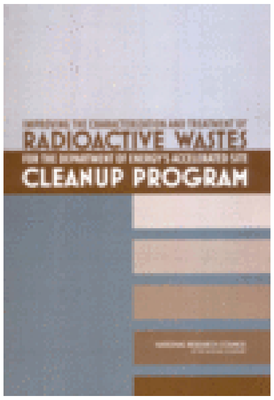

Improving the Characterization and Treatment of Radioactive Wastes for the Department of Energy's Accelerated Site Cleanup Program

Committee on Opportunities for Accelerating Characterization and Treatment of Waste at DOE Nuclear Weapons Sites, National Research Council

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Committee on Opportunities for Accelerating Characterization and Treatment of Waste at DOE Nuclear Weapons Sites

Board on Radioactive Waste Management

Division on Earth and Life Studies

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This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council (NRC) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The content of the review comments and draft manuscript remains confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

David Daniel, University of Illinois
Rear Admiral G. Brian Estes, Westinghouse Hanford Company (retired)
Paul Locke, Johns Hopkins University
Michael Mobley, Independent Consultant
Frank Parker, Vanderbilt University
Della Roy, Pennsylvania State University
Alfred Sattlelberger, Los Alamos National Laboratory
John Swanson, Pacific Northwest National Laboratory (retired)
James Woolford, U.S. Environmental Protection Agency

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Chris G. Whipple, ENVIRON International Corporation, appointed by the Division on Earth and Life Studies, and Steve Berry, University of Chicago, appointed by the Report Review Committee, who were responsible for making certain that an independent examination of this report was carried out in accordance with NRC procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the NRC.

Preface

To manage the massive cleanup of sites involved in the production of nuclear weapons materials throughout the Manhattan Project and the Cold War, the Department of Energy (DOE) established in 1989 its Office of Environmental Remediation and Waste Management, renamed the Office of Environmental Management (EM) in 1994. Because of the complexity of cleaning up this legacy of waste and contamination, limited experience, and changing requirements, identifying actual costs and time required to complete the cleanup was a challenge from the beginning. In June 1998, EM issued its first comprehensive plan *Paths to Closure* (DOE, 1998a) for accelerating the cleanup and reducing costs. Currently, according to EM's plan for accelerated cleanup, the total life cycle cost is estimated to be about $142 billion, with completion in 2035. EM is considering how the schedule and costs might be reduced further, without compromising its commitments to health and safety.

EM commissioned this study by the National Academies' Board on Radioactive Waste Management (BRWM) to provide technical advice for EM's accelerated cleanup program, specifically by identifying opportunities for EM to improve its capabilities for characterizing and treating the legacy wastes and contamination that are within the scope of the accelerated cleanup program. While acknowledging that site cleanup is a multifaceted challenge, including establishing cleanup goals, legal and regulatory compliance, and public confidence, the committee confined its study to the technical issues set forth in its Study Prospectus and Statement of Task (see Chapter 1). Clearly, EM's technical capability to manage its wastes and environmental contamination is essential for accomplishing the cleanup regardless of how non-technical issues surrounding site cleanup may change over the next few decades.

The EM program is a limited program, not intended to completely clean up all DOE nuclear sites. EM's plans for accelerated cleanup include leaving some buried wastes, contaminated facilities, and subsurface contamination to the responsibility of a newly created DOE office, the Office of Legacy Management (LM). The committee suggests an approach that may help EM transition these left-in-place liabilities to LM in Chapter 4.

Wastes currently being generated by non-EM programs[1] and future programs are not part of the EM program and so are not addressed in this report. The committee has undertaken to do the requested study, limited to technical opportunities to assist EM's accelerated cleanup, recognizing that there are many questions about facilities and wastes outside the EM program. While it is beyond the scope of this study, the committee believes that DOE has need and opportunity to take a more holistic view of its waste management than is reflected in EM's mission or this report, for example, by including some of the facilities identified in Chapter 3 in plans for treating wastes from ongoing and future programs.

The committee based its findings and recommendations on information received from EM headquarters and its site visits. We very much appreciate the assistance of Patrice Bubar, Lynne Smith, and Alton Harris, who served as the committee's points of contact with EM headquarters at the outset of the study. This responsibility transferred to Mark Gilbertson, Mark Frei, and Ker-Chi Chang upon the formation of EM's Office of Environmental Cleanup and Acceleration, and we benefited greatly from their advice at the close of the study. Our study would not have been possible without the dedicated work of our site visit coordinators: Mildred Ferré and Carolyn Davis at Oak Ridge, Tennessee; Charles Anderson, James Folk, and Laurie Posey at the Savannah River Site, South Carolina; Kathleen Hain, Alan Jines, and Mary Willcox at the Idaho National Engineering and Environmental Laboratory; and Mary Goldie and Mark French at Hanford, Washington.

John Wiley, BRWM staff, served as the study director. We are grateful for his assistance and advice throughout the study. Laura Llanos, BRWM senior program assistant, ably assisted all of the committee's meetings, logistical matters, and report preparation. Robert Bernero provided the committee with valuable insight and advice as BRWM liaison. Finally and especially, I thank the committee members for contributing their expertise, time, and a good deal of hard work—always in a spirit of cooperation and cheerfulness—to making this a successful study.

Milton Levenson
Chairman

[1]National Nuclear Security Administration, other DOE offices, Nuclear Navy, and others. Some legacy cleanups, e.g., the Formerly Utilized Sites Remedial Action Program managed by the Army Corps of Engineers, are also outside the scope of the EM program and this report.

Contents

Synopsis

The focus of the recommendations in this report is on more effectively characterizing and treating *the orphan and special-case wastes* in the DOE Office of Environmental Management's (EM's) accelerated cleanup program. Most of these wastes are outside EM's current focus on dealing with its high-level tank wastes and stored transuranic wastes. Nevertheless, the "orphans" have the potential to interfere with site closure schedules and will become more significant as EM closes out its facilities capable of handling them. This synopsis highlights only some of the committee's advice and it not a substitute for the more detailed discussion and recommendations in the text.