppressed. Water acts as a fixative during cutting and effectively contains contamination that mechanical and thermal means would send airborne. Safely staged at a distance, workers do not endure ergonomic or physical strain and are not exposed to fall danger, confined spaces, or cutting and breaching hazards.

6.4.3 Explosive Cutting

The explosive cutting process involves using small charges to cut bolts, hangers, and other metal and masonry materials, principally to take elevated materials and drop them to floor level for further processing. At the Rocky Flats Site, components removed by this process included an overhead crane, mezzanines, plenums, and stair landings. As an example, a large uranium facility duct at ceiling level was cut into large lengths by workers on man-lifts while it was still suspended, and then the hangers were cut explosively to lower it to the floor level for further size-reduction. Explosive cutting was performed during off hours with workers removed from the building. The driver for explosive cutting was worker safety, in particular to avoid elevated work with heavy materials on scaffolds.

6.5 Solids Removal Systems

6.5.1 Raschig Ring Vacuum System

Raschig rings are borosilicate glass rings approximately 1½ inches wide by 1½ inches long and are similar in appearance to napkin holders. The rings contain boron that absorbs neutrons and prevents the occurrence of a criticality chain reaction. Raschig rings are used to stabilize fissile radionuclide solutions in tanks. Removal of Raschig rings and commingled residue was considered to be one of the significant hazards in the cleanup of the Rocky Flats Site (DOE 2006b).

A closed-loop vacuum system was used for Raschig ring removal (Figure 6-5). The system consists of a wand assembly to extract the material from inside the tanks, an intake hose to transport the material from the wand to a 55-gallon receiver drum, a suction unit to create a vacuum condition in the wand assembly and intake hose, and an exhaust hose to return the vacuum system exhaust flow to the tank. The exhaust hose is routed through high-efficiency particulate air (HEPA) filters to remove contamination from the exhaust flow. The wand assembly slides and rotates in a ball joint assembly so that the operator can move it to reach all of the surfaces in the tank. The ports in the tank through which the intake wand and exhaust hose pass are sealed so that closed-loop integrity can be maintained. The rings and any accompanying residue are deposited directly into the receiver drums.

Figure 6-5. Raschig ring vacuum system.

This technology saves time and contributes to safety by eliminating the requirement for secondary handling and/or containment of the material. Earlier manual methods of Raschig ring removal exposed workers to significantly higher levels of radiation and were time consuming.

6.5.2 Vac & Ship System

The Vac & Ship system (Figure 6-6) uses an industrial vacuum similar to those used in the mining industry. The MAXVAC vacuum is designed to remove heavy loads of sand, gravel, and dirt instead of manually shoveling the waste out from below-grade locations. The MAXVAC system pulls a negative pressure of approximately 9 psi. A separate HEPA filter unit ties into the system and filters radiological particulates, controlling contamination and limiting worker exposure. The waste container size is optimized for the DOT maximum allowable shipping weight of 40,000 pounds and minimizes the empty void space, allowing for the natural angle of gravel (angle of repose). The system allows one-step, closed waste removal directly into a shipping container approved for disposal as well. The filtration equipment protects the vacuum from contamination,



Figure 6-6. The Vac & Ship system removed gravel from an 18-foot deep pit.

supporting reuse. With minimal parts used to tie in each piece, the system requires little maintenance, ultimately resulting in uninterrupted duty and low operating expenses.

6.5.3 New Pumping and Centrifuge Systems for Removing Tank Sludge

Two separate technologies have been developed to empty waste tanks safely and efficiently using a specialized, remote-controlled pumping system. The system includes a unique, remote-controlled track vehicle attached to a vacuum hose (see Figure 6-7). The hose removes sludge as the vehicle is remotely maneuvered inside a tank. A centrifuge system can be used to separate solids from liquids and can aid in waste volume reduction.

Figure 6-7. Workers introduce the remote-controlled track vehicle to remove sludge from a waste tank at Rocky Flats.

During an actual application, cost savings provided by use of the two technologies were negligible because of the surprise appearance of an algae bloom while processing waste from one waste tank and fewer solids produced than anticipated from a second waste tank. Regardless, the two technologies were proven effective and could offer significant cost savings if used at other sites. The most significant benefit was worker safety, as worker radiation exposure was greatly reduced.

6.6 Liquids Removal

A commercially available biodegradation reagent composed of naturally occurring bacteria enhanced to metabolize oil products has been used to remove oily sludge in areas with radiological contamination. After the reagent is placed in liquid to be treated, a small water pump is used to circulate the water and provide aeration. The recirculated water provides oxygen and activates the conversion process, changing the oily water to carbon monoxide and water, resulting in a significant reduction of waste.

It was demonstrated that biodegradation of oils and oily sludges can be very cost-effectively achieved. Key to the success was continuous aeration providing oxygen to the microbes. Biodegradation rates of the free phase increased as temperature and aeration rose.

6.7 Robotics

Robotics is a branch of engineering that involves the conception, design, manufacture, and operation of robots. For purposes of D&D, a robot is a machine designed to execute one or more tasks repeatedly, with speed and precision.

6.7.1 Radioactive Tank Cleaning Systems

Two robotic technologies that clean up high-level hazardous/radioactive storage tanks and facilities are the Houdini and the Modified Light-Duty Utility Arm (MLDUA). Houdini is a remotely controlled (through a tether), hydraulically powered, folding vehicle that can pass through 24-inch openings in tanks ("risers") and then open to a 4 × 5 foot minibulldozer, complete with a plow blade; a dexterous, high-payload manipulator; and remote camera system.

The MLDUA is a large, robotic manipulator with seven degrees of freedom. It can deploy a 200-pound payload through risers as narrow as 12 inches in diameter. The MLDUA is equipped with a gripper end-effector that allows the arm to grasp other tools. The MLDUA is also equipped with two cameras located at the mast and arm junction and an additional camera in the gripper. It is skid-mounted so a crane can position it on the tank platform where it rests on adjustable outriggers. A second skid contains the hydraulic power unit, oil reservoir, pumps, oil chiller, and controls cabinets.

The radioactive tank cleaning system can be used in conjunction with the MLDUA and Houdini. It includes the Confined Sluicing End-Effector, which dislodges waste with its high-pressure water jets (10 gpm of water at 7,000 psi). The Confined Sluicing End-Effector is equipped with handles that can be grasped by the MLDUA and Houdini for positioning within the tank. The hose management arm carries dislodged waste from the tank through its transfer hose.

The MLDUA and Houdini can be used together in tank cleanups. The plow on Houdini pushes sludge toward the MLDUA and accumulates piles of sludge to be sluiced. The MLDUA works best for removing thicker piles of sludge, while Houdini is better at cleaning floor surfaces. The ability to preprogram robotic trajectories for the MLDUA enables wall cleaning without the possibility of collisions with the tank walls or floor.

In addition to major cost and time savings in tank waste management operations, the stabilization of the inactive tanks can result in huge savings in tank S&M costs.

6.7.2 Modified Brokk Demolition Machine with Compact Remote Console

The Brokk 250 uses a teleoperated, articulated, hydraulic boom with various tool-head attachments, including a hydraulic hammer, an excavating bucket, a concrete crusher, and a La Bounty Shear. Weighing approximately 600 pounds, the La Bounty Shear can cut rebar, pipe, and other metal. The commercially available Brokk 250 has been combined with the Compact Remote Console (CRC) to perform remote D&D activities such as concrete sizing and removal.

To perform D&D activities from a truly remote non-line-of-sight location, the Brokk 250 can be retrofitted with two image-stabilized cameras mounted in a pan-and-tilt aluminum enclosure. These two cameras are mounted on two actuated arms located on the Brokk 250’s cover. The CRC consists of a four-panel video array mounted on a mast. A control computer with touch-screen serves as an intuitive graphical user interface to the Modified Brokk Demolition Machine and is also mounted on a swivel arm on the CRC (DOE 2001a).

A cost analysis concludes that a Brokk 250 with a crew of two people days can perform the same work in four days that would take 40 days for a crew of four people using manual labor. Use of the Brokk 250 also has the advantage of increased worker safety because the use of scaffolding is eliminated and because personnel are never present in an area of falling debris. The analysis concludes that it costs $8,560 for the Brokk 250 to perform a job that would cost $75,446 with manual labor, a savings of $66,886 (DOE 2001a).

Figure 6-8. The Brokk 250 performing demolition at INEEL.

6.8 Large-Structure Demolition

Demolition is the act or process of wrecking or destroying.

6.8.1 Harmonic Delamination

Harmonic delamination is a technique used to fracture concrete away from rebar in thick hardened-concrete buildings. A building is prepared by drilling from the roof down to make hollow openings in the thick walls. Small amounts of explosives are placed in the holes and detonated sequentially. When the charges are detonated, high-velocity detonation waves move through the walls, separating the concrete from the rebar reinforcement. These pressure or sonic waves are tuned to the rebar/concrete laminate to literally shake up the building and make conventional mechanical demolition feasible. The building is wrapped in engineering fabric to help contain flying debris (see Figure 6-9). Following the detonation of the harmonic delamination charges, the structure remains standing, but is substantially weakened. Once the building is weakened, the mechanical demolition stage can begin and excavator operators can remove large portions of the building much easier. The harmonic delamination technique results in a much safer and more efficient demolition of heavily reinforced buildings compared to conventional demolition processes.

6.8.2 Explosive Demolition

Figure 6-9. Building 886 at Rocky Flats is shown draped in engineering fabric at the moment of detonation.

The explosive demolition process at Rocky Flats used commercial explosive demolition contractors to explosively cut the building structural members and allow the structure to collapse upon itself ("implode"). The resulting debris was then most often disposed of as sanitary waste or as recycled concrete using standard construction equipment. In the case of Building 881, which was mostly underground and had no plutonium contamination, the building was first decontaminated of uranium and beryllium, then had most mechanical, electrical, and structural metal components removed. The concrete structure, originally designed to withstand aerial bombardment, was then explosively demolished, and the concrete debris was left in place and filled to grade with regulatory approval (DOE 2006b).

Figure 6-10. Explosive demolition of a guard tower at Rocky Flats.

Explosives were also used to topple the water tower, air stacks, and guard towers (Figure 6-10) at Rocky Flats and similar structures at other DOE sites. Prior to demolition, building surfaces were first decontaminated, if necessary, to release levels or acceptable residual contamination levels. During demolition, water sprays were used to reduce fugitive dust emission and the air monitored in the vicinity of the demolition to confirm the absence of contaminant releases (no detectable releases occurred).

Although the demolition itself was rapid, it was associated with substantial preparation times. Some preparation could not be conducted in parallel with in-building activities. The building structural members required weakening so that the final explosive detonations would collapse the structure with confidence. This step required additional structural engineering analysis to verify that adequate building structural integrity was maintained for worker safety. The technology depended on decontamination and surveying techniques and on air dispersion and other computer modeling of short- and extended-duration demolition activities. Transport of explosives on site also provided significant security and safety authorization basis challenges.

At Rocky Flats, the drivers for explosive demolition were to enhance worker safety (i.e., removing workers from the vicinity of unstable structures) and to improve demolition efficiency for concrete buildings. The major difficulty in implementation was to assure the public of the site's ability to control any release of radioactivity through decontamination, modeling, water spray, monitoring, and test projects. Coordination with public and regulatory organizations was key to the successful deployment of this technology.

Routine commercial demolition of buildings with large excavators proved to be a comparatively cheaper, more controllable demolition technology for one-story or two-story metal frame buildings. Explosives were used more often and were relatively more effective for smaller-scope applications, such as towers and stacks.

6.9 Waste Sampling for Disposition

The aim of waste sampling is to determine the proper waste disposition method by obtaining one or more samples representative of the waste stream. The first step is to identify what questions need to be answered about the site and why. The next step is to develop an initial sampling plan to produce the data needed to answer those questions. The final steps include incorporation of sampling design, quality assurance/quality control (QA/QC), and statistical considerations. MARSSIM (MARSSIM 2001) provides some very good information on sampling design.

A high-range alpha ion chamber was developed to measure extremely high levels of surface contamination. These types of measurements are needed to take advantage of the DOT SCO shipping classification, which allows transport as LLW. An SCO is a solid object that is itself not radioactive but has fixed and/or removable radioactive contamination distributed on any of its surfaces. Examples of SCOs that have been disposed as LLW include tools, desks, cabinets, computers, wallboard, flooring, plastic sheeting, cardboard, light fixtures, and glovebox components. SCO characterization requires upper detection limits of 500 million disintegrations per minute (dpm) per 100 cm^2.

The instrument consists of an ion chamber probe and a readout unit. The design incorporates an electronic performance test that can be done in the field, even if the detector itself becomes highly contaminated, improving the QA of the measurement. Test results demonstrated that the instrument can measure alpha contamination levels from 10,000 to 1 billion dpm per 100 cm^2. It has no significant interfering response to beta, gamma, or neutron radiation at levels likely to be found at most facilities with radiological contamination. Other important characteristics—such as linearity, temperature response, response to radio frequency interference, ability to calibrate, field maintenance, price, availability and human interface—equal or exceed characteristics of normal survey instruments.

When SCO criteria are achieved, size-reduction is minimized because larger containers can be used for disposal. Characterization rework is minimized because the characterization and package inventory calculations are completed prior to sealing the container. Cost of characterization is significantly lower because measurements are performed by technicians using inexpensive instruments in the field instead of at centralized counting facilities. Combined with new decontamination techniques, use of the SCO criteria can result in a dramatic reduction in the amount of waste that would otherwise be shipped to the WIPP. The ability to characterize, package, and ship waste as SCO can have an extremely positive impact on cost, schedule, and safety.

6.10 Packaging and Transportation

The requirements for packaging and transportation of each waste type should be determined as early as possible. Packaging and transportation requirements are affected by the type of waste, type and level of contamination, waste acceptance criteria of the disposal site, and the method of transportation. The technologies presented in this section are examples of techniques used to simplify the process of meeting packaging and transportation requirements for specific wastes and sites. These examples are intended to help others develop waste and site specific strategies for improving safety and reducing the cost of packaging and transportation.

6.10.1 Polyurethane Foam Developed to Block and Brace Waste Container Contents

Dispersible polyurethane foam has been used as a block and brace media for waste shipments. The physical properties of a closed cell, self-expanding polyurethane foam are ideal as a stabilizing material. A 2-pound/cubic foot foam has an expansion factor of approximate 30 times the initial volume, compression strength of 24 psi, and tack-free cure time of 160 seconds and can be applied from a position outside the standard waste container. The low-density foam product flows into low points to fill voids between objects (Figure 6-11). The weight of the expanded foam contributes minimally to the waste package, three-dimensional strength is added to the total package, foam curing to maximum strength is very rapid, and exposure to workers is all but eliminated. Work stoppage from loading to allow blocking and bracing several times for each waste container is eliminated since the entire, loaded waste container is foamed by a small work crew taking only minutes per container.

Figure 6-11. Structural foam sprayed into a waste container.

In addition to foaming of cargo containers, various foams have been used in heating, ventilation and air conditioning (HVAC) ducts to control the spread of contamination. Foam has also been used in underground ducts to fix contamination during size-reduction and removal of the ducts.

Blocking and bracing waste shipments with spray polyurethane foam has proven to be effective in meeting the requirements of waste acceptance criteria and NUREG-1608, allowing waste to be transported safely with no load shifting, tipping, or sliding to damage the transport container. Several large pieces of waste including drive motors and heavy press bases have been blocked and braced effectively with polyurethane foam. Use of polyurethane spray foam to provide blocking and bracing to standard waste containers significantly reduces workers' exposure to hazards and reduces cost and schedule.

6.10.2 Structural Foam/Encapsulant for Leaded Gloveboxes

An industrial foam supplier and a waste disposal receiver jointly developed a spray foam of sufficient load-bearing and encapsulation properties to meet low-level mixed waste acceptance criteria. It is similar to foam currently used for blocking and bracing of components in waste containers but of sufficient high density to meet the "no void space" requirement. The foam turns to a solid in about two minutes, meeting acceptance criteria for no liquids in the waste unit. The hardened foam adheres to and stabilizes any residual contamination inside a glovebox (Figure 6-12) and effectively macroencapsulates any lead-bearing items. In addition, the foam does not add significant weight to the final package, weighing only 3.95 pounds/cubic foot. Developing structural foam to meet these criteria allows projects to significantly reduce cost and hazards to workers.

Figure 6-12. Glovebox filling with structural foam.

6.10.3 Polyurea Coating for Large-Sized Radioactive Waste

Polyurea plastic coating spray meets the definition of a Strong-Tight Industrial Package and can be used as an alternative to size-reducing extremely large pieces of production equipment to fit into standard waste containers. This approach enables equipment to be transported to a waste receiver site intact on a flatbed trailer. The physical properties of a well-formulated polyurea plastic are ideal to function as a surface packing container. It is resistant to punctures and tears and impermeable to moisture and other environmental stresses.

Plastic film is first applied to cover the entire piece of equipment, then shrink-wrapped using a propane heat gun. Using the shrink-wrap surface as a continuous substrate, polyurea is sprayed over the entire work area to a thickness of 3/16 to 1/4 inch. For superior performance, workers apply a light, thin initial coat followed by additional spray coating to the specified thickness.

DOT and the Nevada Test Site (NTS) approved the use of polyurea plastic for packaging LLW for shipment. Nearly all safety and health hazards associated with size-reducing and packaging are eliminated, and the process has saved millions of dollars in costs.

6.10.4 Coated Tarp Material Used as Transportation Package for Noncompliant Cargo Containers

Older, deteriorating cargo containers can be effectively packaged and filled with LLW from decommissioning operations by using a special coated tarp material as an overpack. The method also provides a practical disposal path for the otherwise wasted cargo containers and adds an extremely large number of usable waste packaging containers without the high cost of procuring additional cargo containers. Additionally, this type of containment can be used as a means by which oversized equipment might be packaged for shipment and disposal without time-consuming and expensive size-reduction work.

The overpack system, made of single-ply, 19 mm coated tarp material (two-part polypropylene/ polyethylene), consists of two dish-style pieces—a 12-inch-deep bottom section and an 8-foot-deep upper section. The two parts are connected by 4-inch fabric fastener strips, covered by a protective flap and enclosed by a second 4-inch fabric fastener strip. The package is then secured to a structural platform for better handling (see Figure 6-13). The platform also functions as the base when pieces of equipment were placed into these types of packages. The package is certified to meet the Strong-Tight Package requirements as specified in DOT 173.411 and is approved for disposal at the NTS.

Figure 6-13. After the decontamination process, a glovebox is weighed, packaged, and loaded into a cargo container.

Savings resulted by avoiding size-reduction or other forms of costly disposal alternatives. Although the package is routinely purchased in a configuration to fit an 8 × 8.5 × 20 foot cargo, it can be ordered in a number of sizes, including custom sizes to fit various packaging needs.

6.11 Work Monitoring

6.11.1 Mobile High Performance Lung Counter

Lung counting is part of the routine and special bioassay programs used to detect and quantify intakes of radioactive material in workers and is part of the Radiation Protection Program implemented to meet requirements of 10 CFR Pt. 835, Occupational Radiation Protection. A Mobile Lung Counting Trailer (Figure 6-14) allows a site to maintain a lung-counting capability on site after existing medical facilities have been removed by D&D operations. The system combines the required performance in terms of instrumentation, analytics, and shielding materials/configuration with a platform that is mobile (to conform to a site's building demolition schedule).

Figure 6-14. View of the shielded room and counter.

The mobile counter has the following features:

- one graded shield room (~4 × 4 × 8.3 feet)
- 57-foot enclosed trailer equipped with air conditioning and heat

- array of two broad-energy germanium detectors
- germanium crystals 80 mm diameter (5026 mm^2) × 20 mm thick

The trailer allows both routine and special lung counts of site workers on an as-needed basis (the system could also perform whole body counts), providing rapid assessments needed to monitor and maintain worker health and minimize potential health uncertainties. This capability can make cleanup work safer and more efficient at the same time, thus avoiding what otherwise would have been significant impacts to the closure schedule.

6.11.2 Radio Frequency Alarms for Deactivation

A wireless alarm system has been developed to replace existing safety systems in buildings undergoing D&D where electrical power has been terminated (Figure 6-15). The system consists of individual wireless transmitters reporting to repeaters which in turn, report to head-end equipment integrated with a fire alarm system. The system operates within the 290-305 MHz band where no commercial radio signals are allowed.

Figure 6-15. A wireless transmitter installed at Rocky Flats.

The wireless transmitting devices can include photoelectric smoke detectors, pull stations, heat detectors, maintenance transmitters for connection to any device with contacts, and a host of security devices. All transmitters are surface-mounted and microprocessor-based to provide special and selectable performance parameters. All devices are supervised for power source, device removal, and transmission reliability.

Integrating solar power in lieu of hard wiring for exterior repeaters provides significant benefits. Solar panel use on external repeaters eliminated reliance on site electrical power, resulting in no impact to future D&D of the site's infrastructure. It also greatly reduced cost to the project. Interior repeaters are powered from temporary power sources.

Cost savings occur by eliminating the need to rewire the site alarm system as buildings are decontaminated and decommissioned. When a facility is closed, the equipment can be redeployed at other sites or sold if uncontaminated.

6.12 Summary Matrix of Relevant Technologies

The following tables summarize relevant D&D technologies. Table 6-1 summarizes technologies presented in this chapter, and Tables 6-2 and 6-3 summarize surface decontamination technologies—both physical and chemical—as presented in *Technology Reference Guide for Radiologically Contaminated Surfaces* (EPA 2006).

Table 6-1. Summary of decontamination and decommissioning technologies

Application	Name	Strengths	Special Considerations	Cost
Site characterization and verification sampling	Horizontal Directional Drilling with Environmental Measurement While Drilling	Allows real-time characterization of subsurface soil under structures.	Environmental measurement is compatible with a variety of directional drilling techniques, including techniques which require little or no drilling fluid.	Cost savings between $150–200K for each building with a footprint of 10–20K square feet
Contamination control	Passive Aerosol Generator	Contaminants are sealed onto the walls and floors of highly radioactively contaminated rooms.	Uses a fluorescent tracer to track residues that may contaminate workers.	Downgraded entry requirements result in cost savings.
Cutting and sizing	Plasma-Arc Cutting Technology	Decreases exposure risks and physical demands on workers.	Can be equipped with remote-control arms, providing additional protection to workers.	
	Ultrahigh-Pressure Water Jet	Abrasive water jet cutting system controlled remotely creating a safer work environment.	Water acts as a fixative during cutting and effectively contains contaminants that other means would send airborne.	
	Explosive Cutting	Used to cut bolts, hangers, and other metal and masonry materials from elevated areas.	Material will likely require additional cutting to reduce to a transportable size.	
Solids removal systems	Raschig Ring Vacuum System	Removes Raschig rings with no secondary handling or contamination of the material.	Ball joint assembly permits operator to move the extractor wand to reach all surfaces.	Saves time and contributes to safety by eliminating the requirement for secondary handling.
	Vac & Ship System	Used for removing large loads of dirt/gravel from deep pits and below-grade areas.	Waste is deposited directly into a shipping container approved for disposal.	Requires very little maintenance resulting in low operating costs.
	New Pumping and Centrifuge Systems for Removing Tank Sludge	Uses two separate technologies to clean wastes from tanks: remote-controlled track vehicle and a centrifuge system.	Algae blooms in a waste tank and fewer solids than anticipated were produced from a second waste tank in one application.	Cost savings were negligible in one application but are potentially significant. Greatly reduces worker exposure.
Liquid removal	Bioremediation of Oily Sludge	Uses naturally occurring bacteria to metabolize oil products. End product is combination of carbon monoxide and water.	Needs continuous aeration to provide oxygen to naturally occurring bacteria.	Very cost-effective due to significant waste reduction.

Application	Name	Strengths	Special Considerations	Cost
Robotics	Radioactive Tank-Cleaning Systems	Two robotic technologies (Houdini and MLDUA) work together to remove radioactive wastes from inside tanks.	Uses Houdini to clean floor surfaces and MLDUA to remove thick piles of sludge. MLDUA's preprogram robotic trajectories enable wall cleaning without the possibility of collisions.	Decreases costs in waste management operations, tank surveillance and tank maintenance.
	Modified Brokk Demolition Machine with Compact Remote Console	Can perform several demolition functions, including cutting rebar, pipe, and other metal; remotely controlled.	Commercially available equipment; easy to operate.	Costs $8,560 to perform a job that would normally cost $75,466, a savings of $66,866
Large-structure demolition	Harmonic Delamination	A small amount of explosives placed within walls is detonated, sending high-velocity waves through walls to separate concrete and rebar reinforcement.	Building will still be standing after harmonic delamination and will require additional mechanical demolition.	Allows more cost-efficient demolition of heavily reinforced buildings.
	Explosive Demolition	Uses commercial explosives to weaken structure of concrete buildings allowing the building fall on itself (implode).	Building is first decontaminated so that debris can be recycled or disposed of as sanitary waste. Release of contaminants is a major concern.	Most effective and efficient with smaller structures.
Waste sampling for disposition	Alpha Detection Instrumentation for Characterizing SCO Waste	Measures high levels of surface contamination immediately in the field.	Allows measurement of other important characteristics that would otherwise require several instruments to measure.	Characterization, size-reduction, and shipping costs can all be significantly reduced.
Packaging and transportation	Polyurethane Foam to Block and Brace Waste Container Contents	Used as a block and brace media for waste shipments. Stabilizes and cushions contaminated material for easier cleanup and disposal.	Foam can also be used in HVAC ducts to control spread of contamination.	Reduces waste loading time, shipping costs and worker exposures.
	Structural Foam/ Encapsulate for Leaded Gloveboxes	Hardened foam stabilizes any residual contamination inside a glovebox and macroencapsulates any lead-bearing items. Does not add much weight to final package.	Readily available, similar to foam used for blocking and bracing, but is of sufficient high density to meet the "no void space" requirement.	Disposal requirements are more easily met, consequently reducing cost.

Application	Name	Strengths	Special Considerations	Cost
	Polyurea Coating for Large-Sized Radioactive Wastes	Used as an alternative to size-reducing extremely large pieces of production equipment to fit into standard waste containers.	Impermeable to moisture and other environmental stresses; resistant to punctures and tears. Meets definition of a Strong-Tight Industrial Package.	Nearly all safety and health hazards associated with size-reducing and packaging are eliminated. Process has saved millions of dollars in costs.
	Coated Tarp Material Used as Transportation Package for Noncompliant Cargo Containers	Can be used on older, deteriorating cargo to safely pack contaminated material.		Savings resulted by avoiding size-reduction or other forms of costly disposal alternatives. No need to buy new, expensive storage units.
Work monitoring	Mobile High-Performance Lung Counter	Movable trailer to detect and quantify intakes of radioactive material in workers.	System used on as as-needed basis.	This system ensures workers' health and safety is closely monitored, thus avoiding potential scheduling, safety, and operational costs
	Radio Frequency Alarms for Deactivation	Used as alarm for high readings of contamination, smoke, heat, and other security devices when a building's electrical power has been terminated.	Can run on other forms of power, such as solar power.	Cost savings occur by eliminating the need to rewire the site's alarm system. Device can be used in multiple D&D locations.

Table 6-2. Chemical decontamination technologies (EPA 2006)

Technology	Strengths	Limitations	Special Considerations	Quality of Performance Data[a]	Cost[b]
Chelation and organic acids	Can be tailored to wide range of contaminants. Safer than other chemical techniques.	Requires considerable on-hand chemical knowledge for best application.	Contaminant solubilization requires great care in waste treatment. Danger of mobilization of the contaminant.	Poor	\$10.76/m^2 (\$1.00/ft^2)
Strong mineral acids and related materials	Can remove very stubborn deposits. Much operating experience from industrial cleaning.	Great care needed operationally due to safety considerations. Can destroy substrate.	Primarily used for metal corrosion products.	Poor	\$21.53/m^2 (\$2.00/ft^2)
Chemical foams and gels	Increased contact time aids performance. Can reach remote and hidden areas.	May require repeated applications to achieve maximum effectiveness.	Care must be taken when flushing since foams can travel to areas beyond the reach of liquids.	Adequate	\$21.53/m^2 (\$2.00/ft^2)

Technology	Strengths	Limitations	Special Considerations	Quality of Performance Data[a]	Cost[b]
Oxidizing and reducing agents	Disrupts matrix where contaminants hide so small amounts can be very effective.	Must be targeted at appropriate situation. Will not work if redox chemistry is not suitable.	Often used as one step of a multiple step process.	Adequate	\$21.53/m^2 (\$2.00/ft^2) and above
TechXtract	Highly flexible. Can be tailored to specific contaminants.	Best for batch operation for small objects or for smaller areas.	Requires optimization for contaminant and substrate.	Good	\$2.15/kg (\$0.98/lb)

[a] The quality of performance is based on professional judgment made on the basis of data collected.
[b] Costs may vary widely depending on site specific conditions such as the size of the decontamination project.

Table 6-3. **Physical decontamination technologies (EPA 2006)**

Technology	Strengths	Limitations	Special Considerations	Quality of Performance Data[a]	Cost
Strippable coatings	Produce a single solid waste. No airborne contamination. No secondary liquid waste.	The spray gun nozzles clog. From a cost perspective, may be best suited for smaller decontamination activities.	Works for only easily removed (smearable) contaminants.	Good	\$52.20/m^2 (\$4.85/ft^2)
Centrifugal shot blasting	Especially good at removing paint and light coatings from concrete surfaces in open areas away from wall-floor interfaces.	Escaped shot may pose a hazard to workers. May require an air compressor, systems for dust collection and air filtration, a forklift, and a generator.	Can be limited by large size, hence unable to get into corners.	Good	\$368.66/m^2 (\$34.25/ft^2)
Concrete grinder	Fast and mobile. Less vibration.	Small size limits utility.	Often best used in combination with other technologies.	Good	\$31.43/m^2 (\$2.92ft^2)
Concrete shaver	Good for large, flat, open concrete floors and slabs. Fast and efficient.	Does not maneuver well over obstacles. Good for only concrete floors and slabs.	Attractive alternative to handheld scabblers.	Good	\$14.21/m^2 (\$1.32/ft^2)
Concrete spaller	Good for in-depth contamination. Fast.	Requires predrilling of holes. Leaves behind a rough, uneven surface.	Limited commercial availability.	Good	\$199.35/m^2 (\$18.52/ft^2)
Dry ice blasting	CO gas generates very little extra waste. Very good for contamination on a surface.	Cannot remove contamination more deeply embedded in the surface matrix.	Requires support systems: air compressors, dryers and filters.	Adequate	N/A[b]

Technology	Strengths	Limitations	Special Considerations	Quality of Performance Data[a]	Cost
Dry vacuum cleaning	Readily available. Works well with other physical decontamination technologies.	Good for only loose particles.	Typically used in conjunction with other decontamination technologies	Adequate	$\$21.53/m^2$ ($\$2.00/ft^2$)
Electro-hydraulic scabbling	Generates less secondary waste than other technologies using water. Very efficient. Removes deep contamination.	Requires a skilled operator. Generates some secondary liquid waste.	Works best for horizontal surfaces.	Poor	$\$107.64/m^2$ ($\$10.00/ft^2$) and up
En-vac robotic wall scabbler	Works well on large, open spaces, including walls and ceilings. Worker exposure to contaminants is limited: remote operation and integrated vacuum system.	Requires additional attachments to address irregular surfaces, obstacles, and tight places such as near wall-ceiling and wall-floor interfaces.	Remote-controlled aspect allows operation in areas unsafe for humans.	Good	\$52.74 per hour; cost-effective at approx. 139.35 m^2 (1500 ft^2)
Grit blasting	Well-established technology. Different types of grit and blasting equipment is available for a variety of applications.	Generates large amounts of dust and particulates during operation.	Wide range of grits and abrasives available for special situations.	Good	Cost based on En-vac system
High-pressure water	High-pressure systems are readily available.	Generates a significant secondary waste stream.	Can physically destroy substrate. Best used on sturdy structures.	Adequate	$\$39.07/m^2$ ($\$3.63/ft^2$)
Soft media blast cleaning (sponge blasting)	Removes virtually all of the contamination from the surface.	Generates significant amounts of airborne contamination. Lower productivity.	Applicable to surface decontamination only.	Good	$\$49.51/m^2$ ($\$4.60/ft^2$)
Steam vacuum cleaning	Easy to use. Washed surfaces dry quickly. Good for large flat surfaces.	Not good for irregular surfaces. Not good for grease. Poor ergonomic design.	Not recommended for surfaces that can be damaged by steam temperatures.	Good	$\$146.82/m^2$ $\$13.64/ft^2$)
Piston scabbler	Remotely operated and standard units are available. Good for open, flat, concrete floors and slabs.	Units are loud. Remote units cannot operate close to wall-floor interfaces.	Remote-controlled aspect allows operation in areas unsafe for humans.	Good	$\$64.58/m^2$ ($\$6.00/ft^2$)

[a] The quality of performance is based on professional judgment made on the basis of data collected.
[b] N/A = Reliable cost information was not available.

7. HEALTH AND SAFETY

Health and safety issues associated with D&D of nuclear facilities are addressed by a complex set of technical and managerial practices. The protection of workers, the environment, and the public against radiation exposure is obviously a critical aspect of D&D and usually dominates public concern. However, it is important to keep in mind that the broad range of activities involved in decommissioning a nuclear facility includes a host of risks that are nonradiological in nature; such risks are covered by OSHA regulations and state occupational safety and health program regulations. It is widely accepted that the radiological hazards associated with a nuclear facility undergoing decommissioning are substantially less than those that pertain when it was in its operating state. Even so, it is also clear that D&D activities, which tend to involve a set of contractors and workers who are new to the facility and operating in a temporary mode, bring risks that were not planned for in the course of routine operations.

The number of safety and health protection issues that must be considered during D&D is thus extremely large and well beyond the scope of this document to cover comprehensively. Instead, this section provides a high-level overview of some of the more important aspects of safety and health protection and provides some sources of further information.

The essence of health and safety protection lies in careful, systematic planning using the wealth of accumulated experience available. Since there are so many issues that can be considered (e.g., nature and history of the facility, age, condition, extent of safety considerations during original design), safety management planning and safety management systems cannot easily be generalized to any great extent and each D&D project must be treated on a case-specific basis. It is recognized that the basis used for safety planning for a facility during its operating phase is different from the basis that needs to be used during D&D. Further, the safety basis is likely to be different between prompt and delayed D&D. Even so, many elements of the various plans turn out to be quite similar, and a clear understanding of the approach and processes used in one set of circumstances may be of considerable value to another.

7.1 Radiological and Nonradiological Hazards

In general, radiological hazards fall into four categories: external exposure, ingestion and inhalation of radionuclides, criticality, and breach of containment. As mentioned above, overall radiological risks can be lower during D&D than during regular operation. However, the nature of D&D activities can mean that there is an enhanced risk of exposure for some workers during this phase. Remote handling and robotics technologies can greatly mitigate these risks, but when these are unavailable, worker exposure must be carefully managed. Similarly, the ingestion and inhalation of radionuclides from surface contamination present a genuine risk that must be clearly addressed by standard worker protection measures. The potential for criticality and breach of containment are usually of less concern, but in some scenarios—such as the case where fissile material remains in process equipment—the possibility must be recognized and field activities planned accordingly. Containment systems can be particularly problematic. Those used during operation may no longer be working, and even if they are, there is no assurance that they can match the increased and varying demands of D&D activities. Radiological protection against these hazards is provided by a number of technical and managerial measures, including isolation and removal of radioactive material, spill prevention and dust/aerosol suppression techniques, bulk shielding of workers, discrete individual shielding through personnel protective clothing etc., training, air filtering, wastewater treatment, and appropriate waste-disposal techniques.

Nonradiological hazards include fire (the most common risk due to presence of flames in cutting technologies coupled with the accumulation of potentially combustible wastes), explosions (originating in dusts produced), toxic materials (particularly in aged facilities where material no longer allowable [e.g., asbestos] may be present), and electrical and physical hazards (e.g., noise, confined space risks, impact trauma from falling objects, etc). Standard industrial and commercial safety practices should be employed to address these concerns.

7.2 Health and Safety Plan

Safety in D&D can best be ensured by having the broad range of individual safety issues properly sequenced and addressed in a manner that progressively removes hazards. These issues are collected in a project-specific HASP. The HASP identifies potential safety and health hazards associated with D&D activities and sets forth a comprehensive set of procedures and controls to mitigate and eliminate the hazards. The major D&D activities addressed by the HASP include sampling; characterization; removal of chemical, hazardous, and radiological materials and associated equipment; major decontamination activities; dismantlement; and remediation of the contaminated environment.

An effective and high-quality HASP must provide a clear chain of command for safety and health activities, accountability for safety and health performance, well-defined expectations regarding safety and health, well-defined task and operational hazards/risks, comprehensive hazard prevention and control methods, and recordkeeping requirements to track program progress. Because each HASP case-specific, a general outline of necessary sections is difficult, but the following provides an example.

1. Regulatory Framework
   - Background Information
   - Outline of Site-Specific HASP Requirements Addressed in Subsequent Sections

2. Key Personnel
   - Background
   - Organizational Structure
   - Essential On-Site Personnel—e.g., Project Manager, Site Safety and Health Officer and Staff, Field Team Leader, Emergency Response Coordinator, Security Officer, Decontamination Station Officer, Specialty Teams
   - Optional Personnel—e.g., Industrial Hygienist, Fire Chief, Health Physicist, Scientific Advisor, Record keeper, Public Information Officer, Medical Staff, Communications

3. Hazard Assessment
   - Background
   - HI

- Hazard Assessment
- Hazard Control—Engineering and Administrative Controls and PPE
- ALARA (a radiation safety principle for minimizing radiation doses and releases of radioactive materials by employing all reasonable methods)

4. Training Requirements
   - Background
   - Training Requirements for Various Essential and Optional Personnel
   - Training for Specific HASP Elements (e.g., Confined-Space Entry)

5. Personal Protective Equipment
   - Background
   - Selection, Levels, and Use of PPE

6. Extreme Temperature Disorders or Conditions
   - Background
   - Heat Stress—Monitoring and Training
   - Cold Exposure—Controls and Monitoring
   - Prevention

7. Medical Surveillance
   - Background
   - Baseline (Initial) Examination
   - Periodic Medical Monitoring
   - Examination after Illness or Injury, or upon Termination
   - Medical Records

8. Exposure Monitoring/Air Sampling
   - Background
   - Air Contaminants
   - Methods and Instrumentation—Direct-Reading and Time-Integrated Sampling
   - Categories of Monitoring—Worker Exposure, Level of Protection, Off Site, Perimeter Monitoring, Meteorological
   - QA/QC, Documentation and Reporting
   - Establishment of Site-Specific Exposure Limits

9. Site Control
   - Background
   - Work Zones—Exclusion, Contamination Reduction, and Support Zone
   - Communications
   - Worker Safety Procedures—Buddy System
   - Medical Assistance

10. Decontamination
    - Background
    - Decontamination Methods
    - Standard Operating Procedures
    - Collection, Storage, and Disposal Procedures

11. Emergency Response/Contingency Plan Background
    - Preemergency Planning
    - Personnel Roles, Lines of Authority, and Communications—Emergency Coordinator, Emergency Contacts, Reporting, and Communications
    - Emergency Recognition and Prevention
    - Safe Distances, Refuge, Site Security and Control, Evacuation Procedures
    - Decontamination Procedures
    - Emergency Medical Treatment/First Aid
    - Emergency Alerting/Response Procedures—Notification, Evaluation, and Rescue/ Response Action

12. Emergency Action Plan
    - Background
    - Escape Route
    - Procedures for Critical Operations Personnel
    - Procedures to Account for All Employees
    - Rescue and Medical Duties
    - Reporting Fires and Other Emergencies
    - Emergency Action Plan Contact Personnel
    - Emergency/Evacuation Alarm System
    - Fire Prevention Plan

13. Confined-Space Entry
    - Background
    - Identification and Evaluation
    - Hazard Assessment and Controls
    - Entry Permits and Procedures—Opening a Confined Space, Atmospheric Testing
    - Isolation and Lockout/Tagout Safeguards—Ingress/Egress Safeguards
    - Warning Signs and Symbols
    - Emergency Response

14. Spill Containment
    - Background
    - Preplanning
    - Reporting, Initial Personnel Safety, and Initial Spill Action
    - Response and Cleanup Procedures
    - Post-Incident Follow-Up

7.3 Integrated Safety Management—DOE Approach

Integrated safety management (ISM) is a process for systematically integrating safety awareness and good practices into all phases of work throughout DOE. It emphasizes safety as an integral part of each activity as opposed to being a stand-alone program and requires all personnel to conduct their work in such a manner that protects themselves, other workers, and the public and does not cause harm to the environment. ISM is defined by a continuous five-step process, derived from eight guiding principles and based on thorough planning and feedback. The five steps are listed below.

- **Define the scope of work:** Missions are translated into work, expectations are set, tasks are identified and prioritized, and resources are allocated.
- **Analyze the hazards:** Hazards associated with the work are identified, analyzed, and categorized.
- **Develop and implement hazard controls:** Applicable standards, policies, procedures, and requirements are identified and agreed upon; controls to prevent/mitigate hazards are identified; and controls are implemented.
- **Perform work within controls:** Readiness is confirmed, and work is performed safely.
- **Provide feedback and continuous improvement:** Information on the adequacy of controls is gathered, opportunities for improving the definition and planning of work are identified, and line and independent oversight is conducted.

The eight guiding principles are as follows (DOE 2007a):

- **Line management responsibility for safety:** Management and employees readily accept personal responsibility and accountability for conducting their activities in accordance with ISM guiding principles.
- **Clear roles and responsibilities:** Roles and responsibilities are defined in a manner that establishes clear authority and accountability to ensure the protection of the employees, public, and environment.
- **Competence commensurate with responsibilities;** Employees possess and maintain adequate knowledge, skills, and abilities to perform work safely and competently and in a manner of doing the right thing the first time, every time.
- **Balanced priorities:** Budgets are allocated in a manner that establishes appropriate resources and work priorities to ensure work tasks are performed safely.
- **Identification of safety standards and requirements:** Adequate processes are effectively used in each work area to identify safety standards and requirements.
- **Hazard controls tailored to work performed:** Hazard controls are tailored to the work being performed and are updated for new work and changing conditions.
- **Operations authorization:** Work is not performed unless it can be demonstrated to be performed safely.
- **Worker involvement:** Workers have the right to be involved in accident investigations, hazard evaluations, and the planning of work. All employees have the right to refuse and/or stop unsafe work and report unsafe conditions.

ISM includes the following elements/components:

The Safety Basis. The starting point for the safety approach in the operation of DOE nuclear facilities is the safety basis, defined (DOE 2000b) as the documented safety analysis and hazard controls that provide reasonable assurance that a DOE nuclear facility can be operated safely in a manner that adequately protects workers, the public, and the environment. The safety basis describes the nuclear facility hazards and the risks to the workers, the public, and the environment and defines the safety-related equipment, procedures, and practices relied on to adequately control those hazards. The safety basis must be established and maintained (for operators of DOE nuclear facilities that meet the threshold for Hazard Category 1, 2, or 3) in accordance with the requirements of 10 CFR Pt. 830, Subpart B, to ensure that operations can be conducted within an acceptable "risk envelope." The safety basis can be modified and reestablished as needed through a formal change control process.

A Safety Basis Program thus comprises a set of safety basis documents and the set of procedures by which the documents are developed and kept current. The major elements of the safety basis are the Documented Safety Analysis (DSA), the Technical Safety Requirements (TSRs) and the Unreviewed Safety Questions (USQ). Other important aspects include considerations of safety design criteria and nuclear criticality safety. To assist in the integration of these components DOE has also established a Safety Basis Information System (SBIS).

The Documented Safety Analysis. The DSA describes the facility and the work to be performed; categorizes the facility in accordance with DOE-STD-1027; evaluates all accident conditions presented by natural and/or manmade hazards; derives the hazard controls (including TSRs) to eliminate, limit, or mitigate identified hazards; defines the process for keeping the hazard controls current and controlling their use; and defines the characteristics of the safety management programs necessary to ensure the safe operation of the facility.

The format and methodology of a DSA depends on the type of facility and its position in the life cycle, but it must be developed using a DOE-approved method, either a "Safe Harbor" methodology or a DOE-approved alternative methodology. "Safe Harbor" methodologies are methods for developing a DSA that are identified in standards developed by DOE, NRC, or OSHA and that have already been approved by DOE for use in the specific circumstances. They are based on many years of experience with similar types of facilities. Specific Safe Harbor provisions for deactivation and decommissioning activities are provided in Table 2 of Appendix A of Subpart B to 10 CFR Pt. 830.

DSAs for deactivation or transition S&M activities may be developed by following the method in either DOE STD 3009-2000, Change Notice No. 1, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis Reports for Nuclear Power Plants* (January 2000), or DOE STD 3011-94, *Guidance for Preparation of DOE 5480.22 (TSR) and 5480.23 (SAR) Implementation Plans* (November 1994). DSAs for decommissioning of a DOE nuclear facility may be developed by following the methods in DOE STD 1120-98, *Integration of Environment, Safety, and Health into Facility Disposition Activities* (May 1998) and 29 CFR Pt. 1910.120.

Technical Safety Requirements. TSRs are the limits, controls, and related requirements necessary for the safe operation of a nuclear facility. TSRs are derived from the DSA and define the operating conditions, safe boundaries, surveillance requirements, and management or administrative controls necessary for safe operations and for reducing the risk to the public, the workers, or the environment from uncontrolled releases of radiological and nonradiological materials or energy. TSRs also contain administrative controls (ACs), which consist of commitments to safety management programs and specific ACs for specific accident scenarios. The purposes of the TSRs are to state clearly the limits of safe operation, ensure that the safety envelope is not breached, supply a consistent and uniform statement of the surveillance requirements, establish ACs to ensure that the requirements are met, and establish the actions to take if the requirements are not met. DOE's (and its contractors') responsibility to protect the public is accomplished by the development of the safety requirements in the TSR for those systems, components, and equipment that provide barriers to prevent uncontrolled releases, mitigate such releases, and prevent inadvertent criticality.

The Unreviewed Safety Questions Process. The USQ process is an important tool to evaluate whether a change affects the safety basis. DOE contractors for Hazard Category 1, 2, or 3 nuclear facilities must use the USQ process to ensure that the safety bases are not undermined by changes in the facilities or activities. The USQ process permits a contractor to make physical and procedural changes to a nuclear facility and to conduct tests and experiments without prior approval, provided these changes do not cause a situation that involves a USQ. The USQ process provides contractors with the flexibility needed to conduct day-to-day operations by requiring only those changes and tests with a potential to impact the safety basis (and therefore the safety of the nuclear facility) be approved by DOE. This approach allows DOE to focus its review on only those changes that have the potential to be significant to safety. The USQ process helps keeps the safety basis current by ensuring appropriate review of, and response to, situations that might adversely affect the safety basis. The USQ process also provides requirements to address the discovery of potential inadequacies of the safety analysis.

The Safety Basis Information System. DOE has committed to provide the public with up-to-date information on its nuclear facility safety bases. The SBIS was created both to meet this requirement and also to provide a managerial tool for obtaining regularly updated DOE safety basis information. DOE's Office of Nuclear and Facility Safety Policy maintains the SBIS at http://hss.energy.gov/NuclearSafety/nsps/sbis/, with DOE Program and Operations Offices providing the information content.

8. CASE STUDIES FROM DECONTAMINATION AND DECOMMISSIONING CLOSURE SITES

The following 10 subsections are presented to document in case studies some real-world examples in which good planning, managerial expertise, and innovative technologies have combined to reduce costs and improve decommissioning performance (Figure 8-1). The first four subsections focus on DOE sites. They are not meant to be a comprehensive examination of all recent D&D projects; rather they seek to provide a number of examples of how D&D was achieved and demonstrate the range of approaches and technologies that are now available in the

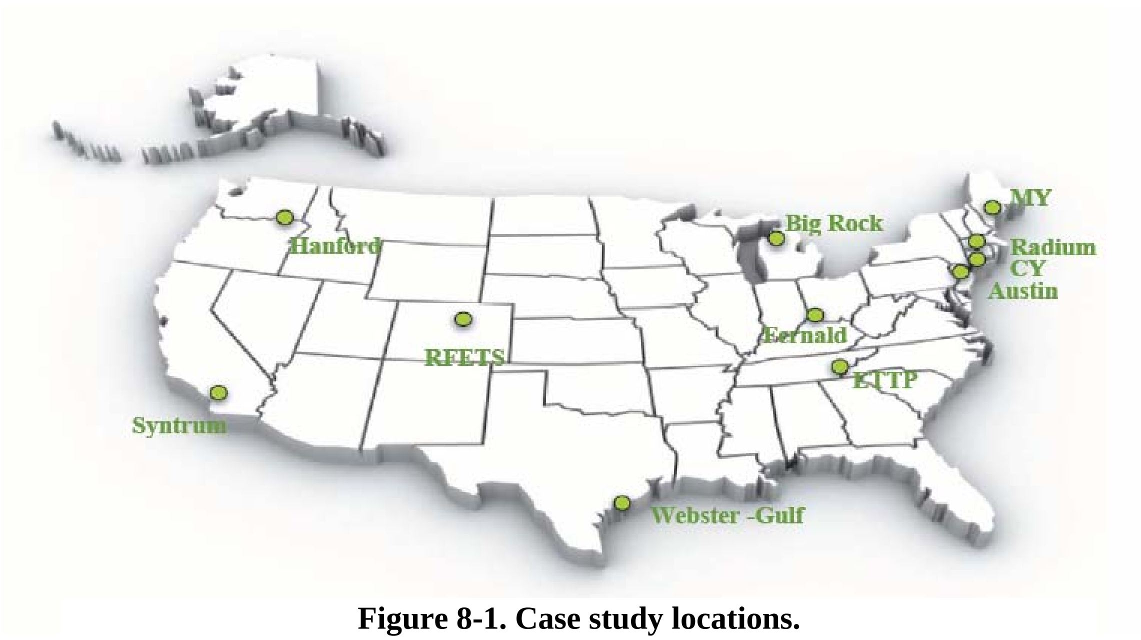

Figure 8-1. Case study locations.

D&D toolbox. The fourth subsection, East Tennessee Technology Park (ETTP), may be regarded as a group of three case studies, since it discusses the work performed as part of a non-time-critical removal action under CERCLA on three buildings at Oak Ridge, Tennessee that were decontaminated and decommissioned as a single project. The second six subsections focus on non-DOE sites and provide information on response actions at former nuclear power plants and other commercial sites with radiological contamination.

8.1 Rocky Flats Closure Project

Land for the Rocky Flats Plant was first acquired in 1951 at the foot of the Rocky Mountains approximately 16 miles northwest of Denver, Colorado. Over the next 25 years, acreage was added as a buffer zone until the site totaled 6,241 acres with a 300-acre industrial area in the center. The site was operated by DOE and its predecessor agencies, producing triggers for nuclear weapons as part of the nationwide nuclear weapons complex.

From 1952 to 1993, the Rocky Flats Site produced components for the U.S. nuclear weapons arsenal. With the end of the Cold War, production of nuclear weapons components ended at Rocky Flats, and the mission changed to risk reduction, cleanup, and closure. As a result of operational problems during the site's history and its abrupt shutdown in 1989 for environmental and safety concerns, facilities had been significantly contaminated, primarily with plutonium and beryllium. Plutonium liquids were left in process piping and in tanks in unknown quantities and chemical configurations, and classified materials were simply left where they were used or processed. In 1989 the site was listed on the NPL and negotiations began on an agreement that would implement cleanup actions. In early 1995, the DOE decided that the site (see Figure 8-2) would transition from a mission of production to one of closure. The major change in mission that lay ahead left the site and its highly trained production staff ill-equipped to tackle the daunting task. In a notable achievement, the cleanup was completed ahead of schedule and under budget in a slightly over 10-year period. The Government Accountability Office (GAO) estimates that the total projects costs were about $10 billion in constant 2005 dollars (GAO 2006).

The success of this closure project can be attributed in part to several critical factors combining. In an effort to document the lessons learned from this success, the Rocky Flats Field Office produced a closure legacy report (DOE 2006b). Much of the following information has been extracted from that report and associated documents.

Figure 8-2. The Rocky Flats site circa 1995.

8.1.1 Initial Planning and Development of Decommissioning Scope

Successful accomplishment of decommissioning was critical to the Rocky Flats Closure Project because it represented most of the overall project scope. Initially, the site mission became deactivation, a transitional state preparing for decommissioning and closure, as distinct from decommissioning, for which the regulatory path was still uncertain. One of the first actions was the approval of the Rocky Flats Cleanup Agreement (RFCA), which established a regulatory framework for decommissioning between DOE, EPA, and the State of Colorado. This agreement established cooperation and collaboration among the parties as the standard. Another major aspect of this agreement was to identify and delineate a lead regulatory agency for different areas of the site. Comments and oversight were coordinated through one agency, which avoided previous problems with confusing and even conflicting comments and regulatory direction. The State of Colorado was the lead regulatory agency for the industrial area, where D&D projects occurred, which allowed jurisdiction over radiological cleanup projects. Although the state's decommissioning criteria were not directly applicable to Rocky Flats since it is owned by the federal government, dose limits in the state regulations were considered in the calculation of cleanup levels for radionuclides. State-promulgated standards for radionuclides in surface water were likewise considered relevant and appropriate requirements for CERCLA.

A part of the overall site planning effort was to determine how to prioritize activities and use the site facilities and infrastructure. It was necessary to determine a status for each facility, i.e. whether a facility would be used in future operations, waste management, or other activities and, if not, whether it should be decommissioned or "mothballed" for later demolition to reduce "landlord" costs. The existing management functions needed to be reorganized and streamlined. Early in the process, the organizational responsibilities for different decommissioning functions (within the DOE, the contractor, and the regulators) were unclear, the regulatory process within RFCA had never been implemented, and there was very little organizational experience in conducting decommissioning work. Early estimates showed that the site decommissioning scope would increase from a few million, to hundreds of millions of dollars a year, a growth level that would be nearly impossible to sustain.

8.1.2 Initial Decommissioning Projects

Several initial decommissioning projects emphasized small or high-visibility activities, such as a small, obsolete, solid radioactive waste treatment facility; large, unused fuel oil storage tanks; unused guard-posts; and additional excess buildings. This approach served the purpose of showing visible changes to the site and emphasizing its future closure while not diverting substantial resources from the overall site focus of nuclear risk reduction. Concurrently, planning began to deactivate and decommission two more difficult contaminated surplus facilities: Building 123, a 1950s-vintage bioassay laboratory facility, and Building 779, the Plutonium Metallurgical Laboratory. The purpose of these two projects was to pilot the site decommissioning process, i.e., the combination of regulatory, management, technical, authorization basis, work control, environmental, and contractual processes necessary to initiate, plan, execute, and close a decommissioning project. While gloveboxes were removed from buildings in bulk at a time, there had not been large-scale removal of contaminated systems in preparation for building demolition. In fact, no plutonium-contaminated building had been demolished anywhere in the DOE complex under anything approaching the rigor imposed by current regulations. The Building 123 Project was completed in September 1998, and the Building 779 Project was completed in March 2000. The implementation of these pilot projects produced several notable results.

The Building 123 Decommissioning Project (DOE 1998) was relatively straightforward from a technical standpoint. There was substantial asbestos and modest radiological and chemical contamination, but only low levels of TRU (alpha) contamination. There were, however, more than 30 significant documents covering regulatory requirements, authorization basis, work control, characterization, waste management, etc. that were often overlapping, sometimes conflicting, all which had to be approved and in place before different aspects of work could begin. As an example, there were three somewhat overlapping safety documents (*Facility Safety Analysis*, *Auditable Safety Analysis*, and *Health and Safety Plan*), two somewhat overlapping waste documents (*Waste Management Plan* and *Unit 40 RCRA Closeout Plan*), and several characterization documents, all of which slightly overlapped with the regulatory decision document (Proposed Action Memorandum). Part of this situation was the result of overlapping regulations (environmental regulation safety requirements vs. DOE orders safety requirements), and part was a result of different organizations staking claim to a future role in decommissioning. One result of the lessons learned from this project was a more defined and streamlined approval process. Most importantly, the site recognized the need to keep approval of documents off the project "critical path," i.e., decoupling the activity (with the implicit approval of regulatory agencies) from the physical work. Once the project baseline with related scheduling tools became more mature, this became an even more powerful tool. The regulators' goal was also to see that a document approval never appeared on the critical path for site closure.

The Building 779 Decommission Project contained more than 100 gloveboxes ranging in contamination from virtually clean to very highly contaminated (many grams of plutonium hydride). Several approaches were used to size-reduce the gloveboxes, develop techniques in cutting metal, and provide waste acceptance criteria–compliant packaging and training operators and foremen in decommissioning equipment with progressively increasing levels of contamination. Methods for disposing of large volumes of debris waste were also developed using cargo containers and the SCO procedure (DOE 2001c) for waste characterization. While used only for potentially or moderately contaminated equipment in the Building 779 project, further refinement of this approach provided substantial improvement in safety and efficiency.

The identification of these projects as pilot projects was useful in several ways. Regulators accepted less up-front detail in the regulatory decision documents in exchange for more active participation and a site commitment to provide greater detail on future buildings as the planning process improved. As pilot projects, they were recognized to be at the beginning of the learning curve (i.e., the concept that work becomes more efficient over time as workers gain experience), and that it was important to develop a baseline process that could be executed and then subsequently improved. If viewed as mature projects with good estimating bases and developed execution techniques, they were less than successful—they would be some of the more costly of the site buildings to decommission on a per-square-foot basis. However, viewed in hindsight in the context of the overall site closure, the learning curve benefits far outweighed the near-term inefficiencies.

The evolution of the building decontamination process illustrates the iterative nature of the decommissioning learning curve. The original assumption was that radiologically contaminated buildings would be decontaminated to free-release criteria so that the buildings could be demolished and disposed of as sanitary waste. After all of the gloveboxes and equipment were removed from an area, the empty rooms were surveyed to determine the location and extent of contamination. Contaminated surfaces were then decontaminated using a number of techniques. Additional surveys were performed to verify that the area was successfully decontaminated and that no cross-contamination had occurred, after which the facility could be released for unrestricted demolition in terms of radiological controls and waste disposal. This approach was used successfully in Building 779; however, the decontamination process had to be adapted in subsequent buildings to address various contamination issues. In some buildings it was impossible to decontaminate some sections of concrete to meet the free-release criteria, and the concrete could not be removed prior to building demolition without damaging the structural integrity of the building. Instead these sections were decontaminated to the maximum extent practical, fixative was applied to prevent cross-contamination during removal, and the area was clearly marked with paint to allow the items to be segregated during demolition for disposal as LLW. In the most extreme cases, the contamination was so pervasive that it was impractical to decontaminate the building or area completely and attempting to identify and segregate small sections of “clean” rubble from contaminated rubble was inefficient and greatly increased worker risks. In these situations, the building or area was decontaminated to the maximum extent practical, fixative was applied, and hot spots were clearly marked. All of the remaining parts of the building that could be released was demolished and disposed of as clean waste. The targeted areas were disposed of as LLW as the building was demolished. The site used large-volume rail shipping when entire buildings or large areas (such as canyons or heavily contaminated equipment foundations) were demolished as radiologically contaminated waste.

Several techniques were used to decontaminate building surfaces before they were demolished. These are provided below, and some are discussed in greater detail in Section 6:

- hydrolasing, which involved using high-pressure water to remove contamination from the surface of concrete walls, floors, and similar surfaces (DOE/Kaiser-Hill 2002)
- mechanical abrasion, which was used when the contamination extended deeper into the material and includes alternative methods such as scabbling and concrete shaving
- concrete section removal, used where the contamination was localized but extended deeply into an entire concrete wall or floor section
- core boring and injecting expansive grout to break up large blocks of reinforced concrete

8.1.3 Decommissioning Sequencing

The site contained four major plutonium operations buildings—Buildings 771, 776, 707, and 371—all of which were actively engaged during D&D in reducing the risks and consequences of nuclear accidents involving residual liquids, equipment, and stored wastes. Buildings 707 and 371 additionally were the locations of operations to stabilize plutonium residues, oxides, and metal prior to disposition off site. Since site closure required disposition of these materials, these two buildings were not available for immediate decommissioning. As the storage location for much of these materials, Building 776 could begin decommissioning only after the materials were either processed or relocated. The nonplutonium buildings represented a lesser risk in their current conditions, could be more easily mothballed, and would have shorter overall project durations that would avoid their impacting the site critical path; hence they became lower priority. So, although there were some smaller activities to continue risk reduction (e.g., removing enriched uranium from Building 886), the post-pilot decommissioning efforts focused on Building 771. Building 776 was anticipated to follow once its accountable material had been relocated.

8.1.4 Deactivation/Decommissioning Interface

Building 771 had contained the bulk of the site's high-concentration plutonium solutions at the curtailment of weapons production, and a substantial portion of the building's subsequent nuclear risk-reduction activities had been draining tanks and solidifying the plutonium-containing liquids. This experience provided an operating cadre available for subsequent "deactivation" activities. As the draining of the tanks was completing and efforts were turning towards the residual liquids in the piping systems, a decision was made to remove not just the liquid but the entire run of piping. This was labeled as *deactivation*, and not *decommissioning*, since *decommissioning* would have been a *remediation* activity covered under RFCA.

In retrospect, since *decommissioning* was the building end-point, the attempt to do closure work as *deactivation* was of limited benefit. The removals engendered arguments and mistrust with the regulators, who viewed it as circumventing RFCA. The distinction between *deactivation* and *decommissioning* caused work to be organized and executed less efficiently than if all work had been covered under RFCA. Once the Building 771 decision document (DOE 2003) was approved, all of the subsequent deactivation work was performed under the RFCA (i.e., CERCLA) framework, and all waste was managed as remediation waste. The action to segregate deactivation for regulatory and management purposes was seen as a poor decision and not repeated.

8.1.5 Detailed Decommissioning Planning—Use of "Sets"

Concurrently with the Building 771 deactivation, planning and estimating for the decommissioning of the plutonium process equipment was proceeding, including the removal and size-reduction of process gloveboxes, tanks, piping, and ducts. This planning incorporated the methods and the cost-estimating factors from the experience being gained in the (at that time) early stages of the Building 779 Project. Building 771 was the first building to focus on planning the process equipment dismantlement based on "sets"—groupings of equipment typically in the same room or portion of a room that would be worked as a unit—and defined in the Building 771 Decommissioning Operations Plan (DOE 2003). The sets were area-based (as opposed to the deactivation activities, which removed runs of process piping that crossed several areas), making the planning and execution easier. The sets were planned based on the methods used in Building 779, with early identification of problems for which there was no acceptable current approach to allow investigation of different technologies. Sets were initially prioritized and scheduled based on numerous criteria. These included initially performing easier work sets both to create space for logistics and waste and to allow newly forming work crews to succeed, removing gloveboxes so that support ventilation system could be removed and clearing out areas of highly contaminated equipment so that the less-experienced building trades subcontractors could accelerate their work. Although the sequencing changed as the Building 771 project progressed, the set concept was robust enough to avoid substantial replanning of the set content and provided the basis for project tracking and control.

8.1.6 Decommissioning Program Development

In 1998 a separate Kaiser-Hill decommissioning program function was established to begin coordinating and refining the processes and infrastructure for the expanding decommissioning. This program evaluated the efforts to plan, estimate, and execute the Building 123 and Building 779 pilot projects. This resulted in cost modeling that would support the subsequent baselining effort, documented in the Facilities Disposition Cost Model (DOE/Kaiser-Hill 2000). The facilities disposition process was flow-charted, and the documentation and approval process established in an attempt to resolve conflicting document requirements, streamline the planning effort, and allow decommissioning to be discussed in common terms. This process development resulted in the *Facilities Disposition Program Manual* (Kaiser-Hill 2001). The effort to create the decommissioning RFCA Standard Operating Protocols (DOE 1999b, 2000a, 2001b) was initiated with regulator input and approval to standardize and streamline the regulatory process. Sitewide facilities characterization methods and procedures were developed, and documented in the D&D characterization protocol (DOE 2002a). Cost modeling, additional activities to streamline the regulatory process, development of a characterization process, waste estimating, and planning and estimating for the decommissioning of the remaining site facilities began. Overall, the program provided substantial support to the subsequent closure baseline development and created a number of sitewide documents that were used throughout site closure.

8.1.7 Closure Project Baseline

In 2000, DOE awarded its integrating contractor, Kaiser-Hill, a contract to complete the Rocky Flats Closure Project. As part of the reorganization and rebaselining effort, decommissioning efforts were divided into five distinct execution projects: the four major plutonium processing buildings and "everything else," which included one smaller plutonium laboratory, five uranium and beryllium processing facilities, and several hundred noncontaminated or lightly contaminated structures. A sixth execution project was responsible for waste management and security. Various separate, sitewide Kaiser-Hill organizations were responsible for planning, business processes, safety and regulatory oversight, etc. Functions necessary for successful project execution, such as procurement, engineering, and safety were projectized; i.e., each execution project had independent procurement, engineering, and safety organizations reporting to the execution project manager. The residual site functional organizations coordinated site policy and supported site-level (but not project-level) execution. The execution projects were given a five-month period to complete a detailed baseline schedule and estimate through the completion of building demolition, with overall cost and schedule parameters based on the site master schedule.

Since the initiation of the Closure Project activities in July 2000, decommissioning execution proceeded essentially consistent with the planning incorporated in the Closure Project Baseline. The overall Closure Project had favorable cost and schedule variances since 2002, largely as a result of some schedule acceleration of outyear activities. Improvements in glovebox size-reduction resulted in some critical path schedule improvement. This was somewhat offset by delays in shipment of accountable nuclear materials from the site and the potential impact on final closure of the Protected Area and removal of much of the remaining nuclear and security infrastructure. There was some reorganization to combine the management of the execution projects for improved efficiency, although having separate projects encouraged the development of slightly different approaches toward resolution of similar problems. The site reevaluated the extensive use of fixed-price contracting for the less-contaminated building trades work, based on difficulties in new contractors moving up the learning curve for doing work on site.

Previous to the approved change, there were parts of the Closure Project that were well-planned, typically near-term activities similar to ongoing work. There were also numerous unplanned parts, typically out-year work for which no organization had clear responsibility. Examples included building demolition, decommissioning of uranium-contaminated facilities, and decommissioning of large, highly contaminated vaults. The 2000 Closure Project Baseline supported accurate planning, assessment of progress, and reporting. Emphasis on additional schedule acceleration through shortening the critical path and on planning of the end of the Closure Project would have been impossible without the level of rigor provided by the baseline. Demolition and environmental restoration activities within the building footprint were integrated through the schedule, so changes in project schedule would be reflected in restoration planning, as appropriate. Although the baseline provided a detailed basis for management, a more detailed level of planning (i.e., the work control documents) was conducted using the "rolling wave" approach of having work packages prepared just a few months before they were needed. This turned out to be a very successful work planning model, allowing the detailed work packages to be prepared under a "just in time" concept and thus take advantage of the latest in technical, regulatory, and management lessons learned.

8.1.8 Project Manager Authority

Under the Closure Project, all decommissioning scope became building-based with no functional management, i.e., no "D&D Program." All projects (e.g., the 771 Project) had distinct cost and schedule baselines over which the vice president–level Project Manager had complete funding and decision-making authority. Functions necessary for successful project execution, such as project control, procurement, engineering, and safety, were assigned to the project, and staff in those functions were paid for by and reported to the Project Manager. This accountability also provided an unambiguous means of identifying project personnel value and improved the ability to control costs and staffing. Cooperation and coordination between Project Managers was accomplished by leadership from the most senior contractor management and corporate board, rather than through an organizational structure. The contractor's most senior corporate managers successfully coordinated between Project Managers, providing a delicate balance between building and site priorities, but only with continuous engagement.

8.1.9 Centralize Plutonium Stabilization Operations

The Security Reconfiguration effort centralized all "operations" previously spread throughout the plutonium buildings into a single building (Building 371), so that all such nondecommissioning plutonium activities were removed from the other three major plutonium buildings. In addition to the dramatic reduction in costs to support security compliance, the ability of the three facilities to focus on decommissioning increased, and the change in the culture resulted in improved decommissioning performance. Similar distinct divisions between operating and decommissioning were established for the nonplutonium facilities, such that buildings that had a continued waste management mission remained distinct from those either awaiting or undergoing decommissioning.

Figure 8-3. The last former plutonium facility to be demolished at Rocky Flats was Building 371, brought down in 2005.

8.1.10 Division of the Decommissioning Scope

There was an issue of distinguishing between the work that would be done by site bargaining unit craft labor (United Steelworkers of America) and the work that would be done by construction crafts (building trades). There was early recognition that a construction workforce greater than that available within the current site steelworker ranks would be required to achieve accelerated closure. The division of the scope during the planning process was necessary to allow contracting and proper scheduling of activities.

This division of scope included separating the work in a given room or rooms between those removals that were highly contaminated and those that were less contaminated. All of this work was considered decommissioning, not deactivation. The site steelworkers first removed the equipment included in their work scope. They then moved to other areas and the building trades removed the remaining equipment, utilities, non-load-bearing walls, and decontaminated structural surfaces and demolished the buildings. Anticipating and separating this work within the Closure Project Baseline allowed the work to be appropriately contracted, scheduled, and controlled. Doing so would have been much more difficult after work had started.

Significant advance work was necessary to allow this separation and coordination in the work planning. The contractor had to approach both the steelworkers and building trades to develop cooperative approaches that would be seen as benefiting the members of both groups. Their success in this effort enabled the efficient division of work during the decommissioning.

8.1.11 Personnel Incentives

There was an early recognition that most of the Closure Project critical activities involved process system equipment removal and that this would be performed by site bargaining unit staff (i.e., the site steelworkers) that would be retrained for that purpose. Real concern existed about the willingness of individuals to change from operators to D&D workers and to accelerate work that would result in more rapidly putting them out of a job.

The issue was addressed in a global fashion by trying to align the interests of the workers with those of Kaiser-Hill and DOE. This was done in three ways. First, the contract was renegotiated to delineate between steelworker and building trades crafts based on level of contamination (e.g., 2000 dpm-alpha) instead of the normal Davis-Bacon divisions. This allowed the workers best trained for higher radiological work and those best trained for construction equipment to be appropriately placed and also ensured that the steelworkers would move from building to building as the Closure Project progressed, ensuring their jobs as long as higher-radiological-hazards work remained. Second was the liberal use of overtime, improving the effective rate of pay for the steelworkers. Third, the steelworkers received an annual incentive bonus based on schedule performance, and considerable spot bonuses were provided at completion of specific activities, ranging from items such as dinners to cash awards of several hundred dollars, given often. In addition to the steelworker staff, it was recognized that the D&D worker supervision was critical to achieving the required acceleration. Several methods were used to provide increased compensation for these staff that would be directly accountable for decommissioning activity schedule.

Although not exactly a personnel incentive, the site supported personnel outplacement as work in certain job categories decreased. In the case of the steelworkers, this included assistance in moving into building trades unions to do Rocky Flats decommissioning work as steelworker work was diminishing. This program involved in excess of 150 steelworkers and provided as much as a year of additional employment; many former steelworkers continue to perform building trades craft work at other locations throughout the Denver area.

8.1.12 Changing the Culture

One consistent theme for the decommissioning projects, as well as the site as a whole, was the need to change the culture. In the context of decommissioning, this means emphasizing the construction aspects of the work. A number of actions were taken to promote this culture change. In one case personnel were moved out of in-building offices into construction trailers. Part of the reason was to free up in-building space for logistics, but more important was to drive home the point that operations were over.

Consistent with changing the culture was bringing in off-site expertise and attitudes. This involved the insertion of senior managers with outside experience at the execution project level while retaining substantial site staff. Staff-level personnel with outside expertise were also inserted. This encouraged the introduction of different approaches while taking into account unique site considerations. Although it took time to achieve a cohesive team, having a single composite project organization minimized the difficulties of organizational interfaces such as would occur if a number of contractor organizations were used.

8.1.13 The Learning Curve

The decommissioning process at Rocky Flats can be described as surprising—surprisingly confused and inefficient at the beginning, and surprisingly improved within a relatively short time. A "learning curve" effect is traditionally thought of as the result of improvement in workforce experience, which was certainly part of the process as the workers, usually former process operators, become more comfortable as D&D workers. During the initial decommissioning projects the efficiency was low; as the understanding of the work improved, the tooling became more sophisticated, and techniques for contamination control became better. The crews also began acting more as teams, anticipating each other's actions in removing PPE, for example. The contractor, Kaiser-Hill, placed substantial emphasis on empowering its first-line supervision (foremen) and in improving both training and management oversight, which resulted in improvements in crew efficiency. There was also a reduction in injuries and accident statistics, which had a collateral efficiency improvement from reduced shutdowns.

An additional area of improvement was in work planning and procedures. Much of the early inefficiency was due to downtime caused by inadequate or incorrect work documentation. Through feedback and increased experience by the engineering and planning staff on decommissioning work, the packages became more timely and accurate, resulting in less work stoppage. As an example, standard work packages were developed that allowed the performance of work with similar scope from one area or facility to another. Additional efficiency came from improvement in the methods of work and identifying and eliminating barriers and unnecessary activities. Examples of improved methods included:

- the decreased reliance on size-reduction resulting from improved glovebox decontamination
- the use of vacuum cleaners to remove Raschig rings (see Section 6)
- the use of plasma arc required significant efforts to overcome safety concerns
- elimination of submitting detailed facility characterization plans to allow the release of office trailers awaiting regulator approval through increased involvement by the regulators in planning and implementation oversight
- consolidating facilities in a way that allowed one document to cover multiple facilities, minimizing the administrative and regulatory effort

Early initiation of larger-scale pilot projects (discussed earlier) that allowed problems to be resolved on one project instead of having to be addressed by all projects simultaneously was one element in particular that was important for moving rapidly up the learning curve. Thus, the inevitable delays and cost variances were not repeated, nor was the site closure end date impacted. The other projects all moved up the learning curve by incorporating the piloted approaches in their planning and baselines. Additionally, it allowed for development of crews, staff and management teams, and replacement of underperformers.

Learning curve issues also caused a rethinking of the use of fixed-price contracting for lesser-contaminated facility decommissioning. Despite attempts to make the demolition of clean facilities similar to commercial construction, there remained site-specific requirements and expectations for safety and conduct, and personnel interactions that needed to be achieved to accomplish work. The learning curve for dismantlement, decontamination, and demolition of uranium- and beryllium-contaminated facilities was greater than anticipated, even for firms experienced in contaminated decommissioning elsewhere.

8.1.14 Technology Development

The decommissioning activities at Rocky Flats demonstrated the capabilities and limitations of applying technology to decommissioning problems. Several problems were solved by the focused use of technology applied to a specific problem. The technology improvement with the largest single impact was the ability to decontaminate plutonium process equipment—such as gloveboxes and tanks—from TRU waste classification to LLW and substantially reduce or eliminate the size-reduction effort in the process.

During the Building 779 project, the only accepted way to determine plutonium levels for characterization of process equipment-generated wastes was to use nondestructive assay (NDA) machinery, which could not accurately assay larger containers. Therefore, all plutonium process equipment was sprayed with fixatives to minimize plutonium airborne activity and then manually reduced to a size that could fit in a Standard Waste Box, the largest container available for disposal of TRU waste. Manual size-reduction of plutonium process equipment was very labor-intensive, requiring several support personnel outside of a contamination control structure to support each supplied-air plastic-suited worker using manual cutting tools inside the structure. The potential for personnel contamination and cutting injuries was high.

Conversely, nonprocess equipment–generated wastes, such as debris from room-air ducting and desks from process areas, could be placed into much larger cargo containers for disposal as LLW at the NTS. The wastes could be radiologically characterized using the SCO procedure. This is a straightforward process that uses direct readings and smears from all surfaces of an object to determine average levels of surface contamination to give a total activity for the object. For materials at lower contamination levels, it can be performed with existing instrumentation. Initial evaluation showed that some, mostly laboratory, gloveboxes could be decontaminated and then characterized using existing decontamination techniques and the SCO procedure. The remaining gloveboxes would both exceed the measurement capabilities of existing equipment and could not be adequately decontaminated using existing techniques. Thus, it appeared that the majority of the site's gloveboxes would require manual (or perhaps automated) size-reduction.

Three decontamination technology development efforts were pursued. First, instrumentation was developed to accurately determine contamination levels in the range of 10–100 million dpm alpha. Simultaneously, two approaches were evaluated for in-glovebox decontamination. One involved the adaptation of a process to dissolve plutonium oxide using cerium nitrate that had been used for tank decontamination. A second brought in a subcontractor for application of proprietary chemicals in a multistage process. These methods successfully reduced the number of gloveboxes requiring manual size-reduction by about 80% and resulted in a similar reduction in TRU waste for a substantial savings in waste management costs. The decreased reliance on manual size-reduction and acceleration of schedule resulted in hundreds of millions of dollars of cost savings (DOE 2005a).

A technology development effort that proved less successful was a project to implement a robotic size-reduction facility. This facility was designed and procured based on programmatic studies of anticipated needs, not at the request of any D&D project. After spending approximately $7 million in development and procurement costs, the installation of this facility was halted, principally due to the success of the decontamination/SCO methods for glovebox dismantlement, continued improvement in manual size-reduction facilities such as the use of plasma arc cutting, and improved work skills that resulted in better contamination control. Additionally, there were concerns that benefits of the robotic system, less worker exposure, and faster size-reduction for standard parts would not compensate for substantial start-up and debugging time and costs and the reduced flexibility for nonroutine activities.

There were several factors that the site considered when it evaluated how to approach technology development:

- Technology development was most successful when initiated by an execution project to solve one of its problems and with that project's buy-in and cost-sharing. It was least successful during accelerated closure when initiated by a technology development organization (a solution looking for a problem).
- Evaluation of technology options must involve active participation of workers at the foreman level or below—even if a technology works, if there is no buy-in from the workers, then it will not be used effectively.
- Incremental improvement, mostly with off-the-shelf items, yielded large benefits in increased productivity. If management is open to the continual, incremental improvement, one good idea often leads to another.
- Employing contractors with specific expertise, such as for characterization or decontamination (perhaps with a contractual capability to transition to site staff at some later date) is preferable to developing technology in-house.

During planning a number of seemingly intractable problems—activities for which there was no clear approach—were identified, such as cleanup of vaults with extremely high levels of airborne contamination. Technology development was initiated to investigate several technologies at once, using DOE Office of Technology Development funding support. The development timelines were evaluated to ensure that the candidate technologies would be available in time to be used.

8.1.15 Beryllium and Asbestos Contamination

Although the radioactive contaminants typically receive most of the attention for decommissioning, beryllium (Be) and asbestos provided significant challenges in the overall decommissioning effort. Asbestos was found in far more places than originally anticipated. Asbestos was unexpectedly ubiquitous in interior and exterior wallboard, spackling and grouting material, and floor coverings. For worker safety, asbestos-containing material (ACM) was removed prior to demolition activities (but generally after facility radiological decontamination) and segregated for waste disposal. The extensive ACM removal provided substantial work sequencing and control challenges and unexpectedly appeared on the critical path for demolition of several major facilities. In the case of Building 776/777, the exterior wall panels were all determined to be ACM. An elaborate subproject replaced the complete "skin" of the building, removing ACM panels one at a time and replacing them with a temporary non-ACM panel, so that the negative differential pressure could be maintained within the building. One positive aspect of the ACM challenge was the success of the ACM-removal subcontractors. The site focused on niche subcontractors with expertise in ACM removal. These were some of the best performing subcontractors, working safely and effectively, even considering the hazards of the asbestos.

Be contamination also provided unique challenges. Originally, the site anticipated that only a handful of nonnuclear production facilities would be contaminated with Be. As facilities were characterized, the site found Be contamination in nuclear facilities and even some administrative support areas. There is still no device that can provide real-time detection of Be contamination. Smear and swipe samples, lapel samplers, and other air samples collected in the field must be analyzed in a laboratory, usually with no less than a 24-hour turnaround. For their protection, workers in areas with suspected Be contamination were required to wear respiratory protection until it could be proven that Be was not present. Even this was not completely successful. Several instances occurred in which a room was surveyed and found to be free of Be contamination, only to have Be uncovered during the removal of a large piece of equipment. Further complicating the work planning and resource scheduling was DOE's desire to limit the number of Be workers, since any Be worker became part of the Chronic Beryllium Disease Prevention Program, with a lifetime commitment for health screening due to the potential to develop chronic beryllium disease. With additional training and management attention, the site worked through both the ACM and Be challenges. The lesson for other sites is to plan for more asbestos and Be contamination than would be expected based on historical knowledge or even initial sampling.

8.1.16 Waste Estimate Tracking

Methods were developed to estimate waste generated during decommissioning activities based on early decommissioning pilot projects. The pilot projects were used to extrapolate waste generation for subsequent building demolition. The initial estimating technique was not very accurate. Although there were some improvements in waste estimation, the estimating process was complicated by the fact that the site identified methods to decontaminate and dispose of significant quantities of LLW that were originally assumed to require disposal as TRU waste. Additionally, the volume of LLW increased tremendously when the decision was made to demolish several buildings/areas as LLW instead of the original assumption that the buildings would all be decontaminated to allow demolition and disposal as sanitary waste. In cases where the site chose an alternative decommissioning method that generated more waste, the cost savings in decommissioning worker efficiency usually offset the additional waste cost; i.e., the overall project cost was reduced. The method also expedited critical path activities allowing closure acceleration. While not a decommissioning issue, the ER program underestimated the amount of contaminated soil that would require disposal, contributing to the quantity of LLW that required disposal in excess of that estimated. The site's sanitary waste volumes dramatically exceeded the planning estimates.

The challenge of waste estimating is recognizing when waste-estimating assumptions change and adjusting the waste estimates when a project decision affects them. For several years at Rocky Flats, these decisions to address decontamination issues or increase project efficiency were occurring at a rate and frequency that made it almost impossible for the planners to accurately estimate waste volumes; instead they were usually bounded (even then the assumptions sometimes proved wrong). Ultimately, the waste programs recognized that waste estimates were just that—estimates—and that the site would continue to generate and characterize waste until the Closure Project was complete. Only then would a final volume be known. Although the Rocky Flats waste-estimation experience may help other sites in their waste-estimating process, the inherent variability of waste-generation processes limits the applicability of the Rocky Flats experience to other sites. The more important lesson is to view waste generation and resulting disposal costs within the total project context.

8.1.17 Property Disposition

A decision process was developed to support facility disposition for small facilities. In these cases, it was feasible to treat a facility (e.g., a small trailer) as property and release it for off-site reuse or sanitary disposal. This method avoided excessive characterization costs under CERCLA.

The disposition of uncontaminated real and (government-owned) personal property in compliance with CERCLA and DOE regulations can require an effort out of proportion to its nominal risk or overall project importance. A decision process was developed to streamline the government process to dispose of real property (DOE 2004, 2005b, 2005c). It included an initial inventory that identified and verified the location and contamination status of all site personal property. Negotiations on property disposition requirements were held with the General Services Administration. As a result, the valuation of contaminated property took into account the cost required to decontaminate it. In practice, the value of most property resulted in a net of no value—it was waste and could be taken off the books. Finally, a congressionally authorized pilot project allowed the revenue from the sale of government-owned personal property at Rocky Flats to be applied to cleanup effort. An aggressive program of matching high-value (typically weapons-mission) equipment with the needs of other DOE sites provided additional value to the department.

8.1.18 Key Success Factors and Lessons Learned

Lessons-learned can be gleaned from every D&D project. These lessons may not always be directly applicable to every cleanup effort, but it is hoped that they can be beneficial at most other sites.

- A key factor to overall project success is to recognize in the planning process what facility or facilities will require the bulk of the decommissioning effort. Organize to focus on executing that work.

- The technical improvement with the biggest single impact was the ability to decontaminate plutonium process equipment such as gloveboxes and tanks from a TRU waste form to an LLW. This ability substantially reduced or eliminated the size-reduction effort, which in turn reduced cost and increased safety. Other benefits, such as less cost to manage LLW vs. TRU, were collateral benefits, not the principal drivers.

- The disposition of uncontaminated property in compliance with CERCLA and DOE regulations can require an effort out of proportion to its nominal risk or overall project importance.

- Pilot projects are necessary in the early phases of a project to develop and train staff and facilitate development of procedures, methods, estimating parameters, working relationships, and processes with regulators and stakeholders.

- Guard against the complexity of the work causing inaction. Minimize studies to determine the "best" approach. Develop a credible plan with best available information, proceed with work safely, and learn by doing with a bias toward continuous improvement.

- Eliminate competing priorities that are not mission-oriented.

- Manual size-reduction of contaminated equipment is hazardous work with significant occupational safety risk. Its redeeming virtue is that people are capable of handling different material configurations (as opposed to robotic or automated processes).

- Decisions to use in-house staff vs. fixed-price contracting depend on how similar the work is to routine construction and whether traditional construction accident rates are acceptable. As the work becomes less standard, disadvantages such as supplemental training, commercial vs. site safety practices, and learning curve inefficiency may outweigh the cost benefit of competitive procurement.

- Organize for success—projectize based on facilities or areas, not functions, to encourage management focus on closure.

- An initial problem was too many interdependent decisions, priorities, and schedules that made it difficult to develop a baseline. Use outside experience, coupled with site knowledge, as a template whenever possible.

- One consistent theme for the decommissioning projects, as well as the site as a whole, was the need to change the culture, which included bringing in off-site expertise and attitudes.

- Work the evolution—encourage incremental improvements in efficiency to yield large collective efficiency improvement.

- Identify "intractable" problems early and begin working multiple paths toward solutions—in some cases the paths may combine.

- The challenge of waste estimating is recognizing when waste-estimating assumptions change and adjusting the waste estimates when the project makes a decision affecting them. The more important lesson is to view waste generation and resulting disposal costs within the total project context.

- Safety is Job 1. This lesson was reinforced throughout the closure project. If work cannot be safely performed, then the project grinds to a halt. Early on in the project it was recognized that a significant investment in hazard identification, safety planning, and safety implementation during the actual work (i.e., the DOE's ISMS) ensured that work was performed safely without unacceptable risks or unnecessary delays to correct safety deficiencies. Later in the project, management came to understand that safety focus did not merely enable work but facilitated efficiency and acceleration by building trust and engaging the workforce.

- The Rocky Flats experience proved that the DOE's contract reforms worked. The first "Integrating Management" contract demonstrated that incentivizing clearly defined performance measures vastly improved actual results. The Closure Contract took the concept to the next level, providing large incentives to the company and the workers to safely and compliantly complete the cleanup and closure scope within a target scope and cost. Additional incentives for schedule and cost savings resulted in closure more than one year ahead of schedule and $530 million under the contract budget.

- Learn to focus on "what," not "how." DOE must manage to a contract, not manage the work for the contractor. The contractor must learn to respond to contractual direction and not informal DOE requests. This was a difficult transition at Rocky Flats due to years of conditioning from the "Management & Operations" contract approach typical at large DOE sites.

Figure 8-4. The Rocky Flats site in October 2005.

- Collaborative working relationships contributed significantly to the successful Rocky Flats closure. Stakeholders (in the broadest sense of the word) were engaged in the process and supportive of the ultimate goal. The interests of numerous key figures, including members of Congress, senior DOE management, state and local elected officials, and state and federal regulators, were actively solicited and ultimately met. Although there were differences in the details, the entire Rocky Flats community shared a common goal: Make It Safe—Clean It Up—Close It Down (Figure 8-4).

8.2 Fernald, Ohio: Closure Project

This case study is taken in large part from the Final Remedial Action Report for Operable Unit 3 at the Fernald Closure Project (DOE 2006c). The Fernald Closure Project (FCP), formerly known as the Feed Materials Production Center, is a 1050-acre DOE facility located in a rural, residential area 18 miles northwest of Cincinnati. The facility was constructed in the early 1950s, and production operations began in 1952. Uranium metal for the nation's defense programs was produced at Fernald, including slightly enriched and depleted uranium. Smaller amounts of thorium metal were also produced. Uranium, radium, and other radioactive materials from mineral beneficiation processes contaminated soils, debris, groundwater, and surface water in the Fernald vicinity. Production stopped in July 1989 to focus resources on environmental restoration.

The primary mission of Fernald during its 37 years of operation was to process uranium feed materials to produce high-purity uranium metal. These high-purity uranium metals were then shipped to other DOE or DOD facilities for use in the nation's weapons program. Manufacture of the uranium metal products occurred in a concentrated 140-acre area of the site known as the Production Area, where 255 production, storage, support, and administrative buildings and structures were situated. During the 37 years of production operations, nearly 500 million pounds of uranium metal products were produced. The site also served as the nation's key federal repository for thorium-related nuclear products, and it also recycled uranium used in the reactors at the Hanford site. This returned uranium was the source of technetium-99 (^{99}Tc), a radiological contaminant that was prevalent at the site.

For purposes of investigation and study, the remedial issues and concerns that were similar in location, history, type/level of contamination, and inherent characteristics were grouped into operable units under the 1991 amended Consent Agreement. Specifically, the site was divided into five operable units. Four of the operable units (1-4) are considered contaminant "source" operable units as they represent the physical sources of contamination that have affected the site's environmental media. The fifth operable unit (Operable Unit 5) is considered the "environmental media" operable unit as it represents the environmental media affected by past production operations and waste-disposal practices (i.e., beyond the contaminant "source" operable unit boundaries), as well as the pathways of contaminant migration at the site. The four contaminant "source" operable units and the fifth environmental media operable unit are described below:

- Operable Unit 1: Waste Pit Area. Waste Pits 1–6, Clearwell, Burn Pit, berms, liners, and affected soil residing within the operable unit boundary.
- Operable Unit 2: Other Waste Units. The Active and Inactive Fly Ash Piles, the South Field disposal area, north and south Lime Sludge Ponds, the Solid Waste Landfill, and the berms, liners, and affected soil residing within the operable unit boundary. The Active and Inactive Fly Ash Piles and South Field area are collectively known as the "Southern Waste Units" because they are collocated in close geographic proximity to one another.
- Operable Unit 3: Former Production Area. Former production and production-associated facilities and equipment (including all above- and below-grade improvements), including, but not limited to, all structures, equipment, utilities, drums, tanks, solid waste, waste, product, thorium, effluent lines, a portion of the K-65 transfer line, wastewater treatment facilities, fire training facilities, scrap metal piles, feedstocks, and coal pile. Note that all affected soil beneath the facilities falls within Operable Unit 5.
- Operable Unit 4: Silos 1–4. Contents of Silos 1–3 (Silo 4 has remained empty); the silos structures, berms, decant sump tank system, and affected soil residing within the operable unit boundary.
- Operable Unit 5: Environmental Media. Affected groundwater, surface water, and all soil not included in the definitions of Operable Units 1, 2, and 4, sediment, flora, and fauna.

Figure 8-5. Pneumatically removing thorium-bearing waste from Silo 3 at the Fernald Closure Project in October 2005.

Between 1994 and 1996, DOE and EPA signed the final RODs for each operable unit, in cooperation with the Ohio Environmental Protection Agency and the Fernald Citizen's Advisory Board, which set in motion the major cleanup requirements and approaches that collectively define the FCP cleanup. The RODs employed a combination of off- and on-site disposal, under which approximately 77% of the remedial waste volume (the lower-concentration, higher-volume materials) was to be disposed of in an engineered On-Site Disposal Facility (OSDF), while approximately 23% (the higher-concentration, lower-volume materials) were to be sent off site for disposal, primarily at permitted facilities in Utah, Nevada, and Texas. At the time the

RI/FS activities were completed and the RODs put in place, an estimated 31 million pounds of uranium products, 2.5 billion pounds of waste, 255 buildings and structures, and 2.75 million cubic yards of contaminated soil and debris were identified as requiring action.

Operable Unit 3 was principally responsible for all D&D activities at the site. One significant factor complicated the D&D at Fernald—the method by which the facility was shut down. Essentially, the decision to shut the facility down was made and processes were halted midstream. This led to significant quantities of materials left within the process lines and throughout the plant, which remained for years as the RI/FS process moved forward. These materials increased maintenance costs, presented significant exposure potential, increased the risk for environmental releases and added to both cost and schedule for completion of D&D operations.

The sources of contamination within Operable Unit 3 consisted of the legacy waste inventories and the various types of materials that composed the physical structures of the former process areas at the FCP. The RI sampling approach involved the analysis of intrusive samples from major media (concrete, asphalt, acid brick, masonry, transite, and steel coatings) and loose samples from supplemental media (residues, floor sweepings, sediment, sludges, etc.). The samples were analyzed for a broad suite of radionuclides, metals, volatile organics, semivolatile organics, and PCBs.

Consistent with Fernald's production history, the results of the RI showed that the most common and highest levels of radiological contamination were associated with uranium and its decay products, followed by thorium and its decay products. The highest levels of uranium were associated with residual material remaining in piping and equipment. Along with uranium, ^{99}Tc and thorium-230 (^{230}Th) were also found to be significant radiological constituents affecting remedial action decision making. Uranium was considered significant due to its widespread distribution across the Operable Unit 3 materials and its impact on potential on- and off-site disposition decisions contemplated in the final remedial action ROD. ^{230}Th (an impurity in the uranium ores and ore concentrates processed at Fernald) was considered significant as it can pose a potential inhalation hazard to workers during remedial activities if the proper PPE is not in place. ^{99}Tc (a trace impurity in recycled uranium processed at Fernald) was considered significant because of its mobility in the environment when leached from affected materials.

At the time that uranium production operations ceased at Fernald, the former production buildings were at or beyond their design lives, and no viable future mission existed for the aging buildings and structures. As a result, DOE and EPA officially decided that all of Fernald's buildings and structures would be dismantled and that the resulting dismantlement debris would be placed in interim storage. The initial dismantlement and interim storage decision was formally documented in the July 1994 Operable Unit 3 ROD for Interim Action (IROD) (DOE 1996). The IROD also provided that a subsequent final remedial action ROD would establish the final disposition strategy and locations for the materials generated by the interim remedial action. The first-step remedial activities approved through the IROD included the following:

- surface decontamination of buildings and structures by removing/fixing loose contamination
- dismantlement of the above-grade buildings and structures

- removal of foundations, storage pads, ponds, basins, and underground utilities and other at- and below-grade structures
- off-site disposal, of up to 10% by volume, of the nonrecoverable waste and debris generated from structural D&D, until issuance of the final remedial action ROD
- interim storage of the remaining waste and debris until a final disposition decision is identified in the final remedial action ROD

The sequence and schedule for which the above-grade portions of the structures would undergo D&D were outlined in the 1995 *Operable Unit 3 Remedial Design Prioritization and Sequencing Report* (DOE 1995a), which was updated and approved by EPA in 1996. Work practices and implementation strategies for the interim activities were defined in the *Operable Unit 3 Remedial Design/Remedial Action: Work Plan for Interim Remedial Action* (DOE 1995b), approved by EPA in 1995. It was also agreed at that time that the at- and below-grade remediation of the Operable Unit 3 structures, storage pads, etc. would be sequenced and scheduled as part of the Operable Unit 5 RA/RD process, to allow the at- and below-grade activities to be coordinated with soil remediation activities.

Concurrent with the ROD process, several removal actions were implemented to expedite the D&D process and make significant reductions in the potential for additional releases of contamination to the environment. Removal Action 9 involved the safe, off-site disposal of existing waste inventories. Containerization of Fernald's major waste streams was initiated in August 1985, and Removal Action 9 was formally set in motion in 1991 to provide for the transfer of inventoried waste to the NTS. The waste management program initiated by Removal Action 9 defined the procedures for waste characterization, treatment, packaging, and transportation of waste in a manner that provides compliance with DOE orders, DOT shipping requirements, and NTS waste acceptance criteria (WAC). Removal Action 9 addressed Fernald's inventory of LLW, mixed waste, and Toxic Substances Control Act (TSCA) wastes that were generated as a result of production operations, facility maintenance, site upgrades, and pre-ROD cleanup activities. Removal Action 12 was created for the removal and disposition of in-process residue materials, excess supplies, chemicals, and the associated process equipment that remained when Fernald stopped production in 1989. Residue materials removed during safe shutdown were containerized and sent for off-site disposal. The removal action also provided for the isolation and deenergizing of former production-related equipment and utilities and provided for the identification of new customers for Fernald equipment and nuclear products.

Three final remedial action alternatives were identified in the FS and carried forward for detailed evaluation: No Further Action (Alternative 1); Selected Material Treatment, On-Property Disposal, and Off-Site Disposition (Alternative 2); and Selected Material Treatment and Off-Site Disposition (Alternative 3).

DOE and EPA signed the final remedial action ROD (DOE 1996) in September 1996, following the receipt and closeout of public comments on the Proposed Plan. The final remedial action ROD adopted Alternative 2, Selected Material Treatment, On-Property Disposal, and Off-Site Disposition, as the selected remedy for final dispositioning of the Operable Unit 3 materials. The key components of the selected remedy for final remedial action are as follows:

- adoption of previous Operable Unit 3 decisions
- incorporation of the facility and structural D&D decisions contained in the IROD so as to provide for an integrated implementation of the interim and final decisions
- adoption of the procedures and off-site disposition decisions (primarily Removal Actions 9 and 12) to continue the off-site disposition of the containerized wastes, products, residues, and nuclear materials generated during historical site operations
- adoption of the prior procedures and decisions for the management of safe shutdown (Removal Action 12), management of asbestos abatement (Removal Action 26), and management of debris (Removal Action 17)
- approved alternatives to disposal—permitting the restricted/unrestricted release of materials, as economically feasible, for recycling or reuse
- treatment of Operable Unit 3 materials—permitting the treatment of materials to meet the on site disposal facility WAC and/or off-site disposal facility WAC
- off-site disposal of materials above the OSDF WAC
- requiring off-site disposal of process residues, product materials, and process-related metals generated during D&D activities
- requiring off-site disposition of acid-resistant brick, lead sheeting, concrete from four designated locations to further minimize the total quantities of ^{99}Tc-contaminated materials placed in the OSDF (top inch of concrete from two areas in Plant 9, an area in Plant 8, and an area in the pilot plant), and any other materials exceeding OSDF physical and numerical WAC
- on-property disposal—materials eligible for placement in the OSDF
- deeming the remaining quantities of Operable Unit 3 D&D materials eligible for disposal in the OSDF, requiring that the materials pass visual inspections for the presence of process residues during implementation
- recognition of the need for institutional controls at the completion of the remedy (consistent with Operable Unit 5)
- recognition of the need for long-term monitoring and maintenance of the OSDF and operation of a groundwater-monitoring network to evaluate performance of the OSDF consistent with Operable Unit 5

The 10 material categories developed during the RI/FS were evaluated as part of the final ROD to determine whether the categories would be eligible for disposal in the OSDF or required off-site disposal based on exceeding OSDF numerical WAC and/or other administrative on-site disposal prohibitions. It should be noted that the January 1996 Operable Unit 5 ROD (DOE 1996), which preceded the Operable Unit 3 decision by nine months, established the sitewide numerical OSDF WAC limits and administrative prohibitions for use in Fernald's decision making, including for adoption by the final Operable Unit 3 ROD (see Table 8-1).

The following quantities of materials were dispositioned as part of the containerized waste removal action (RA #9): 6.6 million cubic feet of LLW shipped to Nevada; 59,000 cubic feet of low-level mixed waste shipped for off-site treatment; 170,000 gallons of low-level MW shipped off site for incineration; and 31 million pounds of nuclear materials shipped off site for other DOE programmatic uses, private-sector uses, or interim storage under DOE's Uranium Facility Management Group.

Table 8-1. Operable Unit 3 waste volume estimates (DOE 1995a)

Material category	Estimated volume (cubic yards)	Actual volume (cubic yards)	Disposition pathway
OSDF-eligible bulk D&D debris	261,481	523,455	OSDF
Ineligible (above-WAC) D&D debris (primarily acid brick, lead flashing, ^{99}Tc-affected concrete identified in the final ROD, process-related metals, and other prohibited items)	6,444	21,724	Envirocare[a] and NTS
Unrestricted release	11,444	NA[b]	Various

[a] Envirocare has been renamed EnergySolutions.
[b] Debris released in an unrestricted manner was generally tracked only by container. No specific quantity released is available.

A number of lessons learned can be taken from the Fernald experience and applied to other D&D projects. The lessons below come from the Operating Unit 3 Remedial Action Report.

- At the time the decision was made to cease production in 1989, it was decided to end production while much in-process material remained in the various production facility's tanks and pipelines. This action complicated the eventual D&D process. This hold-up material resulted in the need for RA 12, Safe Shutdown, which was created to provide the planning, engineering, and program control for the removal and disposition of in-process residue materials, excess supplies, chemicals, and the associated process equipment that remained when Fernald stopped production.

- Since most of the material eligibility, size, and other waste acceptance requirements for the Operable Unit 3 materials were visually based, it proved important to use consistent crews within a given project and properly trained and qualified Waste Acceptance Organization (WAO) personnel to render consistent visual judgments in the field. WAO inspection personnel were required both at the point of debris generation and at the location of placement in the OSDF.

- Crews needed to perform continuous real-time visual observation of the at- and below-grade debris excavations and above-grade dismantlement and decontamination activities to identify debris requiring special handling or segregation. Where necessary, provide a working area to perform the observations away from ongoing heavy equipment operations.

- Recognize the inherent safety risks and considerations in performing the visual inspections; remain clear of pinch points, and keep body parts out from between stationary and/or moving objects. Plan for the impact of PPE on the visual inspection process.

- Provide proper lighting for the visual inspections, especially when multiple day and night shift work is required.

- Develop open lines of communication and a consistent process for obtaining EPA consensus on the types of field decisions that accompany visual-based acceptance criteria.

- Use weekly conference calls with EPA and Ohio EPA to plan upcoming work and field observation activities and exchange observations from the previous week.

- Recognize stockpiling is a necessary requirement to smooth the flow of materials for placement; recognize the impacts of weather delays and winter shutdown conditions on the need for debris stockpiles, while striving to minimize the double handling of material.

- Large, articulated dump trucks proved to be more efficient than smaller articulated or road trucks for the pace and quantities of at- and below-grade debris generated during soil excavation in the former production area.

- Dust and erosion controls in the excavation and dismantlement areas can become major, nearly continuous efforts and should be planned for properly. Such efforts generate large quantities of impacted water that need to be accounted for in storm water planning.

- Feedback from project-boundary perimeter air monitors needs to be coordinated with sitewide efforts to determine the impact of individual projects on the air pathway so that continuous improvements can be evaluated and implemented.

- Use large mechanical equipment such as backhoes with heavy-duty shears rather than manual removal techniques (e.g., saw cutting) wherever possible, to significantly reduce occupational risk to employees. Hand injuries were a key occupational injury category that was significantly reduced by shearing.

- Use implosion techniques on taller structures where feasible to reduce the risks associated with structural demolition.

- Use a borescope wherever possible to conduct interior inspections of piping. It avoids the need to recut piping for inspection that has been crimped during mechanical shearing.

- The use of the oxy-gasoline cutting torch (tested and deployed under the DOE innovative technologies program) was more effective and efficient compared to the standard acetylene torch in cutting through the thicker plate steel encountered.

- The use of fixatives after the gross decontamination of structure was completed proved very effective in mitigating against airborne contamination.

- Use multiple progressive walkthroughs to identify eligible/ineligible WAC materials as early as possible, as work progresses and inspection access avenues develop during the course of the project.

- Develop effective contracting mechanisms to control the work of the D&D subcontractor to the requirements of the site, while still allowing for innovation and adoption of safe, proven, commercial practices in project execution. Address the need for effective independent oversight and construction management interactions with the contractor under in a fixed-price environment.

One of the last D&D projects at the site involved the demolition of the silos treatment facilities. The primary contaminant of concern there was radium, which has a much lower cleanup level than uranium. The combination of the lower cleanup level, a rush to completion, and large volumes of water for dust control led to significant contamination of surrounding soil during D&D. This contamination resulted in a much larger excavation both horizontally and vertically than previously estimated. The importance of adjusting work practices for particular contaminants and maintaining a focus on contamination control as the project ends are important lessons from this final project at the site.

Large cost reductions were realized from the IROD estimates to final actual costs. Actual costs for the adjusted IROD tasks totaled to $174 million. When compared to the 2006 escalated adjusted estimate of $1.4 billion, an 87% reduction in costs was achieved. This significant level of cost savings, which falls below EPA's -30% to +50% guideline, can best be explained based on how the work was performed. The IROD D&D cost estimate was based on a "take it down piece-by-piece, beam-by-beam" approach, recognizing the inherent risks and contaminant release mechanisms associated with radiological demolition work. This "piece-by-piece" approach was adopted for planning purposes in 1993 and drove the cost estimates and schedules under consideration at the time of the IROD. The Plant 7, Plant 4, and Plant 1 design packages were bid, awarded, and executed 1994–1996. Experience with these large-scale and challenging projects demonstrated that the use of current commercial demolition practices, including implosion and mechanical shearing, would drastically reduce the time, labor requirements, and overall cost of the D&D work as compared to the original IROD "piece by piece" deconstruction approach, while still maintaining a safe occupational, radiological, and environmental posture for the work. The dramatic schedule and cost savings that were experienced with these projects formed the basis for the "10-year plan" project acceleration objective for Fernald, which was approved for funding by DOE in 1996.

At the end of October 2006, the contractor, Fluor Fernald, declared physical completion of the Fernald cleanup. Subject to approval by DOE and the regulatory agencies, this signified the completion of the Fernald remediation with the exception of ongoing groundwater remediation. Following D&D and soil excavation, the site was restored to wildlife habitats based on historical references and using native plants. The OSDF contains a little more than 3 million cubic yards of soil and debris and will require perpetual maintenance and monitoring. The site will be open to the public as an undeveloped park or greenspace. An education/visitors center was expected to be created out of a redeveloped warehouse in late 2007. This warehouse and a water treatment facility are the only remaining buildings on the site.

8.3 Hanford, Washington: Reactor Cocooning

8.3.1 Background

The Hanford Site is a 586-square-mile federal facility located in southeastern Washington State along the Columbia River and operated by DOE. In 1943, the Hanford Site was used to produce plutonium for the world's first nuclear weapons. From 1943 to 1989, the primary mission of the Hanford Site was the production of nuclear materials for national defense. Over time the site mission expanded to include other uses of nuclear materials, research and technology development, waste management, and environmental restoration. From the early 1990s to the present, the primary mission at Hanford has been environmental cleanup.

There are four areas at the Hanford Nuclear Reservation originally listed on the NPL: the 100, 200, 300, and 1100 Areas. The Hanford 100 Area site covers 26 square miles, 35 miles north of Richland, Washington. Nine water-cooled, graphite-moderated reactors (B, C, D, DR, F, H, KE, KW, and N) were constructed along the southern bank of the Columbia River in the 100 Area to support the plutonium-production effort. The reactors were constructed between the years of 1943 and 1963. All of the reactors are currently retired from service. The last reactor to operate, the N Reactor, was placed in standby in 1987 and declared retired in 1991. All reactors have been declared surplus by the DOE and are in the process of being decommissioned.

8.3.2 Regulatory Approach to Reactor Decommissioning

In the early 1990s, DOE, EPA, and Washington Department of Ecology (ECY) developed a plan to clean up the reactor buildings and hundreds of subsidiary facilities adjacent to the reactors. In 1993, DOE issued a ROD on an Environmental Impact Statement (EIS) for the decommissioning of the Hanford surplus production reactors. The ROD declared that the preferred alternative for the reactors was to place the reactors into interim safe storage for up to 75 years, followed by one-piece removal of the reactor cores for disposal. Cleanup activities began in 1994 while DOE worked with the regulatory agencies, the Hanford Advisory Board, and stakeholders in the region to come up with a cleanup strategy and develop a long-range cleanup plan. In 1996, as part of that strategy, an interim safe storage configuration for the Hanford reactors, referred to as "cocooning," was established that met the 75-year interim storage criteria of the ROD.

8.3.2.1 Alternatives Considered

Environmental Assessment—F-Area Decommissioning Program, Hanford Site, Richland, Benton County, Washington (DOE 1980) presented alternatives for final disposition of the 105-F Reactor complex. Four alternatives were considered: layaway, protective storage, entombment, and dismantlement with disposal of radioactive waste materials in burial grounds in the 200 Area of the Hanford Site. The preferred alternative was dismantlement and on-site waste disposal. Before any action was taken, DOE concluded it would be more appropriate to consider and implement a consolidated decommissioning program for all surplus production reactors located at the Hanford Site rather than address them separately.

In 1989, a Draft EIS was developed to evaluate potential environmental impacts of decommissioning eight of the nine surplus reactors at the Hanford Site: the B, C, D, DR, F, H, KW, and KE Reactor complexes. The N Reactor was not included in the EIS. At the time the EIS was prepared, the N Reactor was in standby mode awaiting approval for continued production of weapons-grade plutonium and steam for electrical power generation.

Facilities included within the scope of the proposed action included the surplus reactors, their associated nuclear fuel storage basins, and the buildings that housed the systems. No future long-term use of any of the surplus reactors and associated facilities had been identified by DOE. Because the reactors contained irradiated reactor components and the buildings that house the reactors were contaminated with low levels of radioactivity, DOE determined that there was a need for action and that some form of decommissioning and continued S&M was necessary. The primary purpose of the decommissioning and S&M was to remove as much of the contaminated materials as possible and isolate any remaining radioactive or hazardous waste in a manner that would minimize future environmental impacts, especially potential health and safety impacts on the public, and still allow consideration for all the final disposition alternatives in the future.

The alternatives considered in the Draft EIS were as follows:

- No Action—This alternative includes actions to continue routine surveillance, monitoring, and maintenance over a 100-year period. At the end of that period, another disposition activity would be necessary.
- Immediate One-Piece Removal—This alternative includes demolition of the reactor buildings and transport of each reactor block, intact on a tractor-transporter, from its present location in the 100 Areas to the 200 West Area burial grounds for disposal.
- Safe Storage Followed by Deferred One-Piece Removal—This alternative includes activities to place the reactors into a configuration for safe storage followed by a period of up to 75 years during which surveillance, monitoring, and maintenance are continued. Final disposition would include demolition of the reactor buildings and transport of each reactor block intact on a tractor-transporter from its present location in the 100 Areas to the 200 West Area for disposal.
- Safe Storage Followed by Deferred Dismantlement—This alternative includes activities to place the reactors into a configuration for safe storage followed by a period of up to 75 years during which surveillance, monitoring, and maintenance are continued. Final disposition would include demolition of the reactor building and piece-by-piece dismantlement of each reactor core and transport of radioactive waste to the 200 West Area for burial.
- In Situ Decommissioning—This alternative includes demolition of the reactor buildings and filling the voids beneath and around the reactor block. The reactor block, its adjacent shield walls, and the spent fuel storage basin, together with the contained radioactivity, gravel, and grout, would be covered to a depth of at least 5 m with a mound containing earth and gravel.

8.3.2.2 Preferred Alternative and Record of Decision

In 1993, DOE issued a ROD on an EIS for the decommissioning of the Hanford surplus production reactors. The ROD declared that the preferred alternative for the reactors was safe storage followed by deferred one-piece removal—place the reactors into interim safe storage for up to 75 years, followed by one-piece removal of the reactor cores for disposal in a specially prepared burial facility in the central portion of the Hanford Site.

In December 1996, DOE, EPA, and ECY agreed to negotiate an effective surplus reactor disposition program. Negotiations were conducted assuming a phased approach where Phase One includes interim safe storage (ISS) and Phase Two would address final reactor disposition. In August 1997, the Tri-Party Agreement established a major milestone and associated interim milestones and target dates governing the decommissioning and disposition of the surplus production reactors. With the exception of B Reactor, interim milestones were established to complete ISS (Phase One) of each of the 100 Area reactors (including N Reactor) by

September 31, 2012. Interim milestones for B Reactor involve hazard mitigation rather than ISS because the facility has been listed on the National Register of Historic Places and is awaiting a decision on its final disposition. The three parties agreed to postpone development of Phase Two milestones for final reactor disposition until after the surplus reactors were placed in ISS.

8.3.3 Surplus Reactor Interim Safe Storage or Cocooning

ISS has been implemented or is planned for seven of the eight surplus reactors included in the Final EIS and ROD. As discussed above, B Reactor is currently under a hazard mitigation program and is currently deferred from ISS.

8.3.3.1 B and C Reactors

Beginning with C Reactor in 1996, documentation to conduct a removal action under the authority of CERCLA was prepared for each of the reactor facilities with the exception of the KE and KW Reactors. Removal actions at the 105-KE and 105-KW reactors have been delayed until the SNF has been removed from the K Basins.

Engineering Evaluation/Cost Analysis for the 100-B/C Area Ancillary Facilities at the 108-F Building (DOE/RL 1996) was prepared in July 1996. Among the alternatives evaluated in the EE/CA was ISS of the 105-C Reactor Building. The ISS alternative included reduction of the building footprint by demolition of the fuel storage basin and portions of the facility around the reactor core and construction of a safe storage enclosure (SSE). The SSE included sealing the facility up to the shield walls and constructing a roof over the structure with a design life of up to 75 years. The resulting structure is more secure and less likely to release contamination; reduces the radiological inventory; and requires significantly less, and therefore less expensive, S&M over the life of the structure. The ISS alternative carries a higher initial cost than simple S&M. However, it is anticipated the increased initial cost will be recovered by a comparable reduction in cost for final disposition of each of the reactor facilities because much of the decommissioning and demolition has already been completed when the facility footprint was reduced. Based on the recommendations of the EE/CA, ISS was the selected alternative as documented in the AM that was issued in January 1997.

Table 8-2 shows the initiation date, completion date, and actual or estimated cost for performing ISS of the 105-C Reactor Building and the other Hanford Site surplus reactors. The table shows that ISS of the 105-B Reactor Building has been deferred pending decisions on its status as a museum.

8.3.3.2 D, DR, F, H, KE, KW, and N Reactor Cocooning

The cocooning process for the remaining seven reactors at the Hanford Site has been, or will be, essentially the same as described above for the C Reactor. In all cases, ISS was selected as the remedy. Table 8-2 shows the initiation dates, completion dates, and actual costs for ISS for all nine reactors.

Table 8-2. Initiation date, completion date, and cost of interim safe storage for Hanford Site surplus reactors and N Reactor

Reactor building	Initiation date	Completion date	Cost[a] ($ million)
105-C	August 1996	September 1998	31.1[b]
105-DR	March 1998	September 2002	16.2[b]
105-F	January 1998	September 2003	22.8[b]
105-D	January 2000	September 2004	13.8[b]
105-H	October 2000	October 2005	26.50
105-KE	October 2008[c]	September 2012[d]	20.40
105-KW	October 2009[c]	September 2012[d]	20.40
105-B	Deferred	Deferred	20.20
Total of eight surplus reactors			171.40
105-N/109-N	October 2006[c]	September 2009[d]	50.00
Total of all surplus reactors			221.40

[a] Costs reported in 2005 dollars.
[b] Actual cost reported in 2005 dollars.
[c] Proposed initiation date.
[d] Proposed completion date.

8.3.4 Decommissioning by Reactor Cocooning—Technical Approach

The reactor cocooning process involves removing all of the reactor building except the reactor core and the 5-foot-thick shield wall surrounding the reactor core. The buildings around the reactor core, such as the fuel element storage buildings, pumphouses or water processing buildings, offices, and warehouses, are completely removed. Demolition of these buildings generally follows standard practices using heavy equipment. Subsurface structures and contaminated soils are characterized and evaluated in accordance with remedial action objectives and cleanup standards. Foundations or subsurface structures that do not meet the standards are removed. For shallow areas of the reactor undergoing cleanup, excavation of contamination within the top 15 feet may cease when contaminant levels are demonstrated to be at or below the state of Washington's Model Toxics Control Act (MTCA) Method B levels, which ensure protection of the groundwater and the Columbia River. For radionuclides, the EPA CERCLA risk range of 10^{-4}–10^{-6} increased cancer risk is achieved. To meet the 10^{-4}–10^{-6} risk range, the total dose for radionuclides shall not exceed 15 mrem/year, approximately Hanford Site background, for 1000 years following remediation.

Below-grade structures and soils that meet the cleanup standards will be left in place. If not feasible to remediate below-grade structures and soils at the time of reactor cocooning, the site is designated on the Hanford waste site database and disposition of the site is deferred to the soils remedial action project to be dealt with at a future time.

Once all buildings surrounding the reactor core are demolished, openings and penetrations in the core are completely sealed with corrosion-resistant materials, and only one entrance (a door) remains, which is welded shut. The existing reactor shield wall is used to create the safe storage enclosure (SSE), and a 75-year metal roof is placed over the remaining structure (Figure 8-6). The facility is equipped with heat and moisture sensors that are remotely monitored. The final configuration of the facility will feature the existing shield walls as the exterior of the building, a single-entry door that would be used for inspections, and a metal roof with siding that matches the roof installation. The equipment associated with the monitoring and electrical power and lighting would be installed in a utility room located outside of the SSE so that entry into the SSE would not be necessary to service this equipment.

Figure 8-6. Interim Safe Storage (SSE) or cocooning of D Reactor, the fourth of Hanford's nine plutonium reactors to undergo the process, was completed on September 17, 2004.

The objective of cocooning is to keep the building cold, dark, and dry and to establish a safe, environmentally secure, and stable structure that will protect the public and the environment from potential contamination while significantly reducing S&M costs. The elements of the S&M program include routine radiological and hazard monitoring of the facilities, safety inspections, periodic confirmatory measurements of ventilation inspections, roof inspections and replacement, as necessary, and minor structural repairs.

Reactors can remain in the cocooned state for up to 75 years. This period will allow DOE, regulators, and stakeholders time to consider the final disposition method for the reactor cores and will allow radioactive materials in the reactor cores to decay to more manageable levels.

Disposal of waste from this cocooning action will either be sent to Hanford's Environmental Restoration Disposal Facility (ERDF) or an EPA-approved, off-site disposal facility capable of accepting CERCLA waste. Treatment of waste may be necessary prior to disposal at ERDF. If TRU waste is encountered, it is stored at Hanford's Central Waste Complex until eventual shipment off the Hanford Site. Liquid wastes are either sent to Hanford's Effluent Treatment Facility or treated to meet the acceptance criteria and processed as wastewater.

8.3.5 C Reactor Cocooning

In 1996, C Reactor was selected as the first Hanford reactor for cocooning due to the advanced deterioration of roof sections on the reactor building that would have required extensive and costly repairs. The C Reactor cocooning project involved placing the 46-year-old reactor into ISS. When the work was completed at the end of fiscal year 1998, the C Reactor became the first production reactor in the DOE complex to be placed in safe storage. The new, smaller, safer facility will shield the reactor's core from the environment for up to 75 years or until final disposition.

The cocooning effort at the C Reactor involved reducing the size of the 60,000-square-foot reactor building by more than 80%. Much of the demolition work in the interior of the reactor building focused on removing equipment such as 29 vertical safety rod lifting assemblies. Once the assemblies were removed and housings penetrating the reactor core were sealed, three stainless steel hoppers containing HEPA filters were installed to trap any potential contaminants vented from the reactor core as it naturally "breathes." Workers also removed more than 6,400 cubic feet of asbestos; 630,000 pounds of materials contaminated by low-level radiation; 115 tons of steel and copper; and 50,000 gallons of contaminated water.

Removing the reactor's fuel transfer pits posed a major technical challenge. Some of the pits held sediment from the fuel storage basin floor and contained significant quantities of plutonium. Through sampling, it became clear that any movement of the sediment caused the plutonium to become airborne, creating serious risks to worker safety. The removal option chosen was based on the lowest radiological exposure to employees and cost. Employees poured a concrete cap over the sediment in the transfer pit. All surrounding structures were demolished, and the monolith that was created was then cut to a 12-foot cube. It was removed in two 70-ton lifts and transported for on-site disposal.

In 1998, the cocooning of C Reactor was completed in just over two years for $27.8 million. The reactor "footprint" was reduced by 81%. The one remaining door was welded shut, to be opened only once every five years for an internal physical inspection. In the meantime, sensors and a television camera monitor the interior.

In 2003, workers entered C Reactor to make the first five-year inspection and found it about the same as they had left it. The team used a new high-resolution digital camera with newly developed software that enables the creation of 360-degree photographs. These photographs were used to develop a virtual tour of the interior for future comparison. This recent surveillance of C Reactor confirmed that cocooning creates a safe, environmentally secure structure while significantly reducing S&M costs.

8.3.6 Lessons Learned: Five Reactors Complete and One In Progress

The lessons learned from the D&D work on C Reactor allowed the DOE contractors to develop efficiencies that allowed them to complete DR Reactor ISS for nearly half the cost of C Reactor. Similarly, the work at F, D, DR, and H Reactors was completed for significantly reduced costs and required less time. Cocooning of the N Reactor started in February 2006 and is on track for completion well before the scheduled due date of September 2012.

8.3.6.1 Reactor Cocooning Costs

As shown in Table 8-2, the actual or projected costs for cocooning the eight reactors range from a low of about $14 million to a high of about $31 million. In some instances, the variation results from the fact that some of the reactors had more ancillary facilities or from the fact that problems were encountered, primarily with the fuel storage basins. All things being equal, the costs generally decreased, in many cases significantly, as lessons were learned from the previous reactor cocooning projects. Cost savings resulted from operating efficiencies that resulted from eliminating unnecessary duplication of management at multiple project sites, subcontracting for multiple scopes of work, and from retaining an experienced workforce. Cost avoidances were also realized from not requiring demobilization, remobilization, workforce reductions, and retraining of a new workforce when the next project started. To date, five of the nine Hanford retired production reactors have been successfully and cost-effectively cocooned.

8.3.6.2 New and Innovative Technologies Used for Reactor Cocooning

The Hanford reactor cocooning project provided a test bed to demonstrate new and innovative D&D technologies that had the potential benefit of lower life-cycle costs, accelerated schedules, and reduced worker exposure, among others. Innovative technologies were identified and evaluated in the areas of characterization, decontamination, dismantlement, demolition, waste minimization and disposal, facility stabilization, and worker health and safety. The technologies were competitively selected using a "market search" approach where the project presented problems to industry responded with ideas for innovative technologies and/or new application of existing technology. The technologies used at the reactors have been added to the Hanford decommissioning toolbox and have been deployed on other DOE projects around the United States. Some of the technologies developed or enhanced as part of the reactor cocooning project are as follows:

- Controlled Explosive Demolition—Used to demolish stacks and very thick concrete walls
- Remote Retrieval System—Track-mounted, remote-controlled retriever
- Compact Remote Console Deployment—Used to control the Remote Retrieval System for cleanout of the fuel storage basins
- In Situ Object Counting System—Used to find/characterize irradiated fuel and other contaminated materials that have been covered over or buried prior to D&D activities
- GammaCam—Used to find/characterize irradiated fuel and other radioactive materials that have been covered over or buried prior to D&D activities.
- Track-Mounted Shearing Tool
- Diamond Wire Saw—Used to cut large pieces of heavily reinforced concrete.
- Demolition Ram—Hoe-ram used to demolish concrete
- Auto Demolition Dust Suppression System—Used to control dust generated by a concrete demolition ram
- Andros Robot—Used to deploy radiological or chemical characterization instruments in areas unsuitable for manned entry
- Long-Handled Tools
- Rock Splitter—Hydraulic ram or wedge used to split or fracture rock or concrete in limited-access areas

- Arc Saw—Toothless circular saw that cuts through metal using electric arc technology instead of mechanical blade sawing
- KT-15 and KT-30 Remote Excavation and Dismantling Machines—Track-mounted, mobile, telescopic boom-type machines that can be equipped with a variety of attachments to perform demolition work

8.3.7 Final Reactor Disposition Alternatives

After cocooning is completed for each of the surplus production reactors in 2012, the reactors will remain in ISS for up to 75 years until final disposition. The three final disposition alternatives being considered include one-piece removal, dismantlement, and in situ decommissioning. It is expected that the final disposition decision of the reactors will not be made until near the end of the ISS period, which ends in 2068. The final reactor disposition decision is being deferred to allow DOE to take advantage of new information or technologies that may be identified in the future that could significantly change the final disposition decision.

8.3.7.1 One-Piece Removal

One-piece removal involves transporting each reactor block intact on a tractor transporter, from its present location in the 100 Areas to the 200 West Area burial grounds for disposal, a distance of about 8–22 km (5–14 miles), depending on the reactor. The reactor block portion that will be transported includes the graphite core, the thermal and biological shields, and concrete base. Each SSE enclosing the reactor core would be removed.

The Final EIS (1992) estimated that the one-piece removal process would take about 2.5 years for each reactor. Based on a staggered schedule, one-piece removal for all nine reactors is estimated to take approximately 14 years. Following reactor removal, the site formerly occupied by the reactor will be backfilled, graded, seeded, and released in accordance with land-use requirements.

Based on escalation of the cost estimates presented in the Final EIS (1992), the estimated total cost for one-piece removal of all nine reactors is about $327.6 million in 2005 dollars.

8.3.7.2 Reactor Dismantlement

Reactor dismantlement involves piece-by-piece dismantlement of each reactor (including the graphite core) and transporting the radioactive wastes to the 200 West Area for burial. All contaminated equipment and components would be packaged and transported to the 200 West Area for disposal. Uncontaminated material and equipment would be released for salvage or disposed of in an approved landfill.

The Final EIS (1992) estimated that 6.5 years would be required for dismantlement of each reactor. Based on a staggered schedule, the entire dismantlement process for all nine reactors would take approximately 30 years to complete. Following reactor removal, the site formerly occupied by the reactor would be backfilled, graded, seeded, and released in accordance with land-use requirements. Based on escalation of the original cost estimates in the Final EIS (1992), the estimated total cost for dismantlement of all nine reactors is about $433.4 million in 2005 dollars.

8.3.7.3 In-Situ Decommissioning

In situ decommissioning involves preparing the reactor block for covering with a protective mound (barrier) and constructing the mound. Surfaces within the facility that are potentially contaminated would be painted with a fixative to ensure retention of contamination during subsequent activities. The voids beneath and around the reactor block would be filled with grout and/or gravel as a further sealant and to prevent subsidence of the final overburden. The roofs and superstructures of the SSE and concrete shield walls would be removed down to the level of the top of the reactor block. Finally, the reactor block, its adjacent shield walls, and the spent fuel storage basin, together with the contained radioactivity, gravel, and grout, would be covered to a depth of at least 5 m with a mound containing earth and gravel. The mound would include an engineered barrier designed to limit water infiltration through the barrier to 0.1 cm/year.

The Final EIS (1992) estimated in situ decommissioning of one reactor would take about 2 years. Based on a staggered schedule, in situ decommissioning of all nine reactors is estimated to take about 7 years. Based on escalation of the original cost estimates in the Final EIS (1992), the estimated total cost for in situ decommissioning of all nine reactors is about $336.3 million in 2005 dollars.

8.4 East Tennessee Technology Park, Tennessee: Equipment Removal and Building Decontamination

This case study is an overview of D&D operations performed at ETTP in connection with the actions taken on Building K-29, K-31 and K-33. Information on these actions is largely contributed from the RA Report for K-29, K-31 and K-33. This case study presents a much greater amount of information than the prior three case studies, in large part because it involved the D&D of three buildings managed under one project and also involved the disposal of wastes that were produced by other site cleanup operations and had been temporarily stored in the buildings.

8.4.1 Background

Equipment removal and building decontamination has been performed for Buildings K-29, K-31, and K-33 at ETTP as part of a non-time-critical removal action under CERCLA. The three buildings used the gaseous diffusion process to enrich uranium and were contaminated from past operations with uranium and other hazardous substances. This removal action, which was implemented as part of the ETTP Three-Building D&D and Recycle Project, mitigated the threat of release and reduced the potential health and environmental risks from exposure to radiation and hazardous substances present in these buildings.

Buildings K-29, K-31, and K-33 had not been used since 1987 but remained structurally sound. Although the contaminants were contained within the buildings and the current risk to the public and the environment was negligible, the probability of a future contaminant release to the environment would have increased as the buildings aged, due to inevitable structural failure.

Therefore, some action was necessary to address the contamination. A secondary (non-CERCLA) reason for DOE to empty the three buildings of all process equipment and hazardous materials was to prepare the three buildings, totaling more than 4.5 million cubic feet of industrial space, for potential reuse by industry.

DOE documented its decision to clean up the three buildings in an AM signed September 30, 1997 (DOE 1997). DOE implemented the cleanup decision consistent with CERCLA, in accordance with the provisions of the 1992 FFA for the Oak Ridge Reservation, and with concurrence from EPA and Tennessee Department of Environment and Conservation (TDEC). The removal action was originally intended to accomplish the following for Buildings K-29, K-31, and K-33:

- Remove all process equipment and materials from the three buildings.
- Decontaminate the interior of buildings to specified end-point criteria.
- Perform S&M during the length of the project.
- Dispose of all waste.
- Decontaminate and recycle materials where economically practical.

Additional work to be performed as part of the removal action included the removal and disposal of all equipment from the K-31/K-33 Switchyards, the >20,000 pond waste drums, Portsmouth soil drums, and other LLW containers in interim storage in Buildings K-31 and K-33.

The primary changes to the removal action that occurred over the life of the project include the following:

- Decontamination to specified end-point criteria was not fully accomplished for the three buildings.
- The PCB and radiological end-points were modified.
- Recycling of scrap metal was suspended on July 13, 2000 by the Secretary of Energy.

The project duration was slightly over 8 years, and the cost was approximately $356 million. The work completed has significantly lowered the risk to the workers, the public, and the environment. DOE's principal contractor for the D&D was BNG America (formerly known as BNFL Inc.). A fixed-price contract for implementation of the removal action was awarded to BNG America in August 1997. The project was completed with a "very good" overall safety record.

The amount of material removed and disposed amounted to more than 160,000 tons. A total of 80% of the waste was shipped either to EnviroCare of Utah or to the NTS for disposal. More than 10,100 waste shipments were made to these two facilities. More than 800,000 total lifts were made in dismantling, disassembling, and shipping involving this material.

At the time of publication, radiological decontamination of Buildings K-31 and K-33 was approximately 98% and 85% complete, respectively. DOE is validating the final radiological status of the surfaces. However, sampling also indicates surface and volumetric PCB contamination in the buildings. The radiological and PCB contamination are not necessarily co-located. PCB contamination is primarily on the Operations Floor, whereas radiological contamination affects more surface area on the Cell Floor. Information as to the extent of the residual contamination in Buildings K-31 and K-33 will be used by DOE to evaluate future reuse options for those buildings. The K-29 Building was not decontaminated to meet the end-point criteria by direction of DOE. DOE judged that it was in the best interest of the government at this time not to complete certain work established in the AM. The work that was not completed, for reasons discussed below.

- Approximately 5000 tons of contaminated nickel barrier material extracted from the converters in Buildings K-29, K-31, and K-33 was not recycled as originally envisioned. Instead the material was placed in storage until its future could be considered further. The material was not recycled because of DOE's continuing moratorium on the release of recyclable metal from radiological areas.

- The smallest of the three buildings, Building K-29, was not decontaminated though all of the equipment and material were removed and disposed (the only exception is the nickel barrier material that was removed and stored as indicated above). DOE reevaluated the original decision to decontaminate Building K-29 because the building was extensively contaminated, resulting in increased D&D cost, and there were concerns about its long-term structural integrity. Taken together, these factors would have significantly limited its reuse potential. As part of a separate project, DOE demolished the K-29 Building and is currently packaging and disposing of the demolition waste.

- Buildings K-31 and K-33 were not completely decontaminated to the end-point criteria. All work and expenditures toward further decontamination of Building K-33 have stopped, pending a determination of the reuse potential of the cleaner K-31 Building. The K-33 Building will be safely maintained until its ultimate disposition is decided. Further decontamination of the K-31 Building may occur, depending upon the results of a sampling and risk assessment effort designed to determine its suitability for reuse.

8.4.2 Description of Facilities

8.4.2.1 ETTP

ETTP is part of the Oak Ridge Reservation in East Tennessee. Known as "K-25" during World War II and then as the Oak Ridge Gaseous Diffusion Plant (ORGDP), it supplied enriched uranium for nuclear weapons production as part of the Manhattan Project. Construction of the site began in 1943, and the K-25 Building, the first diffusion facility for large-scale separation of uranium-235 (^{235}U), was fully operational by August 1945. Weapons-grade uranium was produced by enriching uranium in the ^{235}U isotope using the gaseous diffusion process, which was based on the principle that gases of different molecular weights diffuse at different rates through porous barriers. The gaseous diffusion process entailed pumping gaseous uranium hexafluoride (UF_6) through equipment containing porous barrier media. The lower-molecular-weight uranium-235 hexafluoride ($^{235}UF_6$) molecules have a higher molecular velocity and diffuse more readily through the barrier pores than the uranium-238 hexafluoride ($^{238}UF_6$)

molecules. Consequently, the fraction of the gas that passes through the barrier is slightly enriched in the ^{235}U isotope, and the gas that does not is slightly depleted in ^{235}U. Obtaining the ^{235}U enrichments achieved in the fully operable ORGDP equipment, required thousands of separate barrier elements, thousands of feet of piping to carry the UF_6, and thousands of pumps to propel the gas.

8.4.2.2 Three Process Buildings

The three process buildings (K-29, K-31, and K-33 Buildings) are located inside the security fence in the northwestern portion of ETTP. The buildings lie within the Poplar Creek watershed and are well above the 10,000-year flood elevation of the creek.

The three process buildings were similar in purpose (enrichment of uranium by gaseous diffusion) and general configuration. They are two-level concrete and steel buildings with built-up tar and gravel roofs. The gaseous diffusion process equipment was installed on the Cell (upper) Floor. The Operations (lower) Floor previously housed the process support equipment, including lubricating oil equipment, coolant equipment, electrical switchgear, and the seal exhaust equipment.

The three process buildings were originally designed and built to house the low-enriched uranium (LEU) part of the ORGDP cascade. LEU is less than 20% ^{235}U by weight. During ORGDP operations to support highly enriched uranium (HEU), peak enrichment level in the cascade was 12.65% for the K-29 Building, 6.2% for the K-31 Building, and 2.5% for the K-33 Building. With the termination of HEU production in the K-25 and K-27 process buildings, the K-29, K-31, and K-33 process buildings continued until 1987 to produce LEU with a peak ^{235}U enrichment of 4.9% for the K-29 Building, 2.9% for the K-31 Building, and 1.7% for the K-33 Building. ^{235}U in natural uranium is about 0.7%.

Buildings K-29 and K-31 were placed in operation in 1951, and K-33 Building was placed in operation in 1954. Major components of the process equipment (converters and compressors) in K-33 and five of the six units of equipment in K-31 were removed, decontaminated, rebuilt, and reinstalled as part of a Cascade Improvement Project (CIP) and Cascade Upgrade Project (CUP) completed in 1981. Deposits in K-3l and K-33 process equipment involved in the CIP-CUP program were accumulated between 1975 and 1985, as cells were returned to service.

Due to the declining demand for enriched uranium, the three LEU process buildings were placed on standby in 1985 and then designated as permanently shut down in 1987. Between 1987 to 1997, the buildings and process equipment were maintained in a shutdown state. Activities were limited to routine S&M, storage of various types of waste containers (including mixed waste), and the occasional removal of process equipment items for shipment to one of the operating gaseous diffusion plants. In 1989, the Oak Ridge Reservation, which includes the ETTP, was placed on the NPL.

8.4.2.3 Building K-29

The K-29 Building is a two-story structure measuring 558 × 522 × 65 feet with approximately 13.5 acres of floor space on two floors. It is a steel frame building with reinforced-concrete floors. Cylindrical concrete columns supporting concrete beams support the first level. The roof support structure, consisting of exposed steel beams, girders, and trusses, is connected to exposed structural steel columns extending from the upper floor. The roof is a steel deck assembly. The building is constructed with concrete block walls on the lower floor (Operations Floor) and has sandwiched sheet metal siding on the upper floor (Cell Floor). The Cell and Operations Floors stand at 796 and 780 feet above mean sea level (msl), respectively, both well above the 10,000-year flood elevation at Poplar Creek Mile 3 (757 feet above msl). The first and second levels are essentially open areas with no major separating walls.

Three 10-ton and three 13-ton bridge cranes used to install and remove the process equipment serve the entire Cell Floor. The facility does not contain an elevator, but the Cell Floor is accessible by a vehicle door and ramp on the east side. The south side of the second floor contains hatches that extend over a vehicle alley. The cranes hoist material between the second floor and trucks in the alley below through these hatches. The outdoor vehicle alley extends along the length of the south side of the building.

The K-29 Building contained three process units. Each process unit had 10 cells with 10 process stages per cell, for a total of 100 stages in a process unit and 300 stages in the building. The gaseous diffusion process equipment, located on the Cell (upper) Floor, included axial flow gas compressors, stage gas diffusers, process piping, process valves, booster stations, and the coolant and recirculating cooling water piping systems. The interconnecting process gas piping was on the north side of the building at the Cell Floor level.

The design of the K-29 Building differed from that of the other two process facilities in that the individual equipment cells were not located in enclosures (housings).

The floors of the cell and operations levels are poured, reinforced concrete. The floor of the cell level has expansion joints throughout. There are multiple penetrations in the floor between cell and operations levels, including hatches, systems piping, cooling water, roof drains, sanitary sewer drains, and electrical cabling. There are inside stairways between the two floors for access. These stairways are located inside concrete and transite enclosures on the Cell Floor level.

8.4.2.4 Building K-31

The K-31 Building is a two-story structure measuring 1200 × 622 × 67 feet with a total floor area of approximately 32 acres. It is of steel column and beam construction with reinforced-concrete floors. Exposed steel columns supporting steel girders and beams support both levels. The roof support structure, consisting of exposed steel beams, girders, and trusses, is connected to exposed structural steel columns extending from the second floor. The roof is a steel deck assembly. The walls are constructed of corrugated asbestos-cement (transite) siding. The north exterior wall on the Operations Floor is constructed of concrete masonry block. The Cell Floor and the Operations Floor stand at 785 and 762 feet above msl, respectively, both above the

10,000-year flood elevation at Poplar Creek Mile 3.6 (759 feet elevation). The first and second levels are essentially open areas with no major separating walls.

Twelve l5-ton bridge cranes serve the Cell Floor, which has a 45-foot-high ceiling. An outdoor truck alley extends along the length of the building on the north side. A floor hatch under each overhead crane allows material to be lowered to trucks below. A freight elevator on the southeast corner provides vehicle access to the Cell Floor. The north alley has a railroad spur that runs the length of the building.

Individual groups of 10 diffusion stages, called cells, were located inside cell housings on the Cell (upper) Floor. The K-31 Building had a total of six process units each of which contains 10 cells having 10 process stages per cell, for a total of 100 stages in a process unit and 600 stages in the building. “A” and “B” booster stations were provided on the south side of the Cell Floor to pump both the enriched and depleted UF_6 to Building K-29 through a tie-line housing. A purge and evacuation station equipped with three dual-speed centrifugal pumps was located near the center of the floor. Several mezzanine levels were on the Cell Floor for access to the elevated freon condensers, large cooling water lines, UF_6 process pipes, and valves.

The Operations Floor, which has a 22-foot-high ceiling, contained the process control room, offices, maintenance shops, change house, and auxiliary equipment.

The floors of the cell and operations levels are poured, reinforced concrete. The floor of the cell level has expansion joints throughout. There are multiple penetrations in the floor between cell and operations levels, including hatches, systems piping, cooling water, roof drains, sanitary sewer drains, and electrical cabling. There are interior stairways between the two floors for access. These stairways are located inside concrete and transite enclosures on the Cell Floor level.

8.4.2.5 Building K-33

The K-33 Building is a two-story structure with a small basement. The building measures 1450 × 970 × 82 feet and has approximately 64 acres of floor space on two levels. The building is constructed with steel columns and beams, transite siding, and reinforced concrete floors. Concrete-encased steel columns supporting steel girders and beams support the second level. The roof support structure, consisting of exposed steel beams and girders, is connected to exposed structural steel columns extending from the second floor. The roof is a steel deck assembly. In 1982, the initial roof covering was removed down to the bare metal and, as far as practical, was replaced with materials meeting the specification for Factory Mutual (FM) Class I. The Cell and Operations Floors stand at 794 and 765 feet above msl, respectively, both above the 10,000-year flood elevation at Poplar Creek Mile 4 (approximately 761 feet elevation). The first and second levels of the building are basically open areas with no major separating walls.

The following cranes were located approximately 40 feet above the Cell Floor:

- ten 40-ton process equipment cranes
- one 20-ton process equipment crane

- five 10-ton condenser cranes
- five 15-ton condenser cranes

Large equipment accessed the building by outdoor truck alleys along the north and south sides. Hatchways in the Cell Floor, under the overhead cranes, provide access to the truck alleys below. The north and south alleys also contain a railroad spur along the width of the building. A freight elevator on the east side provides access to the Cell Floor for maintenance vehicles and materials. The K-33 Building consists of 8 units with 10 cells per unit and 8 process stages per cell for a total of 640 stages. The process equipment located on the Cell Floor was enclosed in insulated sheet metal and transite cell enclosures. Cell bypass piping ran above the Cell Floor and was enclosed in similar insulated enclosures. The Cell (upper) Floor has a 54-foot-high ceiling. Several mezzanine levels were on the Cell Floor for access to the elevated coolant condensers, large cooling water lines, UF_6 process piping, and valves.

Process support equipment was located on the Operations (lower) Floor. The Operations Floor had a 28-foot-high ceiling. It contained the process control offices, maintenance shops, change house, feed vaporization room, and auxiliary equipment.

Also contained on the Operations Floor were 20,000 drums of pond waste and Portsmouth soils from RCRA closures. Below the control room on the Operations Floor is a small basement area of 8500 square feet, consisting of three rooms and a perimeter corridor. Construction of this basement area is concrete and cement block.

The floors of the cell and operations levels are poured, reinforced concrete. The floor of the cell level has expansion joints throughout. There are multiple penetrations in the floor between cell and operations levels, including hatches, systems piping, cooling water, roof drains, sanitary sewer drains, and electrical cabling. There are 40 interior stairways between the two floors for access. These stairways are located inside concrete and transite enclosures on the Cell Floor level.

A UF_6 feed vaporization facility in the K-33 Building provided UF_6 vapor feed from electrically heated 2.5-ton cylinders to the process system. Major operation of the feed room was discontinued in 1962 when Building K-131 was converted to a UF_6 feed vaporization facility. At that time, the UF_6 inventory was evacuated from the feed room headers. ^{237}Np and ^{239}Pu fluorides contaminated the "reactor returns" UF_6, which was occasionally fed to the cascade. Between 1962 and 1985, 2.5-ton cylinders of UF_6 were occasionally fed at K-33 even though the main feed had been switched to 10-ton and 14-ton cylinders in the K-1131 steam-heated autoclaves.

8.4.2.6 Radiological Contamination

The principal hazard identified in the three buildings was the large number and mass of residual enriched-uranium compounds in the gaseous diffusion process equipment and piping that contained UF_6. These compounds, nominally nonvolatile uranyl fluoride (UO_2F_2), consist of mixtures of nonvolatile uranium fluorides and oxyfluorides. During enrichment operations (prior to 1985), in-leakage of humid air to the subatmospheric process equipment resulted in reactions with UF_6 and the formation of UO_2F_2 deposits. The presence of these residuals created a potential for nuclear criticality that required proper handling of material and other appropriate Nuclear Criticality Safety (NCS) controls regardless of enrichment level.

Feed material was predominantly nonirradiated uranium; however, during the lifetime of the facility the process also received limited quantities of recycled uranium from reactor fuel returns. A consequence of reactor fuel returns in feed material was the introduction of small quantities of fission products (e.g., ^{99}Tc) and activation products (e.g., ^{241}Am, $^{238/239/240}$Pu, and ^{237}Np, into the systems). Due to their physical behavior in the gaseous diffusion process, there was selective enhancement of the relative fractions of these radionuclides within the process equipment. Of particular note was the selective concentration of ^{99}Tc by the process.

As a result of maintenance activities and process equipment failures, some areas of the floor, walls, interior surfaces of ventilation systems, and other building surfaces were contaminated with uranium, technetium, and TRU. The technetium fluoride is relatively volatile, and it tended to diffuse or spread throughout the facility whenever it escaped from the process equipment. This diffusion was greatest in the K-29 Building because the K-29 process equipment was not enclosed with cell housings. The fluorides of Pu and Np, however, are not volatile at room temperature, and any releases tended to remain in localized hot spots near the point of release. Total contamination levels were highly variable, depending on the equipment or structure surfaces surveyed. Many vent pipes from process systems extend to the roofs of the buildings. Because some of these vents, such as those from the seal exhaust pumps, may have discharged uranium compounds, the roofs and the conductors to the storm drains may contain residual radioactive contamination. (Note: The exteriors of the buildings were outside the project scope.)

In February 1998, BNG America subcontracted with Radian International LLC to perform limited characterization of the three buildings. Results are summarized as follows:

- K-29: Results indicated 87% of surveyed surfaces on the Cell Floor and 55% of surveyed surfaces on the Operations Floor were contaminated in excess of 5000 dpm/100 cm^2. Contamination was primarily fixed to surfaces, with about 5% of the contamination being transferable. As anticipated, highest levels of contamination were associated with interior surfaces of process equipment and systems. No analyses for the radionuclide mix were performed; however, shielded beta measurements indicated a likelihood of high relative levels of ^{99}Tc.

- K-31: Results indicated 39% of surveyed surfaces on the Cell Floor and 18% of surveyed surfaces on the Operations Floor were contaminated in excess of 5000 dpm/100 cm^2. The majority of contamination was beta-gamma and fixed. No analyses for radionuclide mixes were performed.

- K-33: Results indicated 19% of surveyed surfaces on the Cell Floor and 11% of surveyed surfaces on the Operations Floor were contaminated in excess of 5000 dpm/100 cm^2. The majority of contamination was beta-gamma and fixed. Exposure rates at several locations were significantly elevated, ranging to 450 µR/h; however, typical levels were indistinguishable from background. No analyses for radionuclide mixes were performed.

During BNG America's final status survey process in 2004–2005, 125 samples of residual surface activity were collected from overhead surfaces in K-31 and K-33 Buildings. An evaluation of these and earlier sampling results showed that radioactive contamination on lower (<2 m above the floor) surfaces was predominantly uranium, whereas on overhead surfaces (>2 m above the floor), conservative activity ratios were 50% uranium and 50% ^{99}Tc for the Cell Floor and 80% uranium and 20% ^{99}Tc for the Operations Floor. The ^{99}Tc contamination was primarily fixed and not easily removed.

8.4.2.7 Chemical Contamination

Nonradiological hazardous materials were also present throughout the three buildings. ACM was present in a number of different building components and materials of construction, such as insulating material, adhesives in floor and ceiling tiles, and roofing materials. PCB oil storage and transfer systems were used to support the electrical systems during plant operation. Prior to the removal action, small quantities of PCBs were known to be present as surface contamination on floors. PCB-impregnated gaskets were present in the exhaust ductwork, which contributed to building contamination. In K-31 Building, for example, PCB contamination appeared widespread, with 36% of the oil-stained floor area above the 10 µg/100 cm^2 criterion for nonrestricted access (40 CFR Pt. 761.125). The PCB contamination in Buildings K-29, K-31, and K-33 is identified and discussed in the Oak Ridge Reservation Polychlorinated Biphenyl Federal Facility Compliance Agreement (August 19, 1997; Rev. 2).

The old electrical systems also incorporated several hundred sealed switches containing metallic mercury. There were also battery acids, water treatment chemicals, and other hazardous/toxic agents associated with specific equipment and activities previously performed in the buildings, such as high metals content in paints on equipment and structures. Be-contaminated waste material was introduced on the K-29 Operations Floor during legacy waste sorting and segregation. The waste material was cleaned up under a legacy waste project in 2004. (Note: Be was never a contaminant directly associated with the historic gaseous diffusion process.) K-31 and K-33 Buildings were being used to store drums of pond sludge that were mixed waste, uranium, and ^{99}Tc-contaminated materials, and PCB-containing capacitors.

A pressurized evaporative cooling system containing dichlorotetrafluoroethane (CFC-114) coolant was used to remove heat from the UF_6 process gas stream via a cooler in the converter and a water-cooled condenser where the heat was transferred to the recirculating cooling water system. The CFC-l14 inventory (approximately 5 million pounds) has been removed and transferred to operating gaseous diffusion plants.

Recirculating lubricating and hydraulic oil systems were provided for the process compressor bearings and the stage control valves in each building. When enrichment operations were shut down, the inventories of these systems were drained to storage tanks on the Operations Floor.

8.4.2.8 End-Point Verification

DOE was to independently certify, through the Independent Verification Organization (IVO), that the end-points for the facilities had been met as specified. Additionally, DOE was to verify throughout the D&D process that materials removed from the buildings were appropriately dispositioned and met all specified regulatory requirements.

Upon completing D&D activities, the contractor was to certify and notify DOE in writing of completion of contract requirements for the associated buildings. Validation activities were to ensure that the performance specifications/project end-point condition (EPC) had been met. These actions were to be completed no later than 120 days after the D&D contractor declared the process complete and were to include all work plan modifications, sampling and analytical results, and a final report.

8.4.3 Post-Action Memorandum Changes to Removal Action

8.4.3.1 K-29 Building Decontamination

The AM required that the building be decontaminated to meet specific radiological and chemical end-points. DOE's contract with BNG America was modified in September 2003 to remove decontamination of the K-29 Building from the overall scope and to delete original building end-points for achieving residual radiological and hazardous materials. In addition, BNG America was not required to remove and dispose of any remaining concrete foundations/pedestals associated with the process systems on either the Cell or Operations Floors in the K-29 Building. At that time, it had been decided K-29 would not be targeted for reuse as an industrial site and that the entire structure would be ultimately demolished under a separate DOE action. The primary reasons for this demolition decision were that the K-29 Building had (1) the least amount of space for leasing/reuse of the three buildings; (2) the highest levels of surface contamination, particularly ^{99}Tc; and (3) some structural integrity concerns.

As a corollary to the above decision, the BNG America contract was again amended in January 2004 to allow sorting and segregation operations of legacy waste from other DOE Oak Ridge Operations activities, using portions of the space on the K-29 Operations Floor. The as-left radiological conditions in the legacy waste processing area were to be compared to preproject conditions to confirm that new contaminants (in addition to those originally present) had not been introduced by the legacy waste operations. Legacy waste operations did not significantly change the nature and extent of contamination in the legacy waste processing area.

8.4.3.2 K-31 Building Decontamination

The AM required that the building be decontaminated to meet specific radiological and chemical end-points. This issue will be discussed further in Section 8.4.8, which explains that the vast majority of the K-31 Building does meet the radiological end-points but that a number of small, localized hot spots (typically 1 m^2 or less) still exist, even after repeated decontamination attempts.

8.4.3.3 K-33 Building Decontamination

The AM required that the building be decontaminated to meet specific radiological and chemical end-points. The storage of wastes in one portion of the K-33 Building at DOE direction prevented the decontamination of that portion of the building. No decontamination was allowed in the storage area, including the ceiling above the storage area.

Although most (85%) of the building interior meets the radiological end-points, there are areas remaining with contamination levels exceeding the end-points, even after repeated decontamination attempts. Section 8.4.8 describes the nature and extent of residual contamination.

8.4.3.4 Recycling

The AM indicated that the removal action included the removal, collection, and transportation of process components, piping, and equipment to the private sector for recycling and processing for reuse. However, recycling of scrap metal was suspended in accordance with a Secretary of Energy memorandum issued July 13, 2000, which directed suspension of release of scrap metals from radiological areas into a “free-release,” open-commerce path. Prior to this recycling moratorium, relatively small quantities of some materials had been recycled through appropriate commercial markets.

8.4.3.5 Radiological End-Point

The radiological EPC in the AM requires that the building floors, walls, ceiling, and remaining equipment have less than the surface contamination levels acceptable for free release cited in DOE Order 5400.5 supplemented with NRC Regulatory Guide 1.86. Implementation of the generic 5400.5 surface contamination guidelines proved to be more difficult and costly than anticipated during planning due to the activity levels and distribution of ^{99}Tc in the upper elevations. Therefore, the radiological EPC was changed to the following:

- Surfaces up to 2 m from the floor elevation on the Operations and Cell Floors in the K-31 and K-33 Buildings should have less surface contamination than the levels acceptable for unconditional release cited in DOE Order 5400.5 supplemented with NRC Regulatory Guide 1.86.

- Overhead surfaces, or surfaces greater than 2 m from the floor elevation on the Operations and Cell Floors in the K-31 and K-33 Buildings, would meet supplemental dose-based limits in place of the surface activity guidelines for unconditional release from DOE Order 5400.5. The overhead surfaces include structural steel and components greater than 2 m above the floor surface, including cranes. The supplemental limits for the building overhead surfaces were developed so that the potential dose from these sources will not exceed 2 mrem/year. The 2 mrem/year dose constraint for overhead surfaces is well within the 100 mrem/year guideline found in DOE Order 5400.5, satisfies “as low as reasonably achievable” (ALARA) criteria, and is protective of an expected future building occupant, the warehouse worker.

- All surfaces below 2 m would be cleaned of removable contamination to less than or equal to 20% of the total activity limit specified in DOE Order 5400.5 supplemented by NRC Regulatory Guide 1.86. Surfaces above 2 m would have a removable contamination limit of 1000 dpm/100 cm^2.

The justification for developing the supplemental limits for the overhead surfaces is as follows. The isotopic ratio of contaminants of concern in the overheads is heavily weighted to ^{99}Tc, whereas uranium isotopes are the predominant radionuclides on other building surfaces. ^{99}Tc and uranium isotopes have very different characteristics with respect to potential dose to building occupants. The ^{99}Tc contamination on overhead surfaces was found to be predominantly fixed and not easily removable.

The supplemental limits will significantly reduce the industrial safety risk to workers performing decontamination and final status survey tasks in the building overheads. The reduction in occupational (nonradiological) risk to decontamination workers is estimated to be 78%. The physical complexity and high elevation above floor level of the overhead structural steel and ceiling network contribute to the high level of industrial safety risk associated with decontamination work in the overheads. Thus, implementation of the supplemental limits would decrease the potential health risk to the most likely receptors.

Use of supplemental limits will significantly reduce the cost of the project. Cost savings are estimated at $95 million. The unit cost associated with decontamination of the overhead structures is approximately 3–4 times higher than that associated with floors and other more accessible surfaces, whereas the potential for exposure to future building occupants is lower. Overhead surfaces in these buildings have a collective surface area approximately 4 times the floor area.

8.4.4 Actions Common to All Three Buildings

Process and nonprocess equipment and materials were dismantled, reduced in size, and segregated. Process ventilation systems and scrap or damaged government equipment were also dismantled and removed. Decontamination of components was performed as needed to protect workers, permit metal recycling, and meet WAC. Uranium deposits were removed from equipment and systems and properly dispositioned. ACM was removed and properly disposed of. Equipment and materials were packaged, stored, and shipped to approved waste facilities for storage or disposal of the wastes. Disposition of equipment and scrap metal took advantage of recycling, reuse, or unrestricted release when possible and economically feasible.

Platforms, cell housings, and concrete foundations/pedestals were removed flush with the concrete floor. An exception is that a small number of pedestals remain in the K-29 Building (i.e., BNG America was no longer required to remove K-29 pedestals after September 2003 when it was decided that the K-29 Building would not be targeted for reuse). Concrete floor slabs were left in place. Structural steel and framework were left in place, and if damaged, repaired or replaced.

Portions of the fire protection systems, steam systems, and lighting systems necessary for accomplishing the project objectives, were left and remain in place. Also, selected systems and facilities remain, including overhead cranes, surveillance and security systems, sanitary water, portions of the electrical drops and lighting circuits (with necessary distribution system components and cables), potable water lines, rain water and waste line piping for the roof, and floor drainage. A mechanical maintenance building also remains in the K-31 Building.

8.4.5 Actions Unique to Buildings K-31 and K-33

The buildings are currently reduced to their structural components: floors, walls, columns, and ceilings. They are open from end to end, except for the stairwell houses, the stairs, and a few walk-in pits. An additional exception is the office/shower/shop facility located on the K-31 Building Operations Floor. Walls and ceilings of the office structure remain in place, but all interior materials and equipment have been removed. The D&D Workshop and the Supercompaction Facility in K-33 Building have been demolished.

The buildings are not environmentally controlled (e.g., no heating or air conditioning). Minor repairs such as the patching of holes, rehanging of doors, and repair of remaining systems have been made as required. Small openings in the concrete floor slab (up to 4 inches in diameter) were repaired by plugging them with foam material; larger openings were repaired with metal plates.

Where needed to remove contamination, floors have been scabbled, paint on structural steel has been removed, and steel surfaces have been ground. Transite panels found to be contaminated have been replaced. Radiological surveys show that almost all of the accessible, interior surfaces of the K-31 Building meet the modified radiological EPC, as modified by DOE. K-31 surfaces that exceed the EPC after two or more aggressive decontamination attempts have been identified. The areas that exceed the EPC are typically small, localized hot spots. For the K-33 Building, radiological surveys show that most of the interior surfaces meet the modified radiological EPC. However, the surfaces that exceed the EPC are much more extensive and numerous than in K-31 Building.

8.4.6 Key Components of the Removal Action

The project consisted of the following key components:

- project start-up and mobilization
- monitoring and maintenance
- equipment dismantlement and removal
- uranium deposit removal and fissile material storage
- metal decontamination
- building decontamination
- project closeout and demobilization

8.4.6.1 Project Start-Up and Mobilization

Project start-up and mobilization addressed the various administrative, logistical, and technical activities necessary for undertaking the actual removal and disposition of equipment and decontamination of building interiors. These activities included the following:

- establishing, furnishing, and equipping office and work space
- hiring project staff and negotiating labor agreements
- obtaining security clearances
- preparing plans (e.g., waste-handling plans, security plans, final status survey plans) and procedures
- procuring supplies and services
- installing information and communications systems
- obtaining permits
- characterizing baseline building conditions
- analyzing safety hazards
- connecting utilities
- installing access controls
- defining worker protection requirements
- developing training requirements and courses

8.4.6.2 Monitoring and Maintenance

Monitoring and inspection during D&D included activities such as asbestos inspection; identification of leak sources (e.g., roof, air, and sanitary water); fire protection equipment inspections; and testing, inspection, and preventive maintenance of the Radiation Criticality Accident Alarm System (RCAAS), building cranes, and air sampling systems. Additional activities included monitoring fissile material storage areas (FMSAs) and inspection of various waste storage areas. Personnel with appropriate experience and training performed each of these activities.

General maintenance activities included cleanup of boundary control station areas, trash cleanup, and moving of material. More specialized activities included maintenance of utility (e.g., electric, water, and sewer) systems inside the buildings, preventing roof leaks, controlling building security and access, emergency management services, and periodic inspection and maintenance of other building support systems (e.g., intrusion alarms and communications). Lighting and fire protection systems were maintained to the extent their preservation did not impede removal and decontamination operations. Personnel also performed major building maintenance and repairs of structural components and roofing. The ETTP Three-Building D&D and Recycle Project area was segregated from the other areas of ETTP by means of administrative or physical controls, or both, and the area was maintained clean and hazard free.

Specific repairs or facility upgrades included (1) replacement of more than 700 transite panels in Buildings K-31 and K-33, (2) addition of three cranes in K-33 Building, (3) installation of a new roof on the southeast corner of K-33 that had been damaged during a storm event, (4) replacement of expansion material found to be contaminated in floor joints and openings, (5) electrical supply upgrades to the building distribution systems, and (6) bridge crane system upgrades.

Stored wastes in K-31 and K-33 Buildings that were being managed under RCRA and TSCA requirements were removed and disposed of at DOE's direction.

8.4.6.3 Equipment Dismantlement and Removal

Process and process support equipment was removed from installed locations. Process equipment included axial-flow gas compressors; stage gas diffusers; process piping; process valves; booster stations; coolant and recirculating cooling water piping systems and associated tanks, pumps, miscellaneous equipment; and piping. This equipment was disassembled, if appropriate, to facilitate deposit removal, size-reduced if needed, and shipped off site for disposal or other use. Nonprocess equipment and piping was removed. This category includes all sanitary plumbing, compressors, hydraulic units, some fire protection systems, some electrical systems, HVAC systems, and miscellaneous equipment and piping, some of which contained ACM.

Activities included cutting the equipment free of the connecting piping and foundations, removing readily accessible uranium deposits, cutting process piping and moving it to suitable storage locations, and removing and storing process support equipment (e.g., R-114 heat exchangers and piping). Various advanced technology cutting tools, including specially built 480 V plasma-arc cutting torches, were used to complete the cascade component removals. Large cascade components were moved from place to place on the Cell Floor using the large, overhead cranes that had been rehabilitated. As uranium deposits were removed from process and process support equipment, they were placed in containers and stored in FMSAs in accordance with NCS controls pending final disposition. In addition, barrier tubes were removed from process equipment during equipment removal, size-reduced, and placed in sealed containers.

To prepare the equipment for shipping, equipment disassembly was conducted principally in the D&D Workshop, a facility of approximately 70,000 square feet of floor space, located in the southwest corner of the Cell Floor of K-33. Areas within the Workshop were kept under negative pressure to ensure confinement of airborne particles and fumes. Air was circulated through a ventilation system with HEPA filtration. Only a minimal amount of sizing was performed at the process equipment location. The D&D Workshop used automated and manual systems to size-reduce the equipment and pipes. Plasma cutting was the preferred means for size-reduction. The converter shells were disassembled; barriers were removed, shredded, crushed, and packed; and motors were dispositioned.

The Supercompaction Facility (K-903) was built by BNG America to support D&D activities. Facility construction commenced March 2000, and operation began January 2001. This facility compacted and containerized contaminated metal sections and other LLW to provide significant waste volume reduction and facilitate more economical off-site waste disposal operations. The process of compaction applied intense pressures, on the order of tons per square inch, to achieve substantial volume reductions. The facility accepted complete components such as coolers, compressor stators, valve bodies, and converter end caps.

The Supercompaction Facility was a stand-alone structure adjoining the south side of K-33 Building near its southwest corner and between the K-33 Building and the north curb of the central roadway between K-31 and K-33. The facility was in close proximity to the D&D Workshop and was connected to the K-33 Cell Floor by a rectangular “tunnel” or opening to allow feed materials for the supercompactor to be moved from a staging area in K-33 into the facility. The facility consisted of 18,000 square feet of building area and had a dedicated rail spur for receiving and dispatching materials. Compactor operations concluded in the fall of 2004, and the building and equipment were decommissioned and removed. The remaining concrete foundation pad remains and was decontaminated and surveyed.

8.4.6.4 Uranium Deposit Removal and Fissile Material Storage

Normal disassembly operations included visual inspections for accumulations or deposits of UO_2F_2 in the components. As these deposits were discovered, they were removed prior to continued processing based upon their accessibility at that time. All deposit material has been processed, packaged, and shipped to Envirocare of Utah.

Containers of size-reduced nickel barrier material generated during converter disassembly were placed in FMSAs. FMSA boundaries were marked and posted as required by the Nuclear Criticality Safety Approvals (NCSAs). The NCSAs also defined storage requirements for the fissile material containers. NCSA changes, including requirements imposed by the NCSAs, were controlled through a formal approval process.

8.4.6.5 Metal Decontamination

Equipment decontamination and recycling were conducted until fiscal year 2000, primarily at the Manufacturing Sciences Corporation (MSC) Kerr Hollow Road treatment facility, although visible uranium was removed to the extent practical before shipping. Typically, dry and mechanical decontamination methods were used within the facilities for equipment decontamination. Clean metal (i.e., with fixed surface contamination below the criteria specified in DOE Order 5400.5 and/or NRC Regulatory Guide 1.86) was released directly from the facilities. Materials were also screened for chemical contamination prior to release from the facilities.

8.4.6.6 Building Decontamination

Following completion of the removal of process and process support equipment, efforts were made to decontaminate the interior building surfaces to end-point levels. Decontamination included a variety of methods, including use of vacuum cleaners, chemical cleaning agents, scabbling of concrete floors, and removal and replacement of contaminated items (e.g., transite siding replaced with fiberglass or other suitable siding materials). Structural steel decontamination involved the removal of the lead-based paint with a commercially available paste designed to dissolve and capture the paint. Typically, when the lead-based paint was removed, the steel would meet EPC. If further decontamination was required, metal grinding was used without lead-abatement concerns. Any liquid wastes generated were disposed of in compliance with applicable regulations. Specific work instructions and instructional guides were prepared by project operations and technical managers to guide craft workers performing decontamination activities.

The building decontamination process began as areas were cleared of process equipment. Activities included removal of concrete pedestals through the use of diamond-wire cutting equipment, elimination of concrete debris from the cutting process, vacuuming and wiping of all surfaces from ceiling to floor, performing removable and fixed contamination surveys on all surfaces, and decontamination of areas identified as exceeding EPC. The amount of surface surveyed ranged from 10% to 100% based on characterization data. For areas surveyed at less than 100% coverage in which contamination above 75% of EPC was detected, increased coverage requirements were imposed in accordance with the DOE approved Final Status Survey (FSS) Plan (DOE 2006d).

These activities were selected to clean the surfaces and to verify the surfaces met the EPC and would pass DOE's independent verification. The FSS Plan provided all EPC in reference to all contaminants and was separately approved by DOE.

8.4.6.7 Project Closeout and Demobilization

Upon completion of equipment removal and building decontamination, cracks, holes, and other like defects in the building slabs resulting from equipment removal were filled, patched, and sealed. Final surveys of the buildings were performed to verify that the buildings meet the defined end-points and DOE's acceptance criteria for the removal action. Attainment of the EPC was documented in building completion reports submitted to DOE by BNG America. Contractor demobilization concluded after DOE's acceptance of the building certifications.

As part of the general project demobilization effort, the D&D Workshop has been dismantled and associated enclosures and equipment removed as radiological waste. Three new remote-operated 25-ton cranes were installed in 1998 and 1999 to support the D&D Workshop, one each in the existing bays of Cranes 9, 10, and 11. The workshop cranes and power supply, or Motor Control Center, were not dismantled but allowed to remain in K-33 Building to support reindustrialization of the facility.

The Supercompactor machinery also was disassembled and removed, and both the K-903 Supercompactor building and the crane-run building link were dismantled and removed from the site. New wall sections were constructed to close temporary openings from K-33 Building into the Supercompactor building. The l3-ton crane installed to support compactor operations was removed as part of the K-903 demolition.

8.4.7 Waste Management and Transportation Activities

8.4.7.1 Waste Volumes and Disposition

Table 8-3 provides a waste disposition summary indicating where the waste was sent, its estimated volume, and a general description of the waste. Table 8-4 provides the tonnage of waste shipped to the primary disposal facilities. The principal project waste disposal outlets for LLW were the EnergySolutions (formerly Envirocare) of Utah facility near Salt Lake City and the DOE NTS, north of Las Vegas. EnergySolutions, a commercial LLW/MW disposal facility, also received mixed wastes from the project. Relatively small quantities of LLW and/or mixed hazardous/PCB waste were disposed of at the TSCA Incinerator located at ETTP.

Table 8-3. Waste disposition summary for the ETTP Three Building D&D and Recycle Project

Disposition	Estimated volume (cubic feet)	Category	General description of material
Bechtel Jacobs	9	Scrap/reuse	Steel pallets
Berkhart Enterprises	25,864	Recycle	Concrete block
BFI/Stericycle	1	Waste	Medical waste
Chestnut Ridge	3,903	Waste	Concrete
Environmental Management Waste Management Facility	401,025	Waste	General LLW debris
Envirocare (EnergySolutions)	4,321,054	Waste	General LLW debris, PCB debris
Framatone	1	Waste	Misc. debris, metal
GE Power Systems	1	Waste	Fissile bucket material
GTS Duratek	4,530	Waste	Condenser parts
Harris WM Group	1,336	Waste	HVAC waste ductwork/metal
Kerr Hollow (MSC)	442,761	Scrap/reuse	Scrap metal material
Knox Metals	1,386	Scrap/reuse	Scrap metal
Nevada Test Site	1,855,585	Waste	Converter waste, motors
On-site use	708	Scrap/reuse	Rubblized concrete[a]
Paducah	32,047	Scrap/reuse	Motors, dry transformers, misc. equipment
Perma Fix—DSSI	800	Waste	Oil, water
Perma Fix—M&EC	704	Waste	Miscellaneous noncontract/secondary waste
PermaFix—Gainesville, Fla.	800	Waste	Oil, water, sludge
Phillips Services	8,562	Scrap/reuse	Misc. scrap metal
Portsmouth	2,596	Scrap/reuse	Electric motors
R&R Electric	153,399	Scrap/reuse	Scrap metal
SC Electric and Gas	133	Scrap/reuse	HEPA vacuum system
Southern Alloys	13,043	Scrap/reuse	Scrap metal
TCI Alabama	36,748	Waste	Wet transformers
TN Metals	14,867	Scrap/reuse	Scrap metal
TOXCO	46,613	Scrap/reuse	190-ton, misc. equipment, cable, scrap
Trans Industries	25,026	Scrap/reuse	Misc. equipment, cable, scrap, dry transformers
Tri-State Steel Drum	12,000	Waste	Oil, water, aqueous waste, debris
TSCA Incinerator	9,696	Waste	Oils, PCB material, spill cleanup
USEC	1	Scrap/reuse	Radiation sources
Y-12	444	Scrap/reuse	One transformer for reuse
Y-12 Industrial Landfill	6,402	Waste	Sanitary concrete/debris
Total	7,422,045		

[a] Clean, rubblized concrete that was located in the area where the compactor was to be built was removed and spread out in the K-762 Switchyard to fill low spots.

Table 8-4. Waste quantities shipped to principal waste disposal facilities

Source	Disposition	Quantity (tons)
K-29, K-31, and K-33 Buildings and ancillary facilities	Environmental Management Waste Management Facility	20,508
	Y-12 Landfill	327
	Envirocare[a]	98,330
	NTS	17,009
	Recycle/reuse (e.g., motors, transformers)	24,591
	Subtotal	160,765
Stored wastes (e.g., drums of pond sludge)	Envirocare[a]	13,156
Switchyards	Envirocare[a]	4,615
Total		178,536

Source: DOE 2006d.
[a] Envirocare has been renamed EnergySolutions.

As previously mentioned, the release of recyclable metal from radiological areas was suspended by the Secretary of Energy memorandum issued July 13, 2000. For a period of time after July 13, 2000, based on the assumption that the suspension was temporary, DOE and DOE subcontractors accumulated large inventories of surplus material and property to preclude their direct release into commerce until the suspension was lifted. The material was picked up, transported, evaluated to estimate any residual value, processed, stored, and managed either as scrap or as surplus property. The material and property was sorted and segregated into lots that had residual activity (1) below or consistent with background radioactivity, (2) above background but below DOE 5400.5 unrestricted release requirements, and (3) above DOE Order 5400.5 unrestricted release requirements. However, because the suspension was never lifted and because it was no longer economically viable to continue managing the surplus material and property, DOE made the decision to dispose of it. Therefore, the potentially recyclable metal that had been accumulated was disposed of as LLW or MW.

Late in the project, some of the waste inventories were shipped to the Oak Ridge Reservation Environmental Management Waste Management Facility (EMWMF) in the Bear Creek Valley watershed west of the Y-12 complex. Waste disposed at this facility primarily consisted of concrete scabbling waste materials and concrete from pedestals/pads. Table 8-5 summarizes the waste lots sent to EMWMF.

Nonradioactive hazardous wastes and PCB wastes from the project were disposed of at licensed commercial facilities. Nonhazardous, nonradioactive, non-PCB solid wastes, including properly packaged ACM, were usually disposed of at the Y-12 Sanitary Landfill.

Table 8-5. EMWMF waste lot summary for ETTP Three Building D&D and Recycle Project

Item	WL 8.2[a]	WL 8.5	WL 8.7	WL 8.8	WL 8.11
Waste stream	K-33 concrete pedestals	K-31/33 compressor blades	K-31 concrete pedestals	K-33 concrete floor scabble	Nonprocess gas/nonfissile components
Approval date[b]	April 9 2003	January 29 2004	October 22 2003	December 23 2003	April 8 2004
Approved volume (cubic feet)	203,877	27,000	89,100	72,900	59,724
Expected carcinogenic sum of fractions	0.02	0.8	0.02	0.1	0.3
Expected hazard index sum of fractions	0	0.1	0.001	0.003	0.03
Principal contaminants					
^{238}U frequency (detects/samples)	72/72	3/3	18/18	69/69	10/10
^{238}U maximum concentration (pCi/g)	5	371	3.81	18	264.5
^{99}Tc frequency (detects/samples)	72/72	3/3	18/18	69/69	10/10
^{99}Tc maximum concentration (pCi/g)	5	122	54.11	131	264.5

[a] WL = waste lot.
[b] The approval date refers to the EMWMF Waste Acceptance Criteria Attainment Team approval of the waste lots.

During the removal action, approximately eight small sample/test cylinders were found. These small cylinders have been characterized and have been stored in a drum in the K-33 Building. DOE is considering disposition options for the cylinders, including shipment of the cylinders to Portsmouth in conjunction with the UF_6 Cylinder Disposition Project. There is also a roughly 10 × 10 foot area in K-33 containing items identified and set apart for purposes of historic preservation. These items will be ultimately relocated to storage with other historic preservation items from the K-25 Building and other buildings at ETTP.

8.4.7.2 Waste Management Strategy

The project applied several overall waste management strategies. These strategies included (1) maximizing economic free release of reusable materials and recycling, (2) minimizing off-site disposal of waste streams, and (3) minimizing waste generation from decontamination. These strategies and their implementation were provided in the project waste management plan for stored wastes, primary waste streams, and secondary wastes.

Stored wastes in Buildings K-31 and K-33 included mixed-waste pond sludges, originally removed from the K-l407-B and -C ponds; PCB-contaminated soils originally from the Portsmouth Gaseous Diffusion Plant site; and solid LLW from Oak Ridge National Laboratory, Y-12, and ETTP facilities. These stored wastes were removed by DOE and properly disposed.

The primary waste streams are categorized as (1) uranium deposits, (2) remainder materials and fluids, (3) process equipment and piping, (4) nonprocess equipment and piping, and (5) structural and architectural components. To the extent practical, primary wastes typically were segregated by waste stream.

Secondary wastes, which are virtually insignificant relative to the primary waste stream being processed, were minimized throughout this project. Decontamination efforts attempted to use the minimal amount of solution necessary to adequately decontaminate the area. Hoods and HEPA ventilation in the facilities and the disassembly areas controlled air emissions. Proper segregation of materials and spent decontamination solutions also minimized wastes requiring commercial disposal.

Whenever economically practical, scrap metal was unconditionally released for recycling. These materials, such as steel released to scrap metal companies, met surface release criteria for radionuclides. Criteria from DOE Order 5400.5, supplemented by NRC Regulatory Guide 1.86 for surface contamination, were used for releasing materials. From Tables 8-3 and 8-4, it can be estimated that only 10% of the total volume or 15% of the total weight of material taken from the three buildings was designated for "scrap/reuse."

If a reusable material exhibited radiological surface contamination above the surface-release criteria and could be decontaminated cost-effectively, it was decontaminated and then surveyed for free release. If decontamination was not effective, the material was compacted, packaged, and transported to a licensed LLW disposal facility. If materials met release criteria that complied with regulatory standards, commercial recycling was used.

Stored Waste

No wastes were stored in the K-29 Building at the start of D&D. Table 8-6 lists the location and quantities of stored wastes in Buildings K-31 and K-33, which were removed and handled as discussed below.

Table 8-6. Wastes stored in Buildings K-31 and K-33

Building	Number of containers	Type of containers	Approximate volume (cubic feet)	Waste
K-31	18,700	89- and 96-gal drums	231,600	Pond sludges—mixed waste solid
K-33	26,000	89- and 96-gal drums	320,800	Pond sludges—mixed waste solid
K-33	2,388	55-, 85-, and 110-gal drums	33,200	Portsmouth soils—PCBs
K-33	168	B-25 boxes	16,100	Solid LLW

Sources: Pond sludge information from DOE 2006d. Portsmouth soil information from BNFL contract amendment A011 signed November 3, 1998.

Pond Sludges. The K-1407-B and -C Ponds were used by ORGDP as holding and settling ponds. As part of pond closure in 1988, the mixed waste sludge (RCRA and radioactively contaminated sludge) was removed, mixed with fly ash and cement, placed in 89- and 96-gal steel drums, and stored outside on an asphalt storage pad. On September 30, 1992, a RCRA Part B Permit (Permit Number TNHW-56) was approved that allowed storage of the drums in Waste Pile Units located in Buildings K-31 and K-33 (a small fraction of the drums were also stored in

K-1065). This hazardous waste was inspected and repackaged (overpacked) as required. Eventually, the waste was shipped to Envirocare of Utah, Inc. (now EnergySolutions) for disposal, and closure activities were initiated for the Waste Pile Units. Shipment of the drums to Envirocare began in November 1998, and the last shipment was completed in February 2000. As part of the management and operations contract with DOE, Lockheed Martin Energy Systems (LMES) shipped approximately 60% of the containers, and then BNG America shipped the remainder. BNG America shipped 7,497 drums from K-31 and 10,034 drums from K-33. On March 15, 2000, DOE notified TDEC of its intent to close the Waste Pile Units in K-31 and K-33. On February 9, 2001, DOE submitted a Notification of Implementation of Class 1 Permit Modification to the RCRA Part B Permit. The Class 1 modification was to remove BNG America as co-operator of the Waste Pile Units and to remove K-31/33 Waste Pile Units from the permit. Documentation and details of the Waste Pile Units closure are in the RCRA Closure Certification Report.

Portsmouth Soils. Drums containing Portsmouth soils were inspected for structural integrity before moving and loading onto railcars or trucks. These soils were LLW that was slightly contaminated with PCBs at an average concentration less than 50 ppm. The drums of soil were shipped to Envirocare.

Solid LLW. The LLW stored in B-25 boxes in the K-33 Building were characterized by NDA, and the B-25 boxes were inspected to ensure conformance to DOT shipping requirements. Any boxes exceeding the radiation levels allowed by DOT or the disposal facility WAC were opened and repackaged. The B-25 boxes of LLW were shipped to Envirocare.

Primary Material and Waste Streams

Described below are the activities that occurred during the removal, reduction, decontamination, recycling, waste compaction, and/or disposal of ETTP building equipment and piping.

Uranium Deposits. The K-29, K-31, and K-33 process buildings were originally built to accommodate the low-enrichment portion of the ORGDP cascade. DOE used NDA techniques to determine the quantities and assays of ^{235}U remaining within the piping and equipment of the three buildings. Based on enrichments, these deposits could have had assays of up to 12.5% (K-29), 6.5% (K-31), and 2.5% (K-33). NDA showed that there were deposits that exceeded the maximum safe mass of ^{235}U and the maximum critical mass of ^{235}U at the measured enrichments of the deposits and that these deposits would have to be handled in a safe manner. Smaller deposits would also require safe handling. Uranium deposits removed as part of this project were secured at all times in accordance with the project Nuclear Material Control and Accountability (NMC&A) Plan.

BNG America performed the detection and removal of uranium deposits from within the piping, valves, converters, and compressors in all three buildings. After the equipment was opened or the piping was cut vertically down the middle, the workers removed the uranium with grinders and other tools, collected the uranium using criticality-safe vacuum methods into 1 gal (~3.79 L) containers and then placed the containers in storage in a criticality-safe geometry (i.e., approximately 2-foot spacing between containers). The ^{235}U gram content of each container was not allowed to exceed safe limits.

The content allowed BNG America to take ownership of the uranium and to then transfer ownership to an NRC Class-1 nuclear materials licensee or facilities operated under a United Kingdom Nuclear Installations Inspectorate Site License or equivalent International Atomic Energy Agency (IAEA)–regulated firm. Indeed, the original intent of BNG America was to reclaim the uranium as a resource rather than a waste and to ship the uranium to a qualified, licensed commercial vendor for processing and uranium recovery. However, none of the uranium was ever actually shipped to a vendor for reuse. After collecting several thousand containers over the life of the dismantlement and disassembly operations of the project, BNG America assayed the deposits and found higher than expected levels of chromium and selenium, which presented RCRA concerns. These concerns, combined with unsuccessful negotiations with potential vendors and the relatively low value (enrichment) of the uranium eventually persuaded BNG America and DOE to evaluate treatment and disposal options for the deposits instead of reuse.

Disposal of all recovered deposit material occurred at Envirocare. However, prior to disposal, the uranium had to be treated to meet shipping and disposal requirements. The result was a BNG America–proprietary treatment that down-blended the uranium with a grout in such a manner as to render the material fissile-exempt for shipment and acceptable for disposal as LLW.

Remainder Materials. As one of the initial steps in the equipment removal process, any materials/fluids remaining in the LEU process equipment or the building process systems were drained, segregated, and collected. Remainder fluids included process oils and lubricants, waste oils, PCB-contaminated oils, degreasers, hydraulic fluids, freon, and other miscellaneous fluids, some of which were contaminated with uranium. These remainder waste streams were dealt with during initial stages of the work—to the extent practical and safe—to minimize the potential for uncontrolled hazardous or toxic releases and cross-contamination of adjacent areas and equipment.

Recovered fluids were segregated by waste stream and containerized. The chemical and radiological waste compositions were ascertained using either process knowledge or sampling and analysis. Process knowledge-based methods complied with applicable regulatory requirements. The material was characterized and disposed as follows:

- If radiologically and PCB-contaminated, it was incinerated at the TSCA Incinerator or disposed of at Envirocare.
- If not radiologically contaminated but contained PCBs (solids and/or liquids), it was treated off site by a facility licensed to treat and dispose of TSCA wastes.
- If radiologically contaminated and contained RCRA wastes, it went to a licensed MW-disposal facility.
- If not radiologically contaminated but contained RCRA wastes, it went to a licensed treatment, storage, and disposal facility (TSDF).
- The removed, recirculating cooling water sludge was characterized and disposed of as RCRA hazardous waste, and other generated waste, such as ductwork gaskets and lead-paint chips, were disposed of as mixed waste or triple waste (i.e., RCRA, PCB, and radiologically contaminated).

- If not contaminated, it was recycled or disposed of at a solid waste landfill.

Process Equipment and Piping. All process equipment was removed. Most of the process equipment and piping was radiologically contaminated. Appropriate criticality safety measures were used during process equipment and piping removal activities.

Conventional brushing, wiping, and criticality-safe vacuuming were used to remove significant deposits from equipment as it was cut or decoupled. Deposits were weighed, containerized, and assayed using conventional methods and were secured according to the project NMC&A Plan.

A significant fraction of the equipment items and piping removed from the former process buildings was radioactively contaminated in configurations that rendered cost-effective decontamination and metal recycle infeasible. Some of this LLW material was also co-contaminated with RCRA hazardous waste constituents (i.e., was MW). This waste material was transported off site for disposal at appropriate NRC- or agreement state–licensed disposal facilities for LLW and, if hazardous constituent co-contamination was involved, at facilities also permitted as RCRA Subtitle C TSDFs.

After September 2000, as a means to dramatically reduce waste material transportation and disposal costs, these wastes were preprocessed in a new Supercompactor Facility that was constructed between K-33 and K-31 Buildings. It is estimated that the Supercompactor reduced the volume of contaminated bulk metal waste material from the project by a factor of at least 5, and perhaps by a factor as high as 10 in some cases.

Nonprocess Equipment and Piping. Equipment and piping not considered part of a process system were removed. Existing fire protection systems in the buildings were retained as long as they did not block equipment removal. Waste materials and fixtures historically known to contain mercury, lead, and PCB contamination were also removed and dispositioned. The duct system, known to be PCB-contaminated, was removed and disposed of at Envirocare. Prior to the moratorium, PCB-contaminated transformers were shipped off site to a licensed PCB recycling and decontamination facility, where the metal was recovered.

Underground piping/conduit and piping exterior to the building (e.g., tie lines between the process buildings) were excluded from the scope of work. These pipes were blanked-off at the point they exited the building or entered the slab. Areas where pipe had been blanked-off or left in place were appropriately marked to indicate that no treatment of these pipes had been performed.

Three significant types of ACM were abated in Buildings K-29, K-31, and K-33. These included surfacing materials, such as ACM sprayed or trowelled onto ceiling surfaces such as decorative plaster, acoustical ACM on the underside of concrete slabs or docking, or fireproofing materials on structural members. The second type was thermal system insulation, such as ACM applied to pipes, boilers, tanks, and ducts to prevent heat loss or gain or condensation. The third type consisted of miscellaneous ACM, such as asbestos-containing ceiling or floor tiles, textiles, and asbestos-cement panels, asbestos siding, transite panels, and roofing materials. At the switchyards next to K-31 and K-33 Buildings, abatement of ACM occurred within the powerhouses, as well as on insulated outdoor lines.

Abatement activities monitored for compliance with 29 CFR Pt. 1926.1101 included brake pad removal, buss bar wrap removal, electric cabinet top abatement, electric wire/gasket removal, glove bag pipe insulation abatement, pipe insulation abatement, spill cleanup, and Class I enclosure in cold recovery. Sample types collected during monitoring included personal air samples, excursion, area, and clearance samples, which were analyzed using phase contrast microscopy methods as described in National Institute for Occupational Safety and Health 7400 for asbestos and other fibers.

ACM removal complied with National Emission Standards for Hazardous Air Pollutants (NESHAP) guidance. The asbestos was removed and double-bagged. ACM that had radiological contamination was segregated from the nonradiologically contaminated asbestos and shipped to Envirocare. The nonradiologically contaminated ACM was disposed of at the Y-12 Industrial Landfill.

Structural and Architectural Components. Structural and architectural components remained in place; however, some also required decontamination. Decontamination of these surfaces involved both radiological and toxic (e.g., PCBs, asbestos) hazards. The buildings were decontaminated progressively after process and nonprocess equipment, piping, and other associated components were removed. The facilities were cleaned to meet the contamination levels for free release.

Concrete surfaces and motor pedestals were decontaminated by scabbling, shot blasting, or similar methods. The wastes from these operations were containerized and disposed of as solid or radiologically contaminated wastes.

Most of the internal transite surfaces of the exterior walls were decontaminated by wiping, vacuuming, and/or replacement. Special care was taken to avoid generating friable asbestos. If the radiological contamination had penetrated the panels at a significant depth, the panels were removed and disposed of in a licensed commercial landfill.

Structural steel and floor joists were decontaminated by wiping, shot blasting, or another appropriate method. The wastes generated from these activities were characterized, packaged, and disposed of as LLW at Envirocare.

<u>Secondary Waste Streams</u>

Secondary waste streams were generated during disassembly, size-reduction, and plasma-cutting operations. These waste streams included the solid waste associated with size-reduction/disassembly (i.e., torch slag) and used PPE. In the disassembly areas, wastes generated during equipment wiping were containerized, sampled, characterized, and disposed of at a licensed commercial disposal facility. Fumes from plasma cutting were controlled using negative air pressure and HEPA filters.

After the equipment was removed and processed, recyclable material that was radioactively contaminated was sent to the MSC treatment facility until July 2000. Secondary waste streams generated during treatment at the facility are described below:

- Steel shot used for grit-blasting material was collected, containerized, sampled, and characterized. The waste stream was disposed of as a radioactively contaminated solid waste.

- Chemical baths containing a nitric acid solution were typically used for wet chemical decontamination of aluminum and copper. The acid solution was continuously replenished as the spent solution was neutralized and treated by a water filtration system within the process equipment. The spent bath solution was then sampled and released to the sanitary sewer system in accordance with an existing National Pollutant Discharge Elimination System permit. Solid wastes generated during filtration of the neutralized spent solution were disposed of as either a solid waste or a radioactive waste, depending on the analytical results.

8.4.7.3 Transportation Activities

Dismantled equipment was transported (1) within an ETTP facility, (2) between ETTP facilities, (3) from ETTP to the MSC treatment facility, (4) from the MSC treatment facility to a disposal site (residuals only), (5) from ETTP directly to commercial vendors for unrestricted release or reuse, and (6) from ETTP to a disposal site (material that cannot be recycled). Residuals and nonrecyclable wastes to be disposed of were transported to disposal sites that are acceptable under EPA's CERCLA Off-Site Rule. Table 8-7 shows the number and destination of these shipments.

Table 8-7. Number of shipments for the ETTP Three-Building D&D and Recycle Project

Destination	Number of shipments by truck	Number of shipments by rail	Total number of shipments
Envirocare of Utah	1,084	7,812	8,896
Nevada Test Site	1,271	0	1,271
EMWMF[a]/Y-12 Landfill	2,253	0	2,253
Other	264	0	264
Total	4,872	7,812	12,684

[a] EMWMF: Environmental Management Waste Management Facility.

8.4.8 Final Condition of Three Facilities

8.4.8.1 Building K-29

Physical Condition

Process and nonprocess equipment, associated piping and ducting, and out-of-use electrical services were removed on both the Operations Floor and Cell Floor. Platforms and mounting anchors on the Operations Floor were removed or cut off flush with the floor surface. On the Cell Floor, most platforms and anchors were removed or cut off flush with the floor surface, but concrete motor pedestals remain. Wastes and stored materials and equipment were removed.

Lighting fixtures, 480 V and 110 V drops, the majority of the fire protection (sprinkler) system, surveillance and security systems, and bridge cranes remain in place and operational. Roof and floor drains, sanitary drains, and potable water systems also remain. The building is not environmentally/comfort-controlled (i.e., there are no operational HVAC systems).

The building is essentially reduced to its structural components (e.g., floors, walls, ceiling, support columns and framework). With the exception of nine stairwell enclosures, remaining pedestals, and structural members, the Cell Floor is empty and open. A boundary control station, including anticontamination clothing, a dress-out and doffing area, a radiological work permit station, and a personnel contamination monitor, has been established on the east side of the Operations Floor at the access to the contamination control area. Two additional personnel contamination monitors remain at the former location of waste-handling activities, in the south portion of the Operations Floor.

During implementation of the project, an area on the Operations Floor was designated for processing of legacy waste. A portion of the legacy waste area was designated for processing of TRU-contaminated wastes and a portion for beryllium-contaminated wastes. The interior structures associated with the legacy waste processing area no longer exist.

Radiological Conditions

With the exception of cleanup of spills and releases that occurred during BNG America equipment removal and waste-processing operations, radiological decontamination of the K-29 Building interior surfaces was not performed. Limited monitoring of floor surfaces was performed by BNG America during and after legacy waste–handling operations were completed and compared with findings of the initial characterization, performed by Radian International LLC in 1997 soon after start of the project, to demonstrate that project activities had not resulted in a significant change in the nature (radionuclide mix, extent, or levels) of contamination.

Isotopic analyses prior to and following BNG America activities demonstrate that the predominant contaminants are low-enriched (<5% ^{235}U) U and ^{99}Tc. U/^{99}Tc activity ratios are highly variable—typically in the range of approximately 0.14–25. Lower concentrations of TRU nuclides (^{237}Np, ^{241}Am, and ^{239}Pu) are also present with U/TRU activity ratios in the range of approximately 244–660. Details and additional information regarding radiological measurements are provided in *Building K-29 Characterization Results* (BNG 1998) and *K-29 Building Certification Report*, June 2005 (BNG 2005a). These data suggest that post-project radiological conditions of remaining building interior surfaces are generally comparable with the conditions at the start of this project. They also demonstrate that final total and removable radiological contamination levels on most surfaces are in excess of the DOE limits acceptable for unrestricted use. The preproject estimate, based on the survey by Radian, was 87% of the Cell Floor surfaces and 55% of the Operations Floor surfaces were contaminated in excess of the 5000 dpm/100 cm^2 average limit for total contamination. The survey also indicated that about 5% of the total contamination was transferable (removable). Based on results of initial and post-project surveys, it is reasonable to conclude that the locations and levels of interior surface contamination in excess of unrestricted use levels are similar to the Radian preproject estimates. In accordance with DOE radiation control regulations in 10 CFR Pt. 835, the Cell Floor has been designated a High-Contamination Area and the Operations Floor has been designated a Contamination Area.

Nonradiological Contamination

Asbestos abatement throughout the building was performed in support of the removal of equipment and systems. Examples of ACM removed include wire and cable insulation, equipment brake shoes, pipe thermal insulation, and floor and ceiling tile.

Spills and releases involving Be-containing legacy wastes which occurred during BNG America operations in 2004 were cleaned up and monitored. Following waste-processing operations, monitoring of the waste processing area was performed, and all Be concentrations were within the regulatory limit of 0.2 μg/100 cm^2. As described in the *K-29 Building Certification Report*, June 2005 (BNG 2005a), the contract was modified to delete EPC for the building, and monitoring to specifically determine final asbestos conditions was not performed.

The Radian preproject characterization identified 44% of the sampled surface as contaminated with PCBs in excess of the regulatory criterion of 10 μg/100 cm^2. The surveyed locations were biased to surfaces of suspected PCB contamination, based on use history. Limited sampling of floor surfaces in the vicinity of the legacy waste–processing area was performed by BNG America. This was performed after the waste-handling operations were completed to demonstrate that these operations had not resulted in a significant change in the extent or levels of contamination. Results of this sampling are provided in *K-29 Building Certification Report*, June 2005 (BNG 2005a). These results indicate only two of the 27 December 2004 samples and four of the 29 May 2005 samples exceeding the 10 μg/100 cm^2 criterion and a maximum post-project PCB concentration of 35.35 μg/100 cm^2. These sampling data are not likely representative of the same surface types and locations as those sampled by the Radian characterization, and statistical comparisons and inferences are therefore not appropriate. However, because all of the contaminated process and support equipment has been removed from the building, it is reasonable to assume that the Radian survey result of 44% is an upper bound on the extent of current PCB contamination in this building. It should also be noted that radiological and PCB contamination is not necessarily co-located. PCB contamination is primarily on the Operations Floor, whereas radiological contamination affects more surface area on the Cell Floor.

8.4.8.2 Building K-31

Physical Condition

All process and nonprocess equipment and associated piping, ducting, and electrical services have been removed. Platforms, pedestals, and mounting anchors have been removed or cut off flush with the floor surface. Feed-through piping and conduit between the Cell and Operations Floors have been cut off flush; internal wiring and packing have been removed from the penetrations. Other out-of-use electrical services were removed. All but two sets of stairs for accessing Cell Floor penthouses were removed. Covers were removed from expansion joints on the Cell Floor and Operations Floor at locations where contamination was identified. Fill material was removed from the Operations Floor expansion joints to a depth of 1–2 inches and replaced with new material. Metal plates were sealed in place to cover penetrations larger than 4 inches in diameter between the Cell Floor and Operations Floor; penetrations up to 4 inches in diameter were filled with foam. Wastes and materials, previously stored in the building, have been removed.

A mechanical maintenance building located on the Operations Floor that includes an office and change house was left in place, but all equipment and fixtures were removed from the building. Lighting fixtures, 480 V and 110 V drops, the majority of the fire protection (sprinkler) system, surveillance and security systems, and bridge cranes remain in place and operational. Roof and floor drains and sanitary waste and potable water systems also remain. The building is not environmentally/comfort controlled (i.e., there are no HVAC systems).

To remove and/or reduce contamination, the majority of the floor surfaces were scabbled. Additional spot decontamination was performed in some locations by chipping and grinding. At some locations concrete has been removed to the extent that reinforcing bars are exposed. Vacuuming and/or wipedown of steel surfaces were performed. Further decontamination was generally performed using chemical paint remover and, if necessary, by grinding the surfaces. Damaged structural steel and framework was replaced or repaired to maintain structural integrity. Contaminated hatch railings were removed. Transite wall panels with contamination levels above radiological criteria were replaced with new panels.

The building is essentially reduced to its structural components (e.g., floors, walls, ceiling, and support columns and framework). With the exception of 18 stairwell enclosures, a few walk-in pits, an interior office/shower/shop facility on the Operations Floor, and structural members, floor areas are empty and open.

Radiological Condition

Analyses from 2004 BNG America sampling conducted in support of radiological criteria development demonstrate that the predominant contaminants are uranium and ^{99}Tc. An upper-bounding enrichment level of 2% ^{235}U was established for K-31. On surfaces less than 2 m above the floor, the contamination was mainly U, whereas on overhead surfaces the contamination mixture was conservatively established at 50% U and 50% ^{99}Tc on the Cell Floor and 80% U and 20% ^{99}Tc on the Operations Floor. Contamination was primarily fixed on surfaces and was not easily removable. Transuranics (^{237}Np, ^{241}Am, and ^{239}Pu) were typically present at small fractions of the U and ^{99}Tc levels. Exceptions are on portions of the floor surface of Units 1, 2, and 3 of the Cell Floor.

8.4.8.3 Building K-33

Physical Condition

All process and nonprocess equipment and associated piping, ducting, and electrical services have been removed. Platforms, pedestals, and mounting anchors have been removed or cut off flush with the floor surface. Feed-through piping and conduit between the Cell and Operations Floors have been cut off flush; internal wiring and packing has been removed from the penetrations. Other out-of-use electrical services were removed. Covers were removed from expansion joints on the Cell Floor and Operations Floor. On the Operations Floor in the western half of the building, fill material was removed from the expansion joints to a depth of 1–2 inches at locations where contamination was identified. In the eastern half of the Operations Floor, fill material was removed from all expansion joints to a depth of approximately 2 inches. At most locations, new material was used to replace the removed expansion joint fill. Most penetrations between the Cell Floor and Operations Floor were covered with metal plates if larger than 4 inches in diameter or filled with foam if smaller. An area in the K-33 Building is being used at DOE's direction for waste storage and was outside the scope of the project. Other wastes and materials, previously stored in the building, have been removed.

Other than stairwell enclosures, there are no interior structures, such as offices and change houses, on either the Operations or Cell Floor levels. Penthouses on the roof above each Cell Floor unit were also left in place. Lighting fixtures, 480 V and 110 V drops, the majority of the fire protection (sprinkler) system, surveillance and security systems, and bridge cranes remain in place and operational. Roof and floor drains and sanitary waste and potable water systems also remain. The building is not environmentally/comfort controlled (i.e., there are no HVAC systems).

To remove and/or reduce contamination, most floor surfaces were scabbled. Additional spot decontamination was performed in some locations by chipping and grinding. At some locations concrete has been removed to the extent that reinforcing bars are exposed. Vacuuming and/or wipedown of steel surfaces were performed. Further decontamination was generally performed using chemical paint remover and, if necessary, by grinding the surfaces. Damaged structural steel and framework was replaced or repaired to maintain structural integrity. Contaminated hatch railings were removed. Transite wall panels with contamination levels above radiological criteria were replaced with new panels.

The building is essentially reduced to its structural components (e.g., floors, walls, ceiling, and support columns and framework). With the exception of 40 stairwell enclosures, waste storage areas, and structural members, floor areas are empty and open.

<u>Radiological Condition</u>

Analyses from 2004 BNG America sampling conducted in support of radiological criteria development demonstrate that the predominant contaminants are U and ^{99}Tc. An upper-bounding enrichment level of 2% ^{235}U was established for K-33 Building. On surfaces less than 2 m above the floor, the contamination was mainly U, whereas on overhead surfaces the contamination mixture was conservatively established at 50% uranium and 50% ^{99}Tc on the Cell Floor and 80% U and 20% ^{99}Tc on the Operations Floor. Contamination was primarily fixed on surfaces and not easily removable. Transuranics (^{237}Np, ^{241}Am, and ^{239}Pu) were typically present at small fractions of the uranium and ^{99}Tc levels.

Following submission of the March 2005 draft *K-33 Building Certification Report* (BNG 2005b) limited additional remediation and surveys of the floors and several other surfaces were conducted. A report of the results of additional radiological measurements is presented in *K-33 Radiological Status Survey Report for Work Conducted After June 2005* (BNG 2005c). Attachment G of *K-33 Building Certification Report* (BNG 2005b) and the October 2005 supplemental report summarize survey results for each Building Unit, by survey unit (physical location) and material category.

A small fraction of the surface area was reported by BNG America to still exceed the established radiological surface-contamination criteria. Many of these survey units contain multiple locations with activity above the criteria. It should be noted that all areas of contamination, which were identified in the March 2005 draft *K-33 Building Certification Report* (BNG 2005b) as exceeding criteria were not addressed in the October 2005 report. It is therefore assumed that those surface areas remain contaminated. The above-referenced BNG America reports also did not indicate the real extent, exact locations, or residual contamination levels of locations of residual contamination exceeding criteria.

Exposure rates throughout the K-33 Building satisfied the project criteria, with the exception of a small area in Cell Floor Unit 4, Cell 8, associated with an area of residual activity. The maximum exposure rate at this location was 35 μR/h, including background.

Based on data from the March 2005 and October 2005 BNG America reports and a BNG America presentation of March 14, 2005, Survey Status Update, Potential Path Forward, it is estimated that approximately 85% of the building interior surface satisfies the approved project radiological criteria. Residual contamination is primarily on the floor and is limited to small, isolated spots of activity—typically affecting less than 1 m^2 in area. Many of the survey units with activity above the criteria have multiple areas of contamination. The Cell Floor contains more areas of residual contamination than the Operations Floor. The most highly affected portions of the Building are Units 5, 7, and 8 on the west half of the Cell Floor. Several locations contain activity levels well above the criteria. Surfaces identified by BNG America as exceeding criteria are delineated with paint. The Cell Floor has been designated a Contamination Area.

Numerous areas of residual contamination exceeding the total surface activity guidelines were identified during the Oak Ridge Institute for Science and Education (ORISE) independent verification survey (ORISE 2006). Survey results indicate remaining elevated residual activity on floor, upper steel, lower steel, and stairway surfaces. Surveys also identified multiple locations of elevated activity on cable trays.

8.4.9 Project Organization

For the ETTP Three-Building D&D and Recycle Project, DOE provided direct contract management as well as direct safety, security, and project oversight. DOE used BNG America (formerly BNFL, Inc.) as its prime contractor through a firm fixed-price contract to perform the D&D. The contract was awarded to BNG America on August 25, 1997, and BNG America assumed responsibility of Buildings K-31 and K-33 on January 5, 1998 and Building K-29 on July 1, 1998. Specifically, BNG America provided services such as S&M (including criticality alarms and fire protection systems), NMC&A, security within fenced areas, safety, emergency response, process equipment removal and recycle and/or disposition, interior building decontamination, waste management, and management of RCRA storage areas inside Buildings K-31 and K-33. In addition to BNG America, DOE also received services from various DOE contractors. All of DOE's contracts were fixed-price except for the cost-plus contract with ORISE and some of the contracted work with Bechtel Jacobs Corporation and LMES. BNG America used various subcontractors for major components of the D&D.

8.4.9.1 Project Cost

Table 8-8 provides a summary of estimated costs from Appendix D of the 1997 EE/CA for equipment removal and building decontamination. The total escalated cost was $253 million, but this cost assumes revenues of $67 million from the sale of various types of scrap metal expected to be recovered from D&D operations or the sale of metal fabrications made from such scrap metal. Without these revenues, the total cost would have been $320 million.

Table 8-8. Original cost estimate from EE/CA for equipment removal and building decontamination

Activity	Escalated cost ($K)
Site services	42,300
Equipment removal	80,300
Equipment sizing, decontamination, and recycling	119,200
Building decontamination	23,900
Drum removal (pond sludge, PCB soil, LLW)	15,600
Waste disposal	39,000
Subtotal	320,300
Revenue (from recovering and selling the nickel and other metals to help offset the costs of equipment cleanup)	-67,100
Total	253,200

Note: Costs were escalated over a 7-year D&D period.

Table 8-9 shows a summary of actual costs for the ETTP Three-Building D&D and Recycle Project.

Table 8-9. Actual project cost

Project Activities	Cost[a] ($K)
D&D (BNG America)	333,000
DOE technical support (various)	16,391
Metal recycling (TOXCO)	735
Independent verification (ORISE)	5,426
Perimeter fence construction (M K Ferguson)	447
Total	356,000

[a] D&D cost includes revenue losses based on the nickel and metal recycling moratorium. The D&D cost does not include the costs associated with shipping and disposing of pond sludge waste by LMES.

The accuracy of the EE/CA estimate of $253 million is +50% to -30%. The actual project cost to date of $356 million does fall within the +50% to -30% range of the EE/CA estimate (i.e., $177 to $380 million).

8.4.9.2 Project Schedule

The K-29 Building was turned over to DOE by BNG America on July 1, 2005 for demolition; the K-31 Building was turned over to DOE on September 30, 2005 for completion of the decontamination; and the K-33 Building was turned over to DOE on September 30, 2005 for further evaluation of the need to complete decontamination. The balance of the project site was also turned over to DOE on September 30, 2005.

8.4.9.3 Operation and Maintenance Plans

S&M requirements have been instituted by DOE for the three buildings. The S&M requirements will continue under DOE until the buildings (i.e., K-29 Building) are demolished or until they have been determined to be suitable for transfer per CERCLA 120(h) by EPA and TDEC and transferred.

8.4.10 Monitoring Plans

There are no post-action monitoring requirements specific to the D&D removal action.

8.4.11 Land Use Controls

No additional interim building-specific land-use controls are required following the D&D removal action beyond those that apply generally to ETTP. These controls include periodic patrols by security and the facility manager, security devices on all doors/gates and the boundary controls stations, authorization requirements for entry or work, and radiation protection requirements. The Zone 1, Zone 2, and sitewide RODs will establish land-use controls following remediation of ETTP.

8.5 Radium Chemical Company, Inc., New York: Removal and Remedial Actions

8.5.1 Background

The Radium Chemical Company (RCC) site consisted of an abandoned building on approximately ⅓ acre of land in Queens. The Brooklyn-Queens Expressway is less than 10 feet from the site. A large health club is located within 100 feet of the RCC facility. The majority of the surrounding area is composed of light industry and small businesses, with some residential areas within ½ mile of the site. Approximately 300,000 people reside within 3 miles of the site.

From the mid-1950s through 1983, the company leased specially packaged radium to hospitals for use in the treatment of cancer. When it was abandoned, the facility contained a large quantity of radium-226 (^{226}Ra) sealed in small metal tubes or rods referred to as "needles," totaling approximately 120 Ci. In 1983, the state ordered the company to stop its business operations due to a series of regulation violations. State inspections disclosed violations involving lost shipments of needles, radiation levels exceeding allowable standards within the plant, and elevated radon levels, indicating microscopic defects in the needles. In 1987, the state ordered RCC to remove its inventory of radioactive sources and to decontaminate the work site. In 1988, a state judge declared the RCC site officially abandoned.

The building interior was contaminated with residual radium and radon gas from the former site operations. The potential threat existed from the possible inhalation of radon gas and exposure to gamma radiation if people should enter the building on the site. There was also the possibility of either inhalation or ingestion of radioactive materials as a result of either fire or vehicular collision with the building from the Brooklyn-Queens Expressway. The amount of ^{226}Ra at the site was estimated at the time to be 100 Ci. Also on site were hundreds of containers of laboratory chemicals, many of which were reactive, corrosive, flammable, and/or potentially shock-sensitive.

The highest radiation exposure rate identified in the source vault area was 200.0 μR/h. The highest contamination level identified in the source vault area was 847,000 dpm/100 cm^2 removable beta in a 55-gallon drum filled with lead containers, or pigs, that were used to shield radium sources for storage. Outside of the source vault the highest exposure rate was 50.0 mR/h, and highest contamination level was 483,000 dpm/100 cm^2. Approximately 75% of all survey points in the area with radiation sources and 25% in the administrative office area exceeded acceptable radiation levels for surface contamination.

8.5.2 Decontamination and Decommissioning Approach Development

The site has been addressed in two stages: immediate removal actions focused on removal of the radioactive sources and long-term remedial action focused on cleanup of the residual radioactivity remaining on the entire site.

8.5.2.1 Immediate Actions

Over a 9-month period, a removal action was conducted by EPA. During the months of July and August 1989, all of the needles on site were repackaged to prevent the release of radioactivity and were removed in five shipments to a facility in Nevada dedicated to the disposal of radioactive wastes. In August 1989, noncontaminated flammables, poisons, and other reactive chemicals were sent for incineration and disposal. In September 1989, one shipment of highly contaminated debris, tools, and other materials found in the building also was sent to the Nevada facility. In addition, in September and October 1989, low-activity contaminated debris was sent to an LLW disposal facility in Hanford, Washington. Elemental mercury found in the building was recycled and sent to a facility in Pennsylvania. These removal actions resulted in the greatest hazards being removed from the site.

8.5.2.2 Entire Site

In early 1990, EPA prepared a study that outlined the nature and extent of contamination remaining at the site and described the various cleanup alternatives evaluated. EPA selected the final site remedy, which consisted of partial decontamination of the building, followed by its complete dismantling and disposal in appropriate facilities.

The remedial action was intended to remove from the site all radioactive and hazardous materials above acceptable levels, rendering the site property allowable for unrestricted use. Partial decontamination was to be performed to remove hot spots and reduce the risks of worker exposure and of spreading contamination outside of the site boundary during dismantling.

Bulk material (i.e., masonry, soil) with less than 5 pCi/g of ^{226}Ra was not required to be disposed of in a radioactive waste facility. Surface contamination was addressed through the use of acceptable surface contamination levels in NRC's Regulatory Guide 1.86 (for ^{226}Ra, average of 100 dpm/100 cm^2, maximum of 300 dpm/100 cm^2, and removable 20 dpm/100 cm^2).

8.5.3 Response Actions

The initial emergency response action resulted in the removal of 118.6 µCi of high-activity waste and 188.9 µCi of low-activity waste from the site. Another 197 gallons of hazardous wastes was removed and incinerated off site, 50 pounds of propane was disposed off site, and 500 pounds of elemental mercury was recycled.

The long-term remediation resulted in the off-site disposal of approximately 812 tons of radioactive soil and debris, 92 tons of radiologically contaminated hazardous wastes, 862 tons of uncontaminated masonry and concrete building debris, and the recycling of 45 tons of elemental lead and 20 tons of structural steel. Remedial cleanup actions began in November 1990, and all work was completed in July 1994. The site was deleted from the NPL in March of 1995.

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8.6 Austin Avenue Radiation, Pennsylvania: Remedial Action

8.6.1 Background

The Austin Avenue Radiation site consists of 40 properties located in Lansdowne Borough, East Lansdowne Borough, Upper Darby Township, Aldan Borough, Yeadon Borough, and Darby Borough, Pennsylvania. Contamination of these properties resulted from the disposal of radioactive materials generated by W. L. Cummings Radium Processing Co., which conducted radium-refining operations 1915–1925. Radium tailings resulting from these plant operations were sold or given to local contractors then mixed with materials used to construct buildings or used for fill material at the various properties in Delaware County. In 1991, an advisory was issued to the area by the Agency for Toxic Substances and Disease Registry. In the advisory, the nearby population was warned of the significant risks posed to their safety and health by the radium, thorium, radon, and asbestos present in the structures.

8.6.2 D&D Approach Development

In June 1994, following a comprehensive site investigation, the EPA selected a remedial action to clean up the site. The remedy included the removal of materials contaminated with radioactive waste, the demolition of contaminated houses, the repairing of one contaminated house, the permanent relocation of residents of eight of the demolished houses, the rebuilding of 12 houses, and the removal of contaminated soils on 22 different properties in five municipalities. An additional 18 properties were addressed under EPA's removal authority. Radium contamination in buildings addressed during the remedial action ranged up to 1335 pCi/g.

Federal radiation standards selected as relevant and appropriate requirements included 40 CFR Pt. 192, Subpart B, "Standards for Cleanup of Land and Buildings Contaminated with Residual Materials from Inactive Uranium Processing Sites," and 10 CFR Pt. 20, Subpart D, "Radiation Dose Limits for Individual Members of the Public." For most properties, EPA gave the building owner the choice of government rebuilding of the structure, or off-site relocation, or building repair. While portions of several buildings could be repaired without demolishing the entire structure, the work required to remove contamination in many of these cases would have involved, among other tasks, suspending the structures and excavating the foundations. For these properties, the difference between implementing complex repair work and complete demolition was insignificant. The added oversight required to rebuild the structures, compared to that required to provide off-site relocations, was weighed against the almost universal desire of property owners to have a choice whether to remain on their properties (once cleaned) or relocate. Additionally, the concerns of neighboring residents and community officials that empty lots in the affected neighborhoods would result in off-site relocations and that clean, empty parcels would be turned over to the state had to be considered. EPA determined that both sets of concerns would be best addressed by allowing the affected property owners to choose between the three options, whenever possible.

8.6.3 Response Actions

Under an IAG with EPA, the U.S. Army Corp of Engineers (USACE) cooperated on the design for the remedy selected in 1994. Site cleanup activities began in late 1995 and were completed in November 1997. All the permanent residential relocations were completed. All radiologically contaminated structures were dismantled, and the associated contaminated soils on the affected properties were excavated and shipped off site for disposal. Excavation of the warehouse property, the most heavily contaminated property, began in April 1997 and was completed in November 1997. EPA and USACE transferred ownership of the warehouse property back to its owner. By February 1998, all 11 home rebuilds were completed, and the properties were returned to their respective owners. Some properties were not rebuilt because the homeowners chose to be permanently relocated. These properties were transferred as vacant lots to the municipalities in which they lie, as requested by the municipalities, which agreed to assume ownership and to use the properties for the benefit of the respective communities. In September 1996, EPA issued a No Action ROD for groundwater at the site. The total amount of radiologically contaminated materials disposed off site was 241 rail cars (approximately 20,000 tons).

EPA finalized the close-out report for the Austin Avenue site in August 2001 and deleted the site from the NPL in April 2002. The Site Notice of Deletion was published in the Federal Register on April 18, 2002. A five-year review was completed and demonstrated that the cleanup remains effective. No additional five-year reviews or institutional controls will be needed at the site, as all cleanup goals were met. All the properties at the Austin Avenue Site were restored, returned to their original owners, or transferred to the municipalities in which they lie.

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8.7 Webster-Gulf Nuclear, Texas: Building Dismantlement

8.7.1 Background

The site is a former radioactive material processing laboratory that produced and prepared sealed sources and tracers for the medical, oil production and exploration, and chemical industries. The company had been in Chapter 11 bankruptcy, but on 16 October, 2001, the presiding judge moved it into Chapter 7, virtually causing the site to be abandoned.

Radioactive sources, highly contaminated equipment and debris, and contaminated buildings remained at the site. Radioactive americium, cesium, and radium were the primary isotopes found, but the site also included radioactive isotopes of silver, thorium, plutonium, europium, cobalt, iridium, strontium, and several others in significant quantities. The site is located in a densely populated area near medical clinics, hospitals, and other commercial operations.

8.7.2 D&D Approach Development

It was decided to dismantle the building and its foundation and dispose of the material off site. Also, the soil was to be excavated to meet the cleanup criteria of 40 pCi of cesium-137 (^{137}Ce) and 6 pCi of americium-241 (^{241}Am). Reaching that cleanup goal would allow the State of Texas to “free release” the property for unrestricted reuse.

8.7.3 Response Actions

The response action at Webster-Gulf Nuclear is complete. All radioactive waste has been removed from the site and either disposed of or place in long-term temporary storage. The cleanup goals for the contaminated soil have been accomplished. The Texas Department of Health Bureau of Radiation Control has cleared the site. The fence has been removed, and the vacant lot is ready for reuse.

Crews investigated and segregated material in the buildings. The crews had to work around rooms with the ambient radiation that limited time allowable in the rooms. In some rooms, the annual allowable dose for a radiation worker would have been exceeded in less than 13 minutes. Crews had to choreograph some of the work prior to making the entries to limit their exposure. Additional shielding had to be constructed to enter some rooms and moved in ahead as the crews advanced into the rooms.

The gamma activity inside some of the components exceeded 1000 R/h. Alpha scans of the floors had shown 200 million disintegrations (or counts) per minute. State investigations have found radioactive rats and roaches (2 μR/h and 20,000–30,000 pCi). Several neutron fields existed throughout the site. Some were due to instruments set up in the labs, but others existed due to loose piles of americium and beryllium found in several areas in the building.

Initially, the report had indicated that only a dozen sealed sources were in the building. However, the cleanup found about 300 sealed sources. That included several small check sources, packets of hundreds of radium needles (a packet was counted as a single source), and several 125 Ci ^{137}Ce sealed sources. These were found in cabinets, rolling on the floor, in coffee cups, in the glove-boxes, behind false walls, and hidden in the base of a large component.

Several items required special handling and a variety of waivers. One large component would have required about 1200 man-Rem, or the annual exposure of about 240 radiation technicians, to dismantle it to comply with standard disposal specifications. The State of South Carolina approved a waiver to allow that and other components to be received as a whole unit. This included the 81,000 pounds of lead shielding in a component that, if removed, would not have allowed for the transportation of the component due to the radiation level going down the road. In turn, this led to the need for special permits and waivers for the transportation to the disposal facility of “heavy on the road” items. Cask and specially designed containers were used to ship the waste streams to the disposal facilities.

Separate waste streams exceeded the alpha contamination from the ^{241}Am and gamma contamination from the ^{137}Ce. There is currently no commercial disposal facility for GTCC waste. The State of Texas has worked with EPA and a facility to allow the storage of the GTCC waste until a facility becomes available. It is expected that the GTCC will go to the Yucca Mountain facility when it opens. It is projected that the Yucca Mountain facility will begin accepting waste no earlier than 2010.

The buildings and foundations have been removed and disposed of off site. The radioactive waste was disposed of at a several facilities. Radium needles were sent to the American Ecology facility in Richland, Washington A large volume of contaminated waste was sent to the Envirocare facility in Utah. Highly contaminated material was sent to the Barnwell facility in South Carolina. Several pieces sent to Barnwell required special waivers and unique handling for safety. Several americium, americium-beryllium, and plutonium sealed sources were sent to DOE's Sealed Source Recovery Program. Lead, a small amount of chemicals, and waste under the regulated limits were sent to proper disposal facilities.

Many of the items and some subsequent derived waste are classified as GTCC. GTCC waste is prohibited to be disposed of in any current commercial facility. EPA and the State of Texas worked to provide long-term temporary storage of the 14 casks at the Waste Control Specialists facility near Andrews, Texas. This very contaminated waste will be stored until a facility such as the Yucca Mountain facility begins to accept such waste.

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8.8 Syntrum Corporation Site, California: Removal Action and Decontamination

8.8.1 Background

The Syntrum site is located in a light industrial area of Los Angeles County. The company was a chemical research, development, and manufacturing laboratory that incorporated carbon-14 (^{14}C) into organic compounds. In August 1997, there was a fire and explosion at the facility. The building's sprinkler system flooded the facility, causing water contaminated with ^{14}C to run off into the streets. The Los Angeles County Fire Department shut down the facility, and shortly thereafter the Los Angeles County Department of Health Services Radiation Management Division requested EPA's help.

8.8.2 Decontamination and Decommissioning Approach Development

EPA conducted an assessment of the facility, which was found to contain thousands of improperly stored chemicals and radioactive substances that could result in an additional chemical reaction, fire, or explosion releasing additional radioactive contaminants. Approximately 99% of the laboratory building and an outside dumpster were found to be radiologically contaminated with low-energy beta (^{14}C) and tritium. The laboratory ventilation system was sampled and found to contain radioactive contamination in excess of established guidance limits for ^{14}C. A dumpster at the facility contained radioactive chemicals and other chemical residue. The typical background count for ^{14}C in the area is 42 counts per minute (cpm). The removable residual radioactive contamination inside the dumpster exceed 250,000 dpm; one chemical container read 88,648 cpm.

8.8.3 Response Actions

In 1998, EPA removed all of the removable chemical and radioactive substances and decontaminated the laboratory building. Fixed contamination in excess of 20,000 cpm was left in the structure. California had three alternatives to address the fixed contamination: pressure washing, painting over the contamination, or demolishing the structure. California chose pressure washing. To date, EPA has spent approximately $1.1 million cleaning up the site.

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8.9 Connecticut Yankee

This case study is taken in large part from a paper presented by Wayne Norton during a Decommissioning Conference in December 2006. Wayne Norton is President/CEO Connecticut Yankee Atomic Power Company, Yankee Atomic Electric Company.

8.9.1 Background

Connecticut Yankee, a 560-megawatt Westinghouse pressurized water reactor on the Connecticut River in Haddam Neck, Connecticut, began commercial operation in 1968 and was shut down for decommissioning in 1997. Connecticut Yankee decommissioning was started in 1998 and will be completed in 2007.

Maine Yankee, an 860-megawatt Combustion Engineering pressurized water reactor nuclear power plant on the coast of Maine, began commercial operation in 1972 and was shut down for decommissioning in 1997. Maine Yankee decommissioning was started in 1998 and was completed in 2005.

Yankee Rowe, a 165-megawatt Westinghouse pressurized water reactor in western Massachusetts, began commercial operation in 1960 and was shut down for decommissioning in 1992. Yankee Rowe decommissioning was started in 1992, to be completed in 2007.

Table 8-10. Decommissioning project statistics

Plant	Length (years)	Cost (million US $)	Project OSHA recordable injury rate (injuries/200,000 work hours)	Total dose (person-rem)
Connecticut Yankee	9	850	1.27	860
Maine Yankee	7	500	0.26	515
Yankee Rowe	15	750	1.96	594

All three projects were successful in that the work was accomplished safely, and the sites were (or are being) thoroughly cleaned up to meet the state and federal requirements. While the decommissioning experience for each plant was somewhat unique, the processes for all three were basically the same. Prompt dismantlement was chosen to minimize the time and associated costs without sacrificing safety and worker dose.

As the decommissioning of the sites progressed, lessons were learned that helped to improve efficiency and thereby shorten schedule and cost. It was learned in the course of these projects that effective planning by a strong management team, both early and throughout the process, was the most critical factor in reducing decommissioning time and project cost.

8.9.2 Decommissioning Planning: Begin Early with the End in Mind

8.9.2.1 Waste Management

When a plant shuts down for decommissioning, the entire facility, including the components, becomes waste. Understanding waste streams and how they are handled and disposed of is fundamental to planning how the decommissioning will be done. When starting the decommissioning of Maine Yankee, waste disposal costs were high. This led to embracing decontamination techniques such as surface scabbling to reduce waste volumes. As decommissioning progressed, it was possible to negotiate waste disposal contracts with much lower costs. This change enabled employment of a “rip and ship” approach. While it is true that waste volumes increased, there were substantial reductions in labor costs and time.

The approximate total waste quantities for three plants are listed below:

- Connecticut Yankee: 350 million pounds
- Maine Yankee: 460 million pounds

- Yankee Rowe: 170 million pounds

Despite best efforts at estimating waste quantities at the beginning of the projects, the waste quantities increased as areas were remediated and generated more soil waste than expected. While above-grade structures can be more readily estimated, below-grade remediation is uncertain, even with today's characterization capabilities. Land area characterization data were used to estimate waste volumes. However, spread of contamination in soil is unpredictable due to a variety of factors, including inconsistencies in soil/groundwater conductivity, bedrock surface features, and structural impediments to groundwater flow.

Waste disposal contracts were negotiated and renegotiated throughout the decommissioning projects. These changes were the result of new and less expensive disposal facilities becoming available, changes made by waste disposal vendors, changes in our understanding of the waste streams, and regulatory changes. It was found that having more than one option for significant waste streams was helpful in keeping costs under control.

Having multiple waste transport options also helped to control costs and ensure that wastes could continue to be shipped under a variety of circumstances. Rail proved the best bulk option for shipping wastes across the country. Rail was available on site at Maine Yankee. At Connecticut Yankee and Yankee Rowe, trucks hauled waste to a nearby railhead. Intermodal containers on trucks and rail cars were used to ship waste to disposal facilities. Barge shipment was only used at Maine Yankee and Connecticut Yankee for large components, such as the pressurizer, steam generators, and pressure vessel.

8.9.2.2 Early Decommissioning Planning

At Maine Yankee, a construction management team started decommissioning planning in anticipation of the decision to shut down for decommissioning. This team embraced earned-value performance monitoring, scrubbed the decommissioning cost estimate, and developed a decommissioning plan and schedule with a mission of being "green" in 7 years—start to finish. The team also invited about 15 leading construction firms (either individually or as teams) to submit firm fixed-price proposals for the entire decommissioning scope. To enable these firms to have the maximum knowledge possible when developing their bids, site characterization was undertaken. The firms interested in submitting bids were invited to participate in site characterization process to the extent that they were encouraged to attend the daily meetings and offer suggestions as to what areas would be characterized. The site characterization report then became their bid basis.

Even though the winning firm, to be called a Decommissioning Operations Contractor (DOC), would be responsible for the decommissioning schedule, the utility management team developed a plan and detailed schedule. While many aspects of the schedule became more detailed as decommissioning progressed, Maine Yankee management realized the importance of having and maintaining a clear understanding of the optimal schedule throughout the project.

As a result of this planning, it became clear that in addition to site characterization, other activities should also be completed to facilitate the D&D scope. The first focus had to be nuclear safety. At the time of plant shut down, all fuel was stored in the spent fuel pool because no previous dry-storage activities had been implemented. The decision was made to address spent fuel storage in parallel with D&D. Therefore, a nuclear island, including the spent fuel pool and support systems, was designed and developed to maintain protection of the fuel while D&D, including original plant systems removal, was going on around it.

All three plants shut down before the end of their licensed life. None of them had an independent spent fuel storage installation (ISFSI). Fuel transfer from the spent fuel pool needed to occur during decommissioning and became critical path. During the fuel transfer phase, maintaining an operations-like focus in the midst of a decommissioning environment was critical to the success of fuel transfer and therefore the whole decommissioning project. Ideally, plants approaching decommissioning should plan to have their spent fuel pools as empty as possible so that the spent fuel pool island would not be necessary and the final fuel transfer operations would not extend the end date of the project.

Another activity that was implemented prior to the start of D&D was taking the rest of the buildings that needed to be decommissioned to a state of "cold and dark." Electricity was turned off to the buildings, components were depressurized and drained, and hazardous materials were removed. The DOC was responsible for adding temporary power sources, as need, to perform D&D. A system "reclassification and abandonment process" was important to maintaining regulatory compliance while supporting the cold and dark configuration. This process essentially removed the nuclear classification (e.g., "safety class component") for certain systems that were important to plant operations which were no longer important to the shutdown facility. Having done so, the D&D of these systems had no significance in the regulatory/license basis for the facility.

8.9.2.3 Stakeholder "Buy In"

Another critical key to success in the initial planning is to engage key stakeholders to ensure that everyone is on the same page relative to the project objectives, regulatory interfaces, cleanup criteria, issues important to the local community, etc. These relationships need to be developed early and nurtured for the entire project. Without stakeholder acceptance and confidence in the decommissioning process and activities it is difficult, if not impossible, to maintain the project schedule and continuity.

8.9.2.4 Construction Management Team

While effective early planning is vital to efficient decommissioning, the team doing this planning and implementing the plan is critical to success. D&D is more like construction than a nuclear plant outage. While the scheduling is similar, the planning is quite different. In both cases industrial safety is an absolutely critical consideration throughout the work. However, in the D&D process, it eclipses radiological safety toward the end of the project as radiological sources are removed and the risk is virtually eliminated.

A team of construction managers with nuclear experience worked well at Maine Yankee. They were able to get the D&D project on the right track early and maintain project momentum even through unexpected difficulties, such as DOC bankruptcy and consequent termination. In the end, the best approach is to balance people with plant knowledge who possess the right disposition for decommissioning coupled with new management to aggressively reduce, eliminate, and simplify processes where practical. A mix with “change managers” who have clear authority is essential.

8.9.2.5 Downsizing Operations Workforce

The biggest controllable cost in decommissioning is manpower. It is difficult to downsize the operating workforce as a plant moves into decommissioning—particularly when the shutdown for decommissioning is unexpected, as it was for Maine Yankee. However, the plants that have been slow to efficiently accomplish this downsizing have had higher decommissioning costs. Maine Yankee developed an early destaffing plan that retained needed workers and released the rest. Severance packages, early retirement, and worker transition services helped workers make the transition. The major downsizing occurred over about a three-month period. While downsizing is never easy, workers generally seemed to cope best with the transition when they understand their expected duration of employment and recognize early on that the end is near.

Another advantage to early and aggressive downsizing is that it opens up opportunities to bring in workers with skill sets that are more suited to a decommissioning environment. Also, if these workers are contractors, they tend to be more accustomed to completing a given scope of work and moving on to another job. They tend to have less of an “employment for life” mindset.

Of course, some plant operations workers will be needed for some time in decommissioning. Maine Yankee retained a few workers from almost every operating plant department throughout decommissioning, particularly maintenance, radiation protection, licensing, finance, and quality assurance. Operators were particularly helpful for tagging out equipment, draining systems, and managing groundwater and process water discharges.

Some nuclear plant operations skills are helpful in decommissioning. Verbatim procedure compliance is essential in decommissioning, as it is in operations. This requirement presents two challenges: having credible procedures and teaching construction workers that they must follow them. In general, most plant operations procedures are not applicable to decommissioning. At Maine Yankee and Connecticut Yankee the site characterization, fuel transfer as well as some decommissioning activities were delayed while procedures were revised or developed to deal with activities that were not anticipated while the plants were in operations. Since verbatim procedure compliance is not optional, procedures vary in terms of the level of specificity and work controls. For example, activities involving the safety of nuclear fuel require more controls than other industrial work activities where “skill of the craft” is sufficient to accomplish a given task.

But the real success in human resource management is the staffing forecast. All positions had end dates in the ones I used. We openly communicated the end dates and updated them on a quarterly basis. Everyone knew where they stood. This reduced uncertainty and anxiety and helped foster trust with senior management. It makes good sense for both the company and its workers.

8.9.3 Decommissioning Management: Set Clear, Realistic Goals and Monitor Performance Routinely

8.9.3.1 Industrial Safety

Decommissioning work can be dangerous. A careful and complete safety analysis is important. This includes industrial and radiation safety of workers, nuclear safety, environmental protection, and public safety. Cost and schedule, although critical measures of success, are less important than personnel safety. It is vital to convince everyone on the project that it takes day-by-day focus and managers "walking the talk" to establish a strong safety culture. Briefings involving the workers and project supervisors should occur before each new job. Daily briefings are important in identifying potential changed conditions. It is important that every worker be empowered to stop a job if unsure about the safety. Managers, likewise, are expected to be safe themselves, insist that workers be safe and get out in the field to validate that their expectations are being met. Two methods to drive the safety message are requiring all site managers to spend time in the field every day and requiring at least one manager to be in the field every hour of the workday to verify performance in the field is consistent with the safety requirements.

8.9.3.2 Radiological Safety

It was found that managers needed to be as frugal with project dose as they were with project dollars. Health physicists who understood the work allocated dose to each project and monitored its use at least weekly. The dose budgets for all the jobs were summed up for an overall annual dose goal, which was then reduced by 15%–25% to encourage dose savings. As with dollars, dose is not used in a linear manner throughout a particular job in that various stages of a job demanded varying exposures depending on the dose of a given task. Dose goals were not considered met for a particular job until the entire job was completed.

Total project dose estimated early in the projects tended to be conservatively high. As radioactive sources were removed and low-dose work practices improved, the actual exposures tended to drop. Strategic use of special robotic tooling was helpful in addressing highly contaminated components or structures, thus allowing us to eliminate "hot spots" early on a reduce the exposure to the workers.

8.9.4 Project Approach

8.9.4.1 Decommission Operations Contractor

Two of the three projects were started with a general or Decommissioning Operations Contractor. In both cases the DOC contract was terminated, and the remaining work was done via self-performance. The lessons learned outlined above, e.g., good planning by a strong team, should help to ensure the success of either approach.

8.9.4.2 Firm Fixed-Priced Contracts

Firm fixed-priced contracting is important to risk-sharing and cost control where project scopes can be well defined by project management. Firm fixed-priced contracting is difficult in first-of-a-kind activities or when well-defined activities are undertaken in substantially different economic environments for the first time. Here again, good planning, detailed cost understanding, and schedules developed by a knowledgeable management team lead to more successful firm fixed-priced jobs. Even if management chooses not to employ firm fixed-priced contracting for the entire D&D scope, it can be employed successfully in major portions of the work.

8.9.4.3 Earned Value Performance Monitoring

Comparing actual spending to budgeted or planned spending isn't good enough. In fact, it can lead to wrong conclusions. All of our spending was measured relative to the work being performed. Each scope of work in the decommissioning had an established cost, based on the initial total-cost-to-complete estimate, for which performance was tracked. Earned-value performance monitoring provided us with the best understanding of project progress. This method is particularly useful with firm fixed-priced contracting when both parties agree to the concept and the earned value metrics. Here again, management needs to know enough about the project to develop credible earned value/cost metrics. Earned-value percent complete also provided stakeholders, particularly our boards of directors, with an understanding of project status and progress.

8.9.5 Project Cost Control

Project cost control needs to be integrated up-front into project planning and must be continually reinforced. We held monthly budget meetings where managers of subprojects were held accountable for their performance and given assistance if required. The project cost-control professionals are more than "bean counters." They need to understand cost estimating as well as the project and field operations well enough to anticipate potential cost problems and help field supervisors stay ahead of them.

8.9.5.1 Financing

Since these three plants were shut down prior to the end of their planned operating lives, decommissioning funds were initially inadequate to finance the total costs for decommissioning. Through a rate regulatory process, costs were reviewed and generally accepted as allowable to be billed to electric customers. Success in completing the projects leads to a higher acceptance that ratepayer costs are being minimized. Today, all three projects have substantially paid for their decommissioning costs and are now building reserves to store spent nuclear fuel for years into the future.

8.9.6 Stakeholder involvement

The stakeholders we worked with included our employees, contractors, boards of directors, regulators, elected officials, media, and the public. We developed performance indicators to provide a simple measure of project safety and regulatory, financial and schedule performance. These indicators were the same for all groups. As a communications tool, straightforward monthly reports to the Board of Directors were provided, and routine Board meetings to address project status were held. These reports included a narrative of progress and issues as well as a monthly update of our key performance indicators. Additionally, meetings were held with elected officials and regulatory agencies on a regular basis to keep them apprised of project progress.

In dealing with public and media communications, we found community advisory panels to be particularly effective. These groups were sponsored by the companies but made up of credible community leaders. The panels usually met on a periodic basis but met more frequently early in the project and during busy times. The panels also met when a particular issue of public concern was anticipated and/or raised in the media. The meetings included briefings by project personnel on project status and issues and opportunities for the panel members and public to ask questions and provide input. Initially, the exchanges could be heated, but over time, as the panel members and others became convinced that we would provide responsive information, the tone became more civil. Also, media representatives who attended these meetings provided the information and context to the public.

8.9.7 Summary: Key Challenges for Decontamination and Decommissioning Work

- Transitioning from operations to decommissioning
- Verbatim compliance: Developing clear procedures, work instructions, and expectations and holding workers, supervisors and managers accountable for compliance
- Developing a strong deconstruction-focused project team while maintaining an operations-focused fuel storage and transfer group
- Building morale of many workers (goal is job elimination not longevity)
- Planning for significant waste volumes with limited waste disposal options
- Integrating site closure with full resolution of all radioactive, nonradioactive, and groundwater remediation issues
- Securing stakeholder approval for the financing of decommissioning due to initial funding shortfalls caused by the earlier than scheduled permanent shutdowns
- Using large-scale demolition equipment while still maintaining radiation exposure controls

8.10 Big Rock Point Decommissioning Project

8.10.1 Background

When the Big Rock Point Nuclear Power Plant shut down August 29, 1997, it was the oldest and longest-running nuclear plant in the United States. Prime contractor Bechtel Corporation had completed the Big Rock Point Plant, the nation's fifth commercial nuclear plant, in just 29 months at a cost of $27.7 million. In September 1962, it became the world's first boiling water, direct-cycle, forced-circulation, high-power-density nuclear reactor facility to produce power. Other events of significance are as follows:

- Provisional Operating License issued August 30, 1962
- Initial criticality achieved September 27, 1962
- Initial power operation achieved December 8, 1962
- Commercial operation began March 29, 1963
- Full-Term Operating License issued May 1, 1964
- Power level increased from 157 MW to 240 MW on May, 1964
- Certification of permanent cessation of operations submitted on June 26, 1997
- Operation permanently ceased August 29, 1997
- Fuel was transferred to the spent fuel pool by September 20, 1997
- Fuel permanently removed from the reactor vessel on September 20, 1997
- Certification of permanent fuel removal submitted on September 23, 1997
- Completion of site remediation on August 29, 2006
- Estimated date for final closure—December 30, 2012

The Big Rock Point Nuclear Power Plant, a relatively small nuclear energy pioneer near Charlevoix, Michigan, was designed by General Electric Company and operated by Consumers Energy. The plant began as an R&D center to study the life extension capabilities and efficiencies of different nuclear fuel combinations and to prove that large power reactors could be a viable source of reliable electric generation. In 1997, Consumers Energy determined that the small size of the plant relative to the size of contemporary power plants was likely to make it too expensive to operate in an increasingly competitive environment.

Shortly after it permanently stopped generating electricity in August 1997, the process of decommissioning the plant began. Over the next nine years, the decommissioning process included all areas used during plant activities and dismantling and removing all plant equipment, structures, piping, concrete and steel.

At the end of 2006, the only remaining evidence of Big Rock Point's career was the dry fuel storage facility and part of the road that once led to the plant. Once the used fuel is shipped to a federal repository (e.g., Yucca Mountain, Nevada), the last remnant of the plant will be removed and the 560-acre site along the Lake Michigan shoreline will be restored to its former condition.

8.10.2 Regulatory Process

The goal of decommissioning was to completely dismantle the plant, remove all waste material and any contaminants, and return the site to unrestricted use. Big Rock Point submitted a Decommissioning Plan in 1995, in anticipation of the expiration of the operating license in 2000. The licensee chose the SAFSTOR (safe storage) option. In 1996, the Decommissioning Plan was converted to a post-shutdown decommissioning activities report (PSDAR).

On September 19, 1997, the licensee, Consumers Energy, submitted a PSDAR in accordance with 10 CFR 50.82(a)(4) along with other documents associated with decommissioning (Offsite Dose Calculation Manual, Defueled Technical Specifications, Defueled Emergency Plan, and Emergency Plan Exemption). This PSDAR changed the decommissioning option to DECON (decontamination and dismantlement) and planned that decommissioning activities would conclude in September 2002. Since this represented a significant change to the licensee's PSDAR, the staff conducted a public meeting on November 13, 1997, to inform the public of the change. On March 26, 1998, Consumers Energy submitted a revised PSDAR that extended the conclusion of decommissioning to about August 2005.

Consumers Energy submitted a license termination plan (LTP) on April 1, 2003. After negotiating a memorandum of agreement (MOA) with the Michigan State Historic Preservation Officer, NRC approved the LTP on March 12, 2005. The LTP prescribes a decommissioning plan for the site that leads to unrestricted use. All systems and structures not needed for the spent fuel storage installation (except the intake piping and sanitary drainfield) have been removed in accordance with the plan. As part of license termination, Consumers Energy plans to release all parts of the site not required for spent fuel storage support in accordance with 10 CFR 50.83. The LTP calls for final status surveys to be completed by October 2006 and anticipates a request for partial site release before the end of 2006. After fuel is removed from the site to a DOE facility such as Yucca Mountain, the independent spent fuel storage installation will be decommissioned and the license terminated. The LTP states there events will occur in 2012.

Early in 2006, Consumers Energy announced that the site, including the spent fuel storage installation, was for sale. In July, it announced that the spent fuel storage installation will be a part of the sale of the Palisades facility to Entergy Corp., who will be required to obtain an NRC license for the installation's operation.

8.10.3 Public Involvement

The primary parties with an interest in the site are the State of Michigan and the City Councils of surrounding areas. The Michigan State Historic Preservation Officer (MSHPO) declared the facility itself eligible for the National Historic Register. Therefore, demolition is defined as an adverse effect that requires a formal MOA in accordance with 40 CFR 800. The MOA was negotiated to address the issues of early notification to State Historic Preservation Officers of NRC plans; documentation of the site using the Historic American Engineering Record System; and post-license termination access to the site by Native Americans, for whom the Big Rock is an historic gathering place. NRC, the MSHPO, and Consumers Energy executed the MOA in February 2006.

Two independent organizations contributed greatly to Big Rock Point's operational and decommissioning success. Plant management voluntarily established the Citizen Advisory Board (CAB) and the Restoration Safety and Review Committee to provide input and guidance concerning operation and decommissioning activities and plans. The CAB was established in 1995 and was composed of community leaders from four surrounding counties.

8.10.4 Decontamination and Demolition

One of the early decontamination steps was a reactor coolant system chemical decontamination performed during December 1997 and January 1998. On February 23, 1999, a separate decommissioning power system was energized to avoid potential electrical hazards hidden within walls, floors, ceilings or the machinery during decontamination and demolition. The system earned a "Project of the Year 2000" award from *Power Engineering* magazine because it increased employee safety and provided a model for future decommissioning projects.

In 2001, the alternate shutdown building was the first structure at Big Rock Point to receive a radiological survey and be pronounced clean prior to demolition. Within three days, the structure—built to withstand earthquakes, tornadoes and floods—was reduced to rubble. All 765,000 pounds of the former building were collected and placed in a quality verification area.

By the spring and summer of 2004, diamond-wire saws were used inside the containment sphere to slice the concrete reactor cavity into sizes weighing up to 20 tons each. In the fall of 2004, the most visible change to the skyline came with the removal of Big Rock Point's 240-foot-tall red and white stack. During the plant's operation, the concrete- and steel-reinforced stack had served as a ventilation structure. Segmentation was chosen over the use of explosives to enable better control of dust and debris. The stack was dismantled in 12 separate sections, each weighing as much as 39,000 pounds. Erecting the 300-foot-tall crane used to dismantle the stack required permission from the Federal Aviation Administration.

In 2005, the turbine building and containment sphere were the last major structures demolished. All interior surfaces of the turbine building had earlier been surveyed for radiological material before dismantlement. In preparation for the sphere removal, more than 1 million pounds of concrete that once cradled the reactor inside the familiar "green ball" were carefully removed and assessed before disposal. The 9,000-pound containment sphere cap was the first of 90 pieces to be removed and lowered to the ground in mid-September 2005. Some of the sections weighed up to 20,000 pounds, and the project spanned two months. Before the concrete monolith inside the containment sphere could be demolished, along with the foundation of the blue-green containment sphere 30 feet belowground, it first had to be "softened" using explosives. In December 2005 and February 2006, four controlled blasts were detonated to fracture—but not drop—the containment structure, which stood nearly eight stories at its apex. A 16,000-pound wrecking ball and hydraulic-powered equipment finished the job.

8.10.5 Waste

The decommissioning process created large volumes of waste material. As an NRC licensee, Consumers Energy was required to consider virtually all decommissioning waste leaving Big Rock Point as low-level radioactive waste (LLRW), unless it could be shown that the material did not include any radioactivity above background levels.

Much of the material was ordinary, uncontaminated building demolition material deemed to be "nonimpacted" by radioactive contaminants. Some of this nonimpacted rubble was shipped to a Michigan Type II landfill as normal demolition debris, following on-site procedures to comprehensively assess the material and ensure that the rubble was free of radioactive contaminants. After passing these procedures, more than 1,000 shipments containing more than 59 million pounds of nonradioactive, clean building material were packaged and shipped for disposal. Consumers Energy had applied for, and received, approval from NRC to dispose of this nonimpacted debris under 10 CFR Section 20.2002 Method for obtaining approval of proposed disposal procedures, allowing for an alternate disposal method. Under this provision, Consumers Energy was required to demonstrate that this disposal method would not adversely affect public health or the environment.

One of the final stages of decommissioning, the removal of the base of the containment sphere, produced a very large volume of rubble. In total, more than 32 million pounds of concrete was removed, including 23 million pounds that once housed equipment and 9 million pounds that supported the sphere. This material was shipped to a radioactive waste treatment facility to undergo a waste evaluation process known as "Green is Clean." This evaluation determines which material is free of radioactive contaminants and can, therefore, be disposed in an ordinary landfill. The remaining material was considered LLRW, which had to be properly treated and disposed. Some hazardous waste was also produced, such as asbestos and contaminated oils.

More than 53 million pounds of LLRW were shipped to South Carolina, Tennessee, and Utah. Some of the more than 2,000 shipments presented unique challenges, such as shipping the plant's steam drum, reactor head, and 565,000-pound steel package that contained the reactor vessel. On August 25, 2003, almost six years to the day after the plant's historic shutdown, the reactor vessel was lifted out of the concrete cavity that encased it. In a process that took nearly seven hours, the reactor vessel was put into a specially designed shipping container. The largest component and the heart of the plant then left for its final resting place at a licensed disposal facility in Barnwell, SC on October 7, 2003. The rail journey took eight days and covered approximately 1,200 miles through seven states. Since the entire package—reactor, concrete packing and shipping container—weighed more than 565,000 pounds, the train was limited to 10 and 25 miles per hour throughout the trip. On November 5, 2003, about one month after removal of the reactor, the steam drum was shipped by rail to a licensed disposal site in Clive, Utah. It arrived 13 days later, after passing through seven states and covering about 1,800 miles. The steam drum weighed 200,000 pounds and was almost 41 feet long and up to 10 feet in diameter.

8.10.6 Dry Fuel Storage

All of the spent fuel was loaded from the pool into transportable dry storage systems at an on-site interim storage facility. By May 2, 2003, after a project that was completed in less than six months, 441 fuel bundles and other equipment had been overpacked and moved into dry fuel storage safely and without incident. The containers are currently guarded and monitored around the clock.

8.10.7 Residual Environmental Contamination

Contaminants at the site include uranium and its decay products, and fission products. Low levels of groundwater contamination, primarily tritium, are nonuniformly distributed at the site because of a dry, silty clay layer that underlies only the south part of the site. Boundaries between the geologic units are only approximated because of limited subsurface data. Reported radionuclide concentrations in groundwater are generally less than the minimum detectable activity (MDA) except for tritium that is less than one half the EPA drinking water standard of 20,000 pCi/L. Soil contamination is also generally below the MDA.

8.10.8 Site Release

The NRC announced on January 11, 2007 that it had approved Consumers Energy's request to release a majority of the Big Rock Point Nuclear Power Plant site for unrestricted public use. The approximately 435 acres being released is below NRC regulatory requirements that allow a maximum radiation dose of 25 millirem per year from residual contamination. NRC concluded that release of this land for unrestricted use poses no threat to public health and safety. Big Rock Point's licenses will still apply to the site's dry cask storage facility, where the spent nuclear fuel from the plant's 35 years of operation is stored, plus a parcel of land surrounding this facility. The total land remaining under the licenses is approximately 107 acres. Consumer's Energy remains responsible for the security and protection of this land and the dry cask storage facility and is required to maintain $44.4 million in nuclear liability insurance coverage for the facility.

9. STAKEHOLDER CONCERNS

Many stakeholders are concerned about planned or ongoing D&D activities. These include communities living nearby nuclear-contaminated facilities, Site-Specific Advisory Boards, tribal governments, local governments, a variety of nongovernmental organizations, as well as most federal and state regulatory agencies. In addition, because all nuclear power reactors will eventually undergo decommissioning, lessons learned from earlier decommissioning and the application of innovative technologies are important considerations in developing cost estimates for power reactors. These costs are paid for by ratepayers and are regulated by state public utility commissions, so the universe of interested stakeholders is very large. The concerns addressed in this section, however, are mainly of those living near facilities that will be decommissioned. These concerns, considered in the following subsections, can be divided into several categories:

- community participation
- decommissioning pathway
- future use
- health and safety
- waste and waste destination
- ecosystem protection

9.1 Community Participation

Prior to beginning D&D activities, the public should be fully informed of planned activities and potential consequences. A community relations plan—which is required under CERCLA—should be developed and interested parties should be involved in the planning process. This approach not only serves the purpose of keeping the public informed but also provides guidance to communities about the timing of potential construction and transport of waste materials through populated areas.

Receiving new information and comments from the community is crucial and required by statute and regulations. In many instances, communities are able to provide valuable information on local history, citizen involvement, and site conditions. However, while recent experience (such as at Brookhaven National Laboratory (BNL), where three reactors are scheduled for decommissioning) indicates that aspects of community participation are often overlooked.

The majority of regulatory statutes applicable during decommissioning, such as the AEA and CERCLA, were enacted with a purpose of protecting public health and safety. These laws typically require certain levels of public involvement. Under a CERCLA action, the party conducting the cleanup is required to conduct a number of activities to ensure community participation. For example, the lead agency normally conducts community interviews and develops a community relations plan to help determine the community's level of interest in the site, its major concerns and potential issues. The lead agency creates an information repository and administrative record for every site and makes it available to community members. The lead agency also typically develops a document specifically for the community which explains the various cleanup options under consideration, holds at least one meeting to explain the options, and invites the community to submit comments on them. Under its Technical Assistance Grant Program, EPA also may make funding available to eligible community members to enable them to obtain technical assistance to better understand the often complex issues associated with cleaning up a Superfund site. By identifying the public's concerns, EPA and the lead agency are able to fashion a response that both is protective of human health and the environment and effectively addresses the community's concerns and needs. DOD and many states may also have technical assistance programs for interested parties.

DOE has mechanisms for involving stakeholders and state and tribal governments in the planning processes. DOE has issued guidance addressing public involvement and holds public meetings and workshops throughout the year to address views and concerns about DOE project planning and decision making. *The Secretarial Policy on the National Environmental Policy Act*, issued in June 1994, established the DOE practice of incorporating National Environmental Policy Act (NEPA) public participation values into CERCLA regulatory documents. The DOE cleanup program currently works with Site-Specific Advisory Boards. In addition, DOE's national cleanup program includes consultation with a national Environmental Management Advisory Board. These boards are a good resource for advice and recommendations concerning environmental restoration, waste management, and technology development (see *Issues of Long-Term Stewardship: State Regulators' Perspectives,* ITRC 2004). Among the wide variety of topics addressed by the advisory boards are future use, risk management, appropriate cleanup levels, economic development, and budget prioritization. Advisory board membership reflects the diverse groups affected by DOE cleanup activities, such as local governments, tribal nations, environmental and civic groups, labor organizations, universities, and industry. DOE once used, though no longer funds, Citizen Advisory Boards. CABs composed of stakeholders were used by DOE in its economic transition, waste management, and environmental restoration programs. The CABs were subject of a major study (Williams 2002) which showed that the stakeholder model was effective: the advisory board was expeditiously organized, reached consensus on critical issues, and accomplished its primary mission. The CAB's performance was such that the

Clinton administration considered it a major example of how federal agencies could be "reinvented" to produce a government that works better and costs less.

NRC has also created various public involvement opportunities to facilitate open communication between NRC and local communities. Additionally, any member of the public may petition NRC to take enforcement actions to address potential health and safety issues. If warranted, the NRC will take the appropriate action, such as modifying, suspending, or revoking a license. NRC also allows interested members of the public to observe meetings between NRC staff and licensees. These meetings are announced on the NRC's public information Web site. Summaries of these meetings are also placed on the Web site to allow the public to review the meeting's discussions.

Under certain circumstances, the National Environmental Policy Act of 1969 may also provide a process for public input on proposed federal actions. Section 102 of NEPA requires that an EIS be prepared for any proposed "major federal action(s) significantly affecting the quality of the human environment." An EIS provides an analysis of the environmental impacts of a proposed action and of all reasonable alternatives and makes the resulting environmental information available to the public and the agency decision makers before the proposed action is taken. NEPA requires that the agency preparing the EIS solicit comments on a draft EIS from other federal agencies, appropriate state and local agencies, Indian tribes, and the public, including any person or organization that may be interested in or affected by the action being considered.

9.2 Decommissioning Pathway

Communities generally do not favor prolonged cleanup approaches with uncertain funding, which shift the burden for environmental cleanup to another generation. Thus, immediate dismantlement (i.e., the DECON approach) is preferred unless it can be demonstrated that it is significantly safer to use SAFSTOR. The public generally is not favorable to the ENTOMB approach because it will leave the object of concern in place for the foreseeable future. Many factors must be considered when determining the disposition path, including the projected cost of ongoing S&M and agreements among the nuclear facility owners, tribal governments, state regulators, local community planners, and various stakeholders. In all cases, the process must have the goal of minimizing exposures to workers and the public, maximizing protection of the environment, and satisfying the concerns of the various stakeholders.

If a decommissioning option leaves radioactive material in place, then an analysis for that option should assess risks over the time period required for the radioactivity to decay to a negligible level. The analysis should consider, for example, the long-term potential for contamination of groundwater and the resulting potential for exposure of people to radiation.

9.3 Future Use

Many stakeholders believe that they should be full partners in future land-use decisions. Generally, the public favors decommissioning that leads to unrestricted use. If not possible, the smallest area possible should be set aside, and institutional and engineering controls should be incorporated into the activity. These should include surveillance and monitoring systems, and permanent markers should be developed for contaminated sites. If D&D leads to restricted land use, a long-term stewardship program must be developed at DOE sites. This program may include institutional controls and long-term monitoring requirements. At NRC regulated sites where the site is designated for restricted use, an equivalent program should also be put in place, including institutional controls and monitoring requirements.

9.4 Health and Safety

During demolition and deactivation, efforts should be taken to keep radioactive exposure to the general public to negligible levels. Risks to worker health and safety should also be kept to a minimum, following NRC's ALARA policy. A related concern is that the strictest cleanup standards be applied. Cleanup standards may differ from site to site based on risk assessments. However, communities generally want to see the most protective standard that has previously been applied nationally. Similar to the PRG approach for identifying remediation goals, communities often ask for cleanup standards that are at least as protective as 10^{-6} levels. For example, the Safe Drinking Water Act sets a limit for tritium in drinking water at 20,000 pCi/L.

As another example, the PRGs selected by DOE for the BNL reactor decommissioning were far less stringent than EPA PRGs. A study by Thompson (2004) conducted a detailed comparison of the PRGs at BNL and concluded that there was no internal consistency in the relative magnitude of the various PRGs even if they were adjusted to the same dose level. See also Section 3.3 for information on PRG tools for decommissioning.

Establishing background levels of some contaminants can be very contentious, since manmade contaminants developed at nuclear facilities often have very few benchmarks with which to establish background levels. At Alameda Naval Air Station, a closed naval facility in California, radium used in paint was disposed of in an on-site landfill. To establish cleanup levels, the Navy used background data from a geographically separate area nearby. The community objected to this. However, it should be pointed out that Alameda is essentially an island that was dominated by naval activities, and therefore obtaining what could be considered to be a representative sample to establish background was difficult if not impossible.

At some facilities, past releases of contaminants are discovered during the D&D process. These levels should not be assumed to be background, although they are not specifically associated with D&D activities. For example, at the Plum Brook Research Reactor near Sandusky, Ohio, coincidental with decommissioning planning, National Aeronautical and Space Administration (NASA, operator of the reactor) discovered radioactive cesium and cobalt in a drainage channel that feeds into Lake Erie. The contamination had spread one mile through a residential area. NASA is currently addressing this problem separately from its selected decommissioning option (SAFSTOR). It may be difficult for the affected public to differentiate the source of this contamination from those releases directly resulting from decommissioning activities. This type of complication needs to be understood by the regulator in the interactions with stakeholders.

The type and extent of radioactive contamination depend on the function of the facility. For example, the major source of contamination in an accelerator facility is likely to be in the form of activated metals and concrete, whereas the principal concern in a fuel-processing facility would probably be surface contamination. In addition, many facilities likely contain chemical and toxic hazards to some degree or other (e.g., asbestos-containing insulation) hazards. In most cases, the identities of the major contaminants can be deduced from the operational histories of these facilities, but their actual magnitudes and distribution must be determined through characterization.

9.5 Waste and Waste Destination

The public generally does not favor interim storage of waste materials on site. If this remedy is chosen, full transparency of waste storage policies is important, with a commitment that storage will not exceed a certain amount of time. Blending waste with uncontaminated material may be discouraged by the general public.

The comparative risks of leaving radioactive material in place or removing it are central to evaluating debates about decommissioning options. If radioactive material is transported to a disposal site, a risk assessment should address the short-term risks associated with removal and transportation of radioactive material and the long-term risks associated with the material's burial at a disposal site.

It is important that waste is properly stored and packaged. If transported, it should be in containers that meet DOE requirements for heat, radiation, pressure, and breakage. In the late 1990s, when DOE was shipping Rocky Flats wastes, it had proposed to ship it in containers that did not meet these specifications. DOE was sued by environmental groups and consequently shipped the waste to a different facility.

A good barometer does not exist for community concerns regarding where waste should be disposed. Each destination will have its detractors. However, lead agencies should expect that this may become an issue and be fully prepared to back up their decision.

9.6 Ecosystem Protection

D&D activities are similar to construction in reverse. Many stakeholder groups are concerned about protecting wildlife and ecosystems. While decommissioning a facility, it is important that measures be taken to minimize impacts to ecological receptors.

10. LESSONS LEARNED

Considerable experience and knowledge has been gathered over the recent years in the United States regarding D&D activities at radiologically contaminated facilities. In a review of the cleanup at Rocky Flats, the GAO observed that DOE has no process for ensuring that all lessons are captured and implemented at other DOE sites. The GAO concluded that DOE may be losing the chance to save both time and money in its ongoing site cleanup efforts (GAO 2006).

This final section summarizes the "lessons learned" that were gathered by the ITRC Radionuclides Team in undertaking the effort to survey the current status of D&D activities and draws both from the material presented in this document and from the considerations and deliberations that took place in team's examination of the material. In addition to the factors listed in this section, lessons learned from specific sites are included in several case studies in Section 8. The list of management considerations in Section 5.6 are also pertinent.

10.1 Lessons Learned from this ITRC Decontamination and Decommissioning Document

In a large D&D site operation where a number of generally similar activities will take place, one should enter the process with an attitude open to learning lessons and use all prior operations, both at the site in question and from earlier efforts, to gain valuable information for all subsequent work. The following factors are offered for consideration in making D&D more successful.

- End-States—The anticipated future site use should be established before implementing D&D activities.

- Unexpected Issues—In all stages of D&D, one should expect the unexpected and hence plan for contingencies. D&D projects vary greatly, and unique situations occur frequently.

- Documentation—Thorough documentation is very important since the final activities of a D&D project may take place years after the first.

- Communication—All responsible parties should be involved early in the process. Stakeholders and regulators are important and should be kept up to date with ongoing plans. The D&D plan should have well-defined goals and mutually agreed-upon end-points. Documentation is an important part of the process and the final record. Former employees are an asset; their knowledge of the facility can be very useful in planning and other activities.

- Planning—Early planning is essential and should incorporate environmental considerations along with technical and economic issues in decision making.

- Removal Actions—At CERCLA sites, D&D can be expedited by using removal authority, also known as "accelerated cleanup." It is a joint policy between DOE and EPA to use removal authority to perform D&D. See Section 3.4 for additional information.

- Residual Material—If in-process material is allowed to remain in the various production facilities' tanks and pipelines, D&D is greatly complicated and future risks and liabilities can be greatly increased.

- Information exchange—Learn from other D&D activities and identify processes that may solve problems at the current site. Technical workshops or public meetings dealing with D&D in other areas should be sought out. Pilot studies and case studies are good sources of knowledge.

- Innovative Technologies—Innovative technologies should be evaluated and can result in lower life-cycle costs, accelerated schedules, and reduced worker exposure. Established technologies from other sites should be reviewed.

- Site History—Past history of the site must be reviewed. Documentation that lays out the purpose, function, and events associated with the site should be gathered, and personnel present during prior operations at the site should be used. Data gaps can then be addressed.

- Characterization—Characterization is a continuous process. It is conducted to understand health and safety concerns for workers, protect human health and the environment, understand the nature and extent of contamination, and anticipate the disposition of waste.

- Cleanup Levels—Standards for acceptable levels of residual contamination must be developed for equipment, soil, and any recyclable resources before release for restricted or unrestricted use. Appropriate decontamination levels may vary from site to site and depend on future site uses, the controlling authority (EPA CERCLA risk range, NRC dose limits, guidelines in DOE Orders, state standards or decommissioning criteria, etc.), stakeholder input, and other site-specific factors. See *Determining Cleanup Goals at Radioactively Contaminated Sites: Case Studies* (ITRC 2002).

- Waste Management—Expertise on regulations for handling and packaging the waste allotments should be available. Waste destination, containers, transportation issues, and cost involved with disposal methods should be evaluated. Uncertainty about waste disposal availability is expected to continue, and decommissioning plans must adapt to changing conditions regarding this important step in the process. Waste reduction, both during operation of the facility and decommissioning, should be an important feature.

- Recycling/Reuse—From a practical point of view, though recycling is commendable, cost and liability considerations often mean that only clean, segregated material can be recycled. If there is an on-site disposal facility, then recycling is unlikely to be cost-effective and is thus unlikely to be chosen as an option, particularly when there is a cost-performance contract in place. If there is no on-site disposal facility, then recycling becomes a more viable option.

- Safety—It is essential to have a good safety program that informs the workers, regulators, and the public of site hazards and either contains or eliminates them. Improved safety performance results from top-management involvement, planning, training, and allocating responsibility to first-line supervisors.

- Detection Limits—If field equipment is not sufficiently sensitive to detect contamination at levels as low as the cleanup criteria, it may be necessary to send samples to an off-site laboratory for analysis. For information on real-time field-detection methods, refer to *Real-Time Measurement of Radionuclides in Soil: Technology and Case Studies* (ITRC 2006).

- Labor/Costs—A contractor with previous knowledge and experience with the D&D process should be hired. To include all goals associated with D&D of the facility, all responsible parties should be involved with planning. A project team with the proper resources and experience to evaluate the task should be assembled. Potential problem areas should be envisioned early so as not to hinder the project target dates. Decommissioning is labor-

intensive; thus final costs are very sensitive to changes in labor rates. Cost savings can result from the following:
- operating efficiencies that result from eliminating unnecessary duplication of management at multiple project sites
- subcontracting for multiple scopes of work
- retaining an experienced workforce
- avoiding demobilization and remobilization

- We expect that, with experience, there will be operational efficiencies generally consistent with a learning curve. With this increase in efficiency, we generally expect some cost reduction.

10.2 Lessons Learned from Other Resources

Many resources on D&D lessons learned are readily available in the wider literature. The following summary of some of the more relevant source is not comprehensive but provides a starting point for further exploration.

NRC provides two Web sites related to decommissioning. The "Decommissioning Lessons Learned" page (www.nrc.gov/about-nrc/regulatory/decommissioning/lessons-learned.html) focuses primarily on regulatory lessons learned associated with decommissioning plans and license termination plans but contains valuable general information on the decommissioning process, such as the benefits of early coordination with all regulatory agencies and waste disposal facilities when considering waste disposal options and of conducting a comprehensive characterization of the site before starting decommissioning activities.

The NRC site's electronic reading room also contains a 2002 regulatory issues summary on "Lessons Learned Related to Recently Submitted Decommissioning Plans and License Termination Plans" (www.nrc.gov/reading-rm/doc-collections/gen-comm/reg-issues/2002/ri02002.html). This is designed to capture some lessons learned from the first six years after the 1996 revision of 10 CFR Pt. 50.82 to define a new process for decommissioning power reactors and contains useful information on communications, groundwater, data quality objectives, inspections, modeling, cost estimate, and environmental assessments.

DOE's Office of Health, Safety and Security has a "Lessons Learned Database" (DOE 2007b) that includes D&D as a work function area. The database no longer allows anonymous access and requires users to sign up for an account to view DOE Lessons Learned data. Much other information on lessons learned from DOE sites is available on the Internet, ranging from higher level summaries (DOE 1999a) to work function level (Dawson, Watson, and Hylko 2002).

IAEA has produced a vast amount of information on decommissioning and has sponsored a number of international conferences on safe decommissioning and safe termination of nuclear activities, though until recently little of the information has been presented in terms of lessons learned. Key issues facing international decommissioning programs (such as program management, waste management, engineering complexity, systems management, training, and stakeholders) have been presented in a *Decommissioning: Lessons to Learn* document (IAEA

2003) that draws on the experience of the United Kingdom Atomic Energy Authority. In December 2006 an International Conference on Lessons Learned from Decommissioning of Nuclear Facilities and the Safe Termination of Nuclear Activities was held in Athens, Greece (IAEA 2006a). A high-level overview (IAEA 2006b) provides some valuable reflections of lessons learned in areas such as planning, strategies, funding, management of radioactive waste, and technology.

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Zacha, N. J. 2007. "Low-Level Radioactive Waste Disposal: Are We Having a Crisis Yet?" *Radwaste Solutions*. May/June 2007.

Appendix A

Resources

RESOURCES

SECTION 3

Nuclear Regulatory Commission Guidance

10 CFR Pt. 20 Subpart E. Radiological Criteria for License Termination. This is commonly referred to as the "License Termination Rule."

10 CFR 20.1402 Radiological Criteria for Unrestricted Use. "A site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a total effective dose equivalent to an average member of the critical group that does not exceed 25 millirem (0.25 milliSievert) per year, including that from groundwater sources of drinking water, and the residual radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA). Determination of the levels which are ALARA must take into account consideration of any detriments, such as deaths from transportation accidents, expected to potentially result from decontamination and waste disposal."

Regulatory Guide 1.86. Termination of Operating Licenses for Nuclear Reactors. Specifies total average, total maximum, and total removable surface contamination limits for alpha and beta/gamma contamination for four categories of radionuclides. Although this standard has been in place for almost 30 years, it remains the standard for the NRC, DOE and state regulators. Original Atomic Energy Commission (AEC) version of Regulatory Guide 1.86.

NUREG 1727. NMSS Standard Review Plan for Decommissioning. Specifies requirements for decommissioning plans. Appendix D of NUREG 1727, As Low As Reasonably Achievable (ALARA), specifies methodology for cost-benefit analysis to demonstrate what levels below a 25 millirem/year cleanup standard are ALARA.

NUREG 1757, Vol. 1. Consolidated NMSS Decommissioning Guidance. Decommissioning Process for Materials Licensees.

NUREG 1757, Vol. 2. Consolidated NMSS Decommissioning Guidance. Characterization, Survey, and Determination of Radiological Criteria. (Draft Report)

NUREG 1757, Vol. 3. Consolidated NMSS Decommissioning Guidance.

NUREG 1761. Radiological Surveys for Controlling Release of Solid Materials.

Memorandum of Understanding Between the Environmental Protection Agency and the Nuclear Regulatory Commission. Consultation and Finality on Decommissioning and Decontamination of Contaminated Sites.

Distribution Memorandum OSWER 9295.8-06a.

Department of Energy Guidance

DOE Order 5400.5. Radiation Protection of the Public and the Environment. Specifies a basic dose limit of 100 millirem/year plus ALARA for operating facilities. Specifies cleanup limits surface contamination that are equivalent to R.G. 1.86. Specifies soil cleanup standards for radium and thorium based on ARARs (1/7/93).

10 CFR Pt. 834 (Draft) Radiation Protection of the Public and the Environment. Translates DOE Order 5400.5 into regulation.

DOE G 441.1-XX (Draft). Guidance for "Release and Control of Material with Residual Radioactive Material" from DOE facilities. It reiterates DOE's adoption of a dose limit of 25 mrem/year for all pathways and Regulatory Guide 1.86 for surface contamination.

California Department of Health Services (DHS), Radiologic Health Branch (RHB)

DECON-1. *State of California Guidelines for Decontamination of Facilities and Equipment prior to Release for Unrestricted Use*, June 1977.

Environmental Protection Agency (EPA) Guidance

OSWER 9200-4.18, "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination," August 22, 1997. This EPA policy memorandum establishes 15 mrem/year as a cleanup goal that is protective of public health and the environment and consistent with the CERCLA risk range of 10^{-6}–10^{-4}.

Memorandum of Understanding Between the Environmental Protection Agency and the Nuclear Regulatory Commission. Consultation and Finality on Decommissioning and Decontamination of Contaminated Sites. Distribution Memorandum OSWER 9295.8-06a.

American National Standards Institute—Health Physics Society

ANSI/HPS N13.12-1999, American National Standards Institute, "Surface and Volumetric Radioactivity Standards for Clearance," August 31, 1999. Demonstrates that Regulatory Guide 1.86 surface contamination limits set in 1974 are equal to or less than an equivalent of 1 mrem/year. Click here (www.philrutherford.com/Dose_equivalents_of_RG_1-86.pdf) for comparison table between Reg. Guide 1.86 limits and those proposed by ANSI/HPS N13.12-1999.

ANSI/HPS N13.49-2001, "Performance and Documentation of Radiological Surveys," August 6, 2001. Provides nonregulatory guidance for the performance of radiation surveys.

Oak Ridge Associated Universities

Oak Ridge Institute for Science and Education.

Environmental Survey and Site Assessment Program. The U.S. center of excellence for protocols, procedures and performance of radiation surveys.

Miscellaneous Guidance

MARSSIM, "Multi-Agency Radiation Survey and Site Investigation Manual." Guidance from the NRC, DOE, EPA, and DOD for performing final status radiological surveys.

Radiological Release Process. Process for the Release of Land and Facilities for (Radiologically) Unrestricted Use.

SECTION 4

DOE (U.S. Department of Energy), *Life-Cycle Asset Management [LCAM]*, DOE O 430.1A, October 14, 1998.

DOE, *Policy on Decommissioning of Department of Energy Facilities Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)*, May 22, 1995.

DOE, *Decommissioning Resource Manual*, DOE/EM-0246, August 1995.

DOE, *Planning and Conduct of Operational Readiness Reviews (ORR)*, DOE-STD-3006-95, November 1995.

DOE, *Safety Management System Policy*, DOE P 450.4, October 15, 1996.

U.S. Department of Energy, *Implementation Guide for Surveillance and Maintenance During Facility Transition and Disposition*, DOE G 430.1-2, September 1999.

DOE, *Deactivation Implementation Guide*, DOE G 430.1-3, September 1999.

DOE, *Decommissioning Implementation Guide*, DOE G 430.1-4, September 1999.

DOE, Office of Nuclear Material and Facility Stabilization, *Facility Deactivation Guide Methods and Practices Handbook*, DOE/EM-0318, Revision 1, August 1999 (http://dev.em.doe.gov/em60/deact/methods.html).

DOE, 10 CFR Part 830, *Nuclear Safety Management*, as amended.

DOE, *Final Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*, DOE/EIS-0200-F, May 1997.

DOE, *Integrated Safety Management System Guide for use with DOE P 450.4, Safety Management System, and DEAR Safety Management System Contract Clauses*, DOE G 450.4-1 (Vols. 1 and 2), November 26, 1997.

DOE, *Integration of Environment, Safety, and Health into Facility Disposition Activities*, Volume One: Technical Standard, DOE-STD-1120-98, May 1998.

SECTION 5

For more information and copies of EPA guidance documents for addressing radiologically contaminated CERCLA sites, see the EPA's Superfund Radiation Web page at http://www.epa.gov/superfund/resources/radiation/index.htm.

For more information and copies of EPA guidance documents for developing cleanup levels for long-term CERCLA sites, see EPA's Remedy Decisions Web page at http://www.epa.gov/superfund/action/guidance/remedy/index.htm.

Both of these Web pages contain numerous OSWER Directives, which are EPA's official guidance for the Superfund program, and other material that is useful for cleaning up CERCLA sites.

SECTION 7

http://www.rfets.gov

http://apps.em.doe.gov/ost/itsrall.html

"Spotlight on the Robotics Technology Development Program," *Initiatives Online* **5**, Fall 1998.

R. L. Glassell, S. M. Killough, P. D. Lloyd, L. J. Love, J. D. Randolph, S. D. Van Hoesen, J. A. Blank, B. L. Burks, R. E. Depew, W. H. Glover, D. D. Falter, and D. P. Vesco, "Use of the Modified Light Duty Utility Arm to Perform Nuclear Waste Cleanup of Underground Waste Storage Tanks at Oak Ridge National Laboratory," *Proceedings of the 8th International Topical Meeting on Robotics and Remote Systems*, Pittsburgh, April 1999.

T. E. Reilkoff, M. D. Hetland, E. M. O'Leary (Energy and Environmental Research Center, University of North Dakota), "Review of Industries and Government Agencies for Technologies Applicable to Deactivation and Decommissioning of Nuclear Weapons Facilities," *Proceedings of the Waste Management '02 Conference*, Tucson, Arizona, February 2002.

Modified Brokk Demolition Machine with Remote Operator Console, Innovative Summary Technology Report, DOE/EM-0597, September 2001.

Appendix B

International Agencies

INTERNATIONAL AGENCIES

From an international perspective, general information on the D&D of nuclear facilities is provided by the International Atomic Energy Agency through such publications as its Safety Series and Technical Report Series (see www.iaea.org/Publications). IAEA issues guidelines and draft codes that can serve as the basis for the development of rules and regulations by individual nations. However, the authority to impose such rules and regulations rests with the government of the nation in question. IAEA's role is thus usually confined to that of an advisory body.

Internationally, nations generally adopt a risk-reduction approach to determine the path to take in pursuing a D&D program and what processes to use. The various regulatory bodies have developed their own methods of evaluating all nuclear-related activities, including D&D. A particularly good example is the approach taken by the Health and Safety Executive in the United Kingdom, described in the publication *The Tolerability of Risk from Nuclear Power Stations* (HSE 1992a). This approach is defined in detail in *Safety Assessment Principles for Nuclear Plants* (HSE 1992b), a straightforward account written for the general public. It discusses how people normally approach risk, shows how industrial risks (including nuclear risks) are regulated, considers the broad principles of risk assessment, and explains the nature of the risk from radiation and how it is calculated. Its approach is that final judgments about whether a risk is tolerable are not matters for experts alone, but for the people who have to bear the risks as well, and emphasizes that "tolerability" means not "acceptability" but rather willingness to live with a risk—in the confidence that it is being properly controlled—so as to secure certain benefits.

Appendix C

Glossary of Terms

GLOSSARY OF TERMS

SOURCES

U.S. Department of Energy
[1] www.eia.doe.gov/cneaf/nuclear/page/umtra/glossary.html
[2] www.oecm.energy.gov/Portals/2/DOE20PM20Glossary.pdf
[3] www.em.doe.gov/bemr/BEMRPages/glossary.aspx
[4] www.orau.gov/ddsc/decomhandbk.pdf

U.S. Environmental Protection Agency
[5] www.epa.gov/radiation/docs/marlap/402-b-04-001a-glossary.pdf
[6] www.epa.gov/radiation/glossary/index.html
[7] www.epa.gov/rpdweb00/marssim/

U.S. Nuclear Regulatory Commission
[8] www.nrc.gov/reading-rm/basic-ref/glossary.html

Agreement State: A state that has signed an agreement with the Nuclear Regulatory Commission under which the state regulates the use of by-product, source, and small quantities of special nuclear material in that state. [5]

ALARA: Acronym for "as low as (is) reasonably achievable." Means making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest (see 10 CFR 20.1003). [5]

Applicable or Relevant and Appropriate Requirement (ARAR): Under the Comprehensive Environmental Responsibility, Cleanup and Liability Act (Superfund), cleanups must follow two kinds of requirements:

- applicable requirements meaning those that directly apply to the situation
- relevant or appropriate requirements meaning those that apply to contaminants that are present at the site or apply to a contaminated medium, such as water, at the site

For example, the standards for cleaning up uranium and thorium processing facility sites are frequently considered "relevant and appropriate" for radiologically contaminated sites that did not conduct such processing. ARARs can be federal, state, or local requirements. [6]

Atomic Energy Act (AEA) as amended (42 U.S.C. 2011-2296): This act administers and regulates the production and uses of atomic power. The act was passed in 1946 and amended in 1954 and several times since then. The AEA requires management, processing, and utilization of radioactive materials in a manner that protects public health and the environment and is the basis for EPA, NRC, and DOE authorities regarding radioactive materials. [3,7]

By-Product: Radioactive material from producing or processing nuclear materials. Some by-products have beneficial commercial uses. [1]

By-Product Material: The tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content. [1]

By-Product: By-product is (1) any radioactive material (except special nuclear material) yielded in, or made radioactive by, exposure to the radiation incident to the process of producing or using special nuclear material (as in a reactor); and (2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from ore (see 10 CFR 20.1003). [5]

By-Product Material: Radioactive materials left over from the production or use of special nuclear material or the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content. Regulatory definition: "(1) Any radioactive material (except special nuclear material) yielded in, or made radioactive by, exposure incident to the process of producing or utilizing special nuclear material, and (2) The tailings or wastes produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source material content, including discrete surface wastes resulting from uranium solution extraction processes. Underground ore bodies depleted by these solution extraction operations do not constitute 'by-product material' within this definition (10 CFR 20.1003)." [6]

Clean Air Act (CAA) as amended (42 U.S.C. 7401-7671 q.): The CAA protects and enhances the nation's air quality through national ambient air quality standards, new source performance standards, and other provisions. Radionuclides are a hazardous air pollutant regulated under Section 112 of the Act. The CAA sets National Emissions Standard for Hazardous Air Pollutants for Radionuclides (40 CFR Part 61, 10 CFR 20.101-20.108). [7]

Compact: A group of two or more states formed to dispose of low-level radioactive waste on a regional basis. The Low-Level Radioactive Waste Policy Act of 1980 encouraged states to form compacts to ensure continuing low-level waste disposal capacity. As of December 2000, forty-four states have formed ten compacts. No compact has yet successfully sited and constructed a disposal facility. [6] (NB: As of 2007, due to states dropping out of compacts, 42 states were grouped into 10 compacts.)

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 as amended (Pub. L. 99-499, 42 U.S.C. 9601-9657): CERCLA authorizes EPA, consistent with the National Oil and Hazardous Substances Contingency Plan (NCP, 40 CFR 300), to provide for remedial action in response to releases of hazardous substances in to the environment. The Act and its amendments created a trust fund, the "Superfund," to finance the investigation and cleanup of abandoned and uncontrolled hazardous waste sites. [3,7]

Containment structure: A gaslight shell or other enclosure around a nuclear reactor to confine fission products that otherwise might be released to the atmosphere in the event of an accident. [5]

Contamination: The deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or people. It may also be airborne, external, or internal (inside components or people). [6]

Deactivation: The process of placing a facility in a stable and known condition including the removal of readily removable hazardous and radioactive materials to ensure adequate protection of the worker, public health and safety, and the environment, thereby limiting the long-term cost of surveillance and maintenance. Actions include the removal of fuel, draining and/or deenergizing nonessential systems, removal of stored radioactive and hazardous materials, and related actions. Deactivation can also include disposition of wastes generated during deactivation efforts. Deactivation does not include all decontamination necessary for the dismantlement and demolition phase of decommissioning, e.g., removal of contamination remaining in the fixed structures and equipment after deactivation. [2]

Decommission: The process of removing a nuclear facility from service by reducing residual radioactivity in buildings or at the site to a level that permits the release of the property for unrestricted use or maintenance under protection for reasons of public health and safety. [6]

Decommissioning: Retirement of a nuclear facility, including decontamination and/or dismantlement. [1]

Decommissioning: The process of closing and securing a nuclear facility or nuclear materials storage facility so as to provide adequate protection from radiation exposure and to isolate radioactive contamination from the human environment. [2]

Decommissioning: The process of closing down a facility followed by reducing residual radioactivity to a level that permits the release of the property for unrestricted use (see 10 CFR 20.1003). [5]

Decommissioning: The process of removing a facility or site from operation, followed by decontamination, and license termination (or termination of authorization for operation) if appropriate. The process of decommissioning is to reduce the residual radioactivity in structures, materials, soils, groundwater, and other media at the site to acceptable levels based on acceptable risk, so that the site may be used without restrictions. [8]

DECON: A method of decommissioning in which the equipment, structures, and portions of a facility and site containing radioactive contaminants are removed and safety buried in a low-level radioactive waste landfill or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations. [5]

Decontamination: Removal of unwanted radioactive or hazardous contamination by a chemical or mechanical process. [1]

Decontamination: The removal of a chemical, biological, or radiological contaminant from, or neutralizing its potential effect on, a person, object or environment by washing, chemical action, mechanical cleaning, or other techniques. Deactivation may also include treatment and disposal of wastes generated during decontamination efforts. [2]

Decontamination: The reduction or removal of contaminating radioactive material from a structure, area, object, or person. Decontamination may be accomplished by (1) treating the surface to remove or decrease the contamination, (2) letting the material stand so that the radioactivity is decreased as a result of natural radioactive decay, or (3) covering the contamination to shield or attenuate the radiation emitted (see 10 CFR 20.1003 and 20.1402). [5]

Dismantlement: The disassembly or demolition and removal of any structure, system, or component during decommissioning and satisfactory interim or long-term disposal of the residue from all or portions of a facility. [4]

Disposition: Those activities that follow completion of program mission, including, but not limited to, surveillance and maintenance, deactivation, and decommissioning. [4]

Dose (radiation): Denotes the quantity of radiation or energy absorbed. Dose may refer to the following:

- absorbed dose, the amount of energy deposited per unit mass
- equivalent dose, the absorbed dose adjusted for the relative biological effect of the type of radiation being measured
- committed dose, a dose that accounts for continuing exposures over long periods of time (such as 30, 50, or 70 years) [6]

End-Points: The detailed specification of conditions to be achieved for a facility's spaces, systems and major equipment. Fundamental to the determination of end-points is risk reduction through elimination or stabilization of hazards, effective facility containment and facility monitoring and control. [4]

Entomb: A method of decommissioning a nuclear facility in which radioactive contaminants are encased in long-lived material, such as concrete. The entombment structure is maintained and monitored until the radioactivity decays to a level allowing decommissioning and ultimately, safe unrestricted use of the property. [6]

ENTOMB: A method of decommissioning in which radioactive contaminants are encased in a structurally long-lived material, such as concrete. The entombment structure is appropriately maintained and continued surveillance is carried out until the radioactivity decays to a level permitting decommissioning and ultimate unrestricted release of the property. [5]

Exposure (radiation): A term relating to the amount of ionizing radiation that strikes a living or inanimate material. (This is a general definition. In health physics, exposure is specifically defined as a measure of ionization in air caused by X-ray or gamma radiation only.) [6]

Final Status Survey: Measurements and sampling to describe the radiological conditions of a site, following completion of decontamination activities (if any) in preparation for release. [6]

Fuel Cycle: The series of steps involved in supplying fuel for nuclear power reactors. It can include mining, milling, isotopic enrichment, fabrication of fuel elements, use in a reactor, chemical reprocessing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material, refabrication into new fuel elements, and waste disposal. [5]

Graded Approach: The depth of detail required and the magnitude of resources expended for a particular management element to be tailored to be commensurate with the element's relative importance to safety, environmental compliance, safeguards and security, programmatic importance, magnitude of the hazard, financial impact, and/or other facility-specific requirements. [4]

Greater than Class C (GTCC) Waste: Low-level radioactive waste that exceeds the concentration limits of radionuclides established for Class C waste in 10 CFR 61.55. [5]

Hazardous Substance: Used synonymously with the term "hazardous material," this includes any substance designated or reflected in 29 CFR 1910.120, to which exposure may result in adverse affects to the worker, public, or environment including: (1) any substance defined under Section 101(14) of CERCLA; (2) any biological agent and other disease-causing agent that after release into the environment and upon exposure, ingestion, inhalation, or assimilation into any person, either directly from the environment or indirectly by ingestion through food chains, will or may reasonably be anticipated to cause death, disease, behavioral abnormalities, cancer, genetic mutation, physiological malfunctions (including malfunction in reproduction), or physical deformations in such persons or their offsprings; (3) any substance listed by the U.S. Department of Transportation as hazardous materials under 49 CFR 172.101 and appendices; and (4) hazardous waste (i.e., a waste or combination of wastes as defined in 40 CFR 261.3 or substances defined as hazardous waste in 49 CFR 171.8). [4]

Hazardous Waste: Any solid waste; concentration; or physical, chemical, or infectious characteristics that may; (A) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible or incapacitating reversible, illness; or (B) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed. [4]

Health and Safety Plan (HASP): A site plan, required by the hazardous materials worker regulations and prepared and followed by any employer whose workers engage in hazardous waste operations, which addresses the safety and health hazards of each phase of site operation and includes the requirements and procedures for employee protection. Guidelines for a HASP can be found in the DOE limited standard DOE-EM-STD-5503-94. [4]

High-Level Radioactive Waste: The highly radioactive material resulting spent nuclear fuel reprocessing:

- liquid waste directly produced in reprocessing or
- any solid material derived from the liquid wastes having a sufficient concentration of fission products

Other highly radioactive materials can be designated as high-level waste if they require permanent isolation. This determination is made by the U.S. Nuclear Regulatory Commission based criteria established in U.S. law. [6]

High-Level Waste (HLW): Radioactive materials at the end of a useful life cycle that should be properly disposed of, including

- the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste directly in reprocessing and any solid material derived from such liquid waste that contains fission products in concentrations
- irradiated reactor fuel
- other highly radioactive material that the NRC determines by rule require permanent isolation

HLW is primarily in the form of spent fuel discharged from commercial nuclear power reactors. It also includes HLW from activities and a small quantity of reprocessed commercial HLW (see 10 CFR 63.2). [5]

High-Level Waste (HLW): (1) Irradiated reactor fuel; (2) liquid wastes resulting from the operation of the first-cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel; (3) solids into which such liquid wastes have been converted. [8]

Integrated Safety Management: The application of the integrated safety management system (ISMS) to a project or activity. The fundamental premise of Integrated Safety Management is that accidents are preventable through early and close attention to safety, design, and operation, and with substantial stakeholder involvement in teams that plan and execute the project, based on appropriate standards. [2]

Integrated Safety Management System: An overall management system designed to ensure that environmental protection; worker and public safety is appropriately addressed in the planning, design, and performance of any task. [2]

Life Cycle: The life of an asset from planning through acquisition, maintenance, operation, and disposition. [4]

Life-Cycle Cost: The sum total of the direct, indirect, recurring, nonrecurring, and other related costs incurred or estimated to be incurred in the design, development, production, operation, maintenance, support, and final disposition of a major system over its anticipated useful life span. Where system or project planning anticipates use of existing sites or facilities, restoration, and refurbishment costs should be included. [2]

Low-Activity Radioactive Waste: Waste containing very low concentrations of radioactive material [6]

Low-Level Mixed Waste (LLMW): LLMW is waste that contains LLRW and hazardous waste. [6]

Low-Level Radioactive Waste: Radioactively contaminated industrial or research waste such as paper, rags, plastic bags, water-treatment residues. It is waste that does not meet the criteria for any of three other categories of radioactive waste: spent nuclear fuel and high-level radioactive waste; transuranic radioactive waste; or uranium mill tailings. Its categorization does not depend the level of radioactivity it contains. [6]

Low-Level Waste: A general term for a wide range of wastes having low levels of radioactivity. Industries; hospitals and medical, educational, or research institutions; private or government laboratories; and nuclear fuel cycle facilities (e.g., nuclear power reactors and fuel fabrication plants) that use radioactive materials generate low-level wastes as part of their normal operations. These wastes are generated in many physical and chemical forms and levels of contamination (see 10 CFR 61.2).

Low-level radioactive wastes containing source, special nuclear, or by-product material are acceptable for disposal in a land disposal facility. For the purposes of this definition, low-level waste has the same meaning as in the Low-Level Radioactive Waste Policy Act, that is, radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product material as defined in section 11e.(2) of the Atomic Energy Act (uranium or thorium tailings and waste). [5]

Mixed Waste: Waste containing both radioactive and hazardous constituents. [1]

Mixed Waste: Waste which contains both hazardous waste (as defined by RCRA and its amendments) and radioactive waste (as defined by AEA and its amendments). It is jointly regulated by NRC or NRC's Agreement States and EPA or EPA's RCRA Authorized States. The fundamental and most comprehensive statutory definition is found in the Federal Facilities Compliance Act (FFCA) where Section 1004(41) was added to RCRA: "The term 'mixed waste' means waste that contains both hazardous waste and source, special nuclear, or by-product material subject to the Atomic Energy Act of 1954." [6]

Mixed Waste: Waste that contains both radioactive and hazardous chemicals. [8]

Mixed Transuranic Waste: Waste which contains both hazardous waste (as defined by RCRA and its amendments) and transuranic waste [6]

Monitored Retrievable Storage Installation (MRS): A complex designed, constructed, and operated by DOE for the receipt, transfer, handling, packaging, possession, safeguarding, and storage of spent nuclear fuel aged for at least one year, solidified high-level radioactive waste resulting from civilian nuclear activities, and solid reactor-related GTCC waste, pending shipment to a high level waste repository or other disposal. [5]

National Environmental Policy Act (NEPA): A law that requires federal agencies to include in their decision-making processes appropriate and careful consideration of all potential environmental effects of proposed actions, analyses of the alternatives, and measures to avoid or minimize adverse effects of a proposed action. These analyses are presented in either an environmental assessment (EA) or in an environmental impact statement (EIS). [3]

National Priorities List: The Environmental Protection Agency's list of the most serious uncontrolled or abandoned hazardous waste sites identified for possible long-term remedial action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The list is based primarily on the score a site receives from the Environmental Protection Agency Hazard Ranking System. The Environmental Protection Agency is required to update the National Priorities List at least once a year. [1]

Naturally Occurring Radioactive Materials (NORM): Radioactive materials that are found in nature. Until recently, technologically enhanced naturally occurring radioactive materials (TENORM) was referred to simply as NORM. The words "technologically enhanced" were added to distinguish clearly between radionuclides as they occur naturally and radionuclides that human activity has concentrated or exposed to the environment. [6]

Naturally Occurring Radioactive Materials or Accelerator-Produced Radioactive Materials (NARM): Radioactive materials not covered under the AEA that are naturally occurring or produced by an accelerator. Accelerators are used in sub-atomic particle physics research. These materials have been traditionally regulated by States. A subset of NARM is NORM. NARM waste with more than 2 nCi/g of 226Ra or equivalent is commonly referred to as discrete NARM waste; below this threshold, the waste is referred to as diffuse NARM waste. NARM waste is not covered under the AEA, not a form of LLW, and is not regulated by NRC. [6]

Non-Time-Critical Removal Action: This is a type of response action recognized by the U.S. Environmental Protection Agency appropriate for addressing hazardous substance threats where a planning horizon of six months or more is appropriate. Removal responses, including non-time-critical removals, are the subject of 40 CFR 300.410 and 300.415. Under a signed agreement with the U.S. Environmental Protection Agency, DOE uses a non-time-critical removal approach tailored for DOE's decommissioning of contaminated facilities. That approach comprises threat assessment; identification, analysis, and documentation of decommissioning alternatives; opportunities for public participation in the decommissioning decision; and planning and performance of decommissioning activities. Under the DOE/EPA agreement, regulatory involvement in decommissioning is determined locally. [4]

Nuclear Fuel Cycle: The series of steps involved in supplying fuel for nuclear power reactors. It can include mining, milling, isotopic enrichment, fabrication of fuel elements, use in reactors, chemical reprocessing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material refabrication into new fuel elements and waste disposal. [6]

Nuclear Power Plant: An electrical generating facility using a nuclear reactor as its power (heat) source. The coolant that removes heat from the reactor core is normally used to boil water. The steam produced by the boiling water drives turbines that rotate electrical generators. [6]

Nuclear Waste: A particular type of radioactive waste that is produced as part of the nuclear fuel cycle (i.e., those activities needed to produce nuclear fission, or splitting of the atom). These include extraction of uranium from ore, concentration of uranium, processing into nuclear fuel, and disposal of by-products. Radioactive waste is a broader term that includes all waste that contains radioactivity. Residues from water treatment, contaminated equipment from oil drilling, and tailings from the processing of metals such as vanadium and copper also contain radioactivity but are not "nuclear waste" because they are produced outside of the nuclear fuel cycle. NRC generally regulates only those wastes produced in the nuclear fuel cycle (uranium mill tailings, depleted uranium, spent fuel rods, etc.). [5]

Radioactive Waste: Radioactive materials at the end of a useful life cycle or in a product that is no longer useful and should be properly disposed of. [5]

Readiness Review: A management review of documents, organizational structure, personnel qualifications, physical preparations and other factors to confirm that decommissioning operations (removal action, if under CERCLA) are ready to proceed. If the facility being decommissioning is classified as a nuclear facility per DOE-STD-1027-92, a graded operational readiness review (ORR) may be required in accordance with DOE Order 5480.31. [4]

Release Criterion: A regulatory limit expressed in terms of dose or risk. [6]

Remedial Action: Activities initiated to assess and clean up inactive DOE facilities or waste sites. Remedial actions are actions consistent with permanent remedy, which are taken, instead of or in addition to removal action, to prevent or minimize the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health, public welfare, or the environment (40 CFR 300.5). The remedial action process typically involves extensive studies to support remedy selection and may take years to complete. For this reason, the remedial action procedure has been determined by EPA and DOE to be generally inappropriate for situations involving surplus DOE facility decommissioning. As the 1995 *Decommissioning Policy* states, EPA and DOE agree that streamlined decision making is to be encouraged in such situations. [4]

Removal Action: The cleanup or removal of released hazardous substances from the environment; actions taken in the event of the threat of a release or to monitor, assess, and evaluate the release or threat of release; the disposal of removed material.

A removal action may be initiated when DOE determines that the action will prevent, minimize, stabilize, or eliminate a risk to health or the environment. The NCP specifies that the factors listed below be evaluated to determine whether a risk to health or the environment warrants a removal action (40 CFR 300.415(b)(2)):

- actual or potential exposure of humans, animals, or the food chain

- the presence of contained hazardous substances that pose a threat of release
- the threat of migration of the hazardous substances
- the threat of fire or explosion
- the availability of an appropriate federal or state response capability

There are three types of CERCLA removal actions: (1) emergency removal actions; (2) time-critical removal actions; and (3) non-time-critical removal actions. Each is designated based on the type of situation, the urgency of the threat associated with the release, and the subsequent time frame in which the action must be initiated. In 1994, DOE, EPA, and DOD issued interagency guidance endorsing an increased use of removal actions to streamline CERCLA response actions at federal facilities. Subsequently, EPA and DOE issued the 1995 *Decommissioning Policy* endorsing the use of the CERCLA non-time-critical removal action process for decommissioning surplus DOE facilities unless the circumstances at a facility make doing so inappropriate. [4]

Residual Radioactivity: Radioactivity in structures, materials, soils, groundwater, and other media at a site resulting from activities under the cognizant organization's control. This includes radioactivity from all sources used by the cognizant organization but excludes background radioactivity as specified by the applicable regulation or standard. It also includes radioactive materials remaining at the site as a result of routine or accidental releases of radioactive material at the site and previous burials at the site, even if those burials were made in accordance with the provisions of 10 CFR Part 20. [6]

Resource Conservation and Recovery Act (RCRA): A federal law enacted in 1976 to address the treatment, storage, and disposal of solid and hazardous waste. [3]

Risk: A measure of the potential inability to achieve overall project objectives within defined cost, schedule, and technical constraints and has two components: (1) the probability/likelihood of failing to achieve a particular outcome, and (2) the consequences/impacts of failing to achieve that outcome. [2]

Risk: The probability of injury, disease, or death under specific circumstances. Risk can be expressed as a value that ranges from zero (no injury or harm will occur) to 100% (harm or injury will definitely occur). Risk-based standards limit the risk that releasing a contaminant to the environment may pose rather than limiting the quantity that may be released. Absolute risk is the excess risk attributed to irradiation and usually expressed as the numeric difference between irradiated and nonirradiated populations (e.g., one case of cancer per million people irradiated annually for each rad). Absolute risk may be given on an annual basis or lifetime basis. Relative risk is the ratio between the number of cancer cases in the irradiated population to the number of cases expected in the unexposed population. A relative risk of 1.1 indicates a 10 percent increase in cancer due to radiation, compared to the "normal" incidence. [6]

Risk Assessment: A detailed analysis that provides a numerical probability that a particular kind of injury will occur (for example, the number of additional cases of cancer in a group of 10,000). [6]

Risk Management: The act or practice of controlling risk. An organized process that reduces risk, prevents a risk from happening, or mitigates the impact if it does occur. [2]

SAFSTOR: A method of decommissioning in which the nuclear facility is placed and maintained in such condition that the nuclear facility can be safely stored and subsequently decontaminated to levels that permit release for unrestricted use. [5]

Sampling and Analysis Plans: If environmental samples are to be collected during a removal action, DOE must develop a sampling and analysis plan that provides a process or obtaining data of sufficient quality and quantity to satisfy data needs. Sampling and analysis plans consist of two parts:

- Field Sampling Plan, which describes the number, type, and location of samples and the type of analyses
- Quality Assurance Project Plan (QAPP), which describes policy, organization, and functional activities and the data quality objectives and measures necessary to achieve adequate data for use in planning and documenting the removal action [4]

Source Material: Uranium or thorium, or any combination thereof, in any physical or chemical form or ores that contain by weight 1/20 of 1% (0.05%) or more of (1) uranium, (2) thorium, or (3) any combination thereof. Source material does not include special nuclear material. [5]

Source Material: Uranium or thorium ores containing 0.05% uranium or thorium regulated under the Atomic Energy Act. In general, this includes all materials containing radioactive isotopes in concentrations greater than natural and the by-product (tailings) from the formation of these concentrated materials.

Source Material: Uranium or thorium ores that contain, by weight, 1/20 of 1% (0.05%), or more, of uranium, thorium, or any combination or uranium and thorium. Source material does not include special nuclear material. Source material is defined in 10 CFR 20.1003 as uranium, or thorium, or any combination of uranium and thorium in any physical or chemical form. [6]

Special Nuclear Material (SNM): Defined in 10 CFR 20.1003 as plutonium, uranium-233, uranium enriched in the isotope 233 or in isotope 235, and any other material that NRC, pursuant to the provisions of section 51 of the Atomic Energy Act, determines to be special nuclear material (does not include source material); any material artificially enriched by any of the foregoing (does not include source material). [6]

Special Nuclear Material: Plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235. [5]

Spent (Depleted) Fuel: Nuclear reactor fuel that has been used to the extent that it can no longer effectively sustain a chain reaction. [5]

Spent Fuel Storage Cask or Cask: All the components and systems associated with the container in which spent fuel or other radioactive materials associated with spent fuel are stored in an Independent Spent Fuel Storage Installation. [5]

Surface Contaminated Object (SCO): A solid object that is not itself classed as radioactive material but which has radioactive material distributed on any of its surfaces. SCO must be in one of two groups with surface activity not exceeding the following limits:

(1) SCO-I: A solid object on which:

i. The nonfixed contamination on the accessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 4 Bq/cm^2 (10^4 microcurie/cm^2) for beta and gamma and low toxicity alpha emitters, or 0.4 Bq/cm^2 (10^{-5} microcurie/cm^2) for all other alpha emitters;

ii. The fixed contamination on the accessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 4×10^4 Bq/cm^2 (1.0 microcurie/cm^2) for beta and gamma and low toxicity alpha emitters, or 4×10^3 Bq/cm^2 (0.1 microcurie/cm^2) for all other alpha emitters; and

iii. The nonfixed contamination plus the fixed contamination on the inaccessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 4×10^4 Bq/cm^2 (1 microcurie/cm^2) for beta and gamma and low toxicity alpha emitters, or 4×10^3 Bq/cm^2 (0.1 microcurie/cm^2) for all other alpha emitters.

(2) SCO-II: A solid object on which the limits for SCO-I are exceeded and on which:

i. The nonfixed contamination on the accessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 400 Bq/cm^2 (10^2 microcurie/cm^2) for beta and gamma and low toxicity alpha emitters or 40 Bq/cm^2 (10^3 microcurie/cm^2) for all other alpha emitters;

ii. The fixed contamination on the accessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 8×10^5 Bq/cm^2 (20 microcuries/cm^2) for beta and gamma and low toxicity alpha emitters, or 8×10^4 Bq/cm^2 (2 microcuries/cm^2) for all other alpha emitters; and

iii. The nonfixed contamination plus the fixed contamination on the inaccessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 8×10^5 Bq/cm^2 (20 microcuries/cm^2) for beta and gamma and low toxicity alpha emitters, or 8×10^4 Bq/cm2 (2 microcuries/cm^2) for all other alpha emitters. [5]

Superfund: A term commonly used to refer to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). [3]

Transuranic Waste: Material contaminated with transuranic elements that is produced primarily from reprocessing spent fuel and from use of plutonium in fabrication of nuclear weapons. [5]

Unwanted Radioactive Material (Orphan Sources): Refers to sealed sources of radioactive material contained in a small volume (but not radioactively contaminated soils and bulk metals) in any one or more of the following conditions (taken from the NRC Orphan Source Initiative):

- in an uncontrolled condition that requires removal to protect public health and safety from a radiological threat;
- controlled or uncontrolled, but for which a responsible party cannot be readily identified;
- controlled, but the material's continued security cannot be assured. If held by a licensee, the licensee has few or no options for, or is incapable of providing for, the safe disposition of the material;
- in the possession of a person, not licensed to possess the material, who did not seek to possess the material; or
- in the possession of a state radiological protection program for the sole purpose of mitigating a radiological threat because of one of the above conditions, and for which the state does not have a means to provide for the material's appropriate disposition. [5]

Uranium Mill Tailings Radiation Control Act (UMTRA) of 1978 (42 U.S.C. 2022): The act that directed DOE to provide for stabilization and control of the uranium mill tailings from inactive sites in a safe and environmentally sound manner to minimize radiation health hazards to the public. It authorized DOE to undertake remedial actions at 24 designated inactive uranium-processing sites and at an estimated 5,048 vicinity properties. Both DOE and NRC implement standards under this act. Additional regulations in 40 CFR Part 192 and 10 CFR 40, Appendix A provide design requirements for closure of mill waste disposal areas. [1,7]

Work Breakdown Structure: A product-oriented grouping of project elements that organizes and defines the total scope of the project. The Work Breakdown Structure is a multilevel framework that organizes and graphically displays elements representing work to be accomplished in logical relationships. Each descending level represents an increasingly detailed definition of a project component. Project components may be products or services. It is the structure and code that integrates and relates all project work (technical, schedule, and cost) and is used throughout the life cycle of a project to identify and track specific work scopes. [2]

Weapons-Grade Uranium: Uranium consisting of more than 90% of the fissile uranium-235 isotope. [3]

Appendix D

Sources for D&D Regulations and Guidance Information

SOURCES FOR D&D REGULATIONS AND GUIDANCE INFORMATION

Regulations and guidance related to the D&D of nuclear facilities are found at both federal and state levels. The following sources of information on decommissioning and radioactive waste management are available:

Department of Energy
Freedom of Information Act Reading Room
Room 1E-190, Forrestal Building
Washington, DC 20585
Telephone: 202-586-3142
Fax: 202-586-0575

Home Pages:
- Department of Energy—www.energy.gov
- Office of Environmental Management (EM)—www.em.doe.gov
- EM Decommissioning—www.em.doe.gov/dd
- Office of Environment, Safety and Health—www.eh.doe.gov

Environmental Protection Agency
Ariel Rios Building
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460
Telephone: 202-272-0167

Home Pages:
- Environmental Protection Agency—www.epa.gov/
- Superfund—www.epa.gov/superfund/
- Federal Facilities Restoration and Reuse—www.epa.gov/fedfac
- Superfund Radiation—www.epa.gov/superfund/health/contaminants/radiation/index.htm
- Superfund Remedy Decisions—www.epa.gov/superfund/policy/remedy/sfremedy/index.htm
- Superfund Community Involvement—
  www.epa.gov/superfund/policy/remedy/sfremedy/cominvolve.htm
- Radiation Waste Management Programs—www.epa.gov/radiation/programs.htm#waste

Nuclear Regulatory Commission
Public Document Room
11555 Rockville Pike
Rockville, MD 20852
Telephone: 800-397-4209
Home Page: www.nrc.gov

Defense Nuclear Facilities Safety Board
P.O. Box 7887
Washington, DC 20044-7887
Telephone: 800 788 4016
Home Page: www.dnfsb.gov/

Nuclear Energy Institute
(The commercial nuclear energy industry's Washington-based policy organization)
Suite 400, 1776 I Street N.W.
Washington, DC 20006-3708
Telephone: 202-739-8000

Appendix E

Radionuclides Team Contacts

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Appendix F

Acronyms

ACRONYMS

AC	administrative control
ACM	asbestos-containing material
AEA	Atomic Energy Act (1946, U.S.)
AEC	Atomic Energy Commission
ALARA	as low as reasonably achievable
AM	Action Memorandum
ANSI	American National Standards Institute
ARAR	applicable or relevant and appropriate requirement
BDCC	Building Dose Cleanup Concentrations
BNFL	British Nuclear Fuels Limited
BNG	British Nuclear Group
BNL	Brookhaven National Laboratory
BPRG	Building Preliminary Remediation Goal
CA	Cost Analysis
CAB	Citizen Advisory Board
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFC-114	dichlorotetrafluoroethane
CFR	Code of Federal Regulations
CIP	Cascade Improvement Project
CRC	Compact Remote Console
CRP	Community Relations Plan
CUP	Cascade Upgrade Project
D&D	decontamination and decommissioning
DCGL	derived concentration guideline level
DECON	NRC decommissioning option (decontamination/dismantlement as rapidly after reactor shutdown as possible to achieve termination of the nuclear license)
DNFSB	Defense Nuclear Facilities Safety Board
DOC	Decommissioning Operations Contractor
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
dpm	disintegrations per minute
DQO	data quality objective
DSA	Documented Safety Analysis
EA	Environmental Assessment
ECOS	Environmental Council of the States
ECY	Washington Department of Ecology
EE	Engineering Evaluation
EIS	Environmental Impact Statement
EMWD	environmental measurement while drilling

EMWMF	Environmental Management Waste Management Facility
ENTOMB	NRC decommissioning option (immediate removal of the highly activated reactor vessel internals for disposal and relocation of the remainder of the radioactively contaminated materials to the reactor containment building, which is then sealed)
EPA	U.S. Environmental Protection Agency
EPC	end-point condition
ERDF	Environmental Restoration Disposal Facility
ERIS	Environmental Research Institute of the States
ETTP	East Tennessee Technology Park
FCP	Fernald Closure Project
FFA	Federal Facility Agreement
FMSA	Fissile Material Storage Area
FONSI	finding of no significant impact
FS	Feasibility Study
FSS	Final Status Survey
GAO	Government Accountability Office
GRS	gamma ray spectrometer
GTCC	greater than Class C
HASP	health and safety plan
HDD	horizontal directional drilling
HEPA	high-efficiency particulate air
HEU	highly enriched uranium
HI	hazard index
HLW	high-level waste
HPS	Health Physics Society
HRS	Hazard Ranking System
HVAC	heating, ventilation, and air conditioning
IAEA	International Atomic Energy Agency
IAG	interagency agreement
INEEL	Idaho National Engineering and Environmental Laboratory
IROD	Interim Record of Decision
ISM	integrated safety management
ISMS	Integrated Safety Management System
ISS	interim safe storage
ITRC	Interstate Technology & Regulatory Council
IVO	Independent Verification Organization
LEU	low-enriched uranium
LLRW	low-level radioactive waste
LLW	low-level waste
LMES	Lockheed Martin Energy Systems
LTP	license termination plan
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual

MARSAME	Multi-Agency Radiation Survey and Assessment of Material and Equipment
MDA	minimum detectable activity
MLDUA	Modified Light-Duty Utility Arm
MOA	memorandum of agreement
MOU	memorandum of understanding
MSC	Manufacturing Sciences Corporation
MSHPO	Michigan State Historic Preservation Officer
MTCA	Model Toxics Control Act (Washington state)
MW	mixed waste
NASA	National Aeronautical and Space Administration
NCP	National Contingency Plan
NCS	Nuclear Criticality Safety
NCSA	Nuclear Criticality Safety Approval
NDA	nondestructive assay
NEPA	National Environmental Policy Act
NEA	Nuclear Energy Agency
NESHAP	National Emission Standards for Hazardous Air Pollutants
NMC&A	Nuclear Material Control and Accountability
NMSS	Nuclear Material Safety and Safeguards
NORM	naturally occurring radioactive material
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
NTS	Nevada Test Site
O&M	operation and maintenance
ORGDP	Oak Ridge Gaseous Diffusion Plant
ORISE	Oak Ridge Institute for Science and Education
ORR	Operational Readiness Review
OSDF	On-Site Disposal Facility
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PA	Preliminary Assessment
PCB	polychlorinated biphenyl
PPE	personal protective equipment
PRG	Preliminary Remediation Goal
PSDAR	post-shutdown decommissioning activities report
PSI	pounds per square inch
QA/QC	quality assurance/quality control
R&D	research and development
RA	Remedial Action
RACER	Remedial Action Cost Engineering and Requirements
RCAAS	Radiation Criticality Accident Alarm System
RCC	Radium Chemical Company
RCRA	Resource Conservation and Recovery Act

RD	Remedial Design
RFCA	Rocky Flats Cleanup Agreement
RFETS	Rocky Flats Environmental Technology Site
RI	Remedial Investigation
RO	Remedy Optimization
ROD	Record of Decision
S&M	surveillance and maintenance
SAFSTOR	NRC decommissioning option (a period of safe storage of the stabilized and defueled facility followed by final decontamination/dismantlement and license termination)
SAP	sampling and analysis plan
SBIS	Safety Basis Information System
SCO	surface-contaminated object
SDCC	Surfaces Dose Cleanup Concentrations
SHPO	State Historic Preservation Officer
SI	Site Inspection
SNF	spent nuclear fuel
SNM	Special Nuclear Material
SPRG	Surfaces Preliminary Remediation Goal
SRS	Savannah River Site
SSE	safe storage enclosure
TBC	to be considered
^{99}Tc	technetium-99
TDEC	Tennessee Department of Environment and Conservation
TENORM	technologically enhanced naturally occurring radioactive material
^{230}Th	thorium-230
TRU	transuranic waste
TSCA	Toxic Substances Control Act
TSDF	treatment, storage, and disposal facility
TSR	Technical Safety Requirement
^{235}U	uranium-235
UF_6	uranium hexafluoride
UMTRCA	Uranium Mill Tailings Radiation Control Act
USACE	U.S. Army Corps of Engineers
USQ	Unreviewed Safety Question
WAC	waste acceptance criteria
WAO	Waste Acceptance Organization
WIPP	Waste Isolation Pilot Plant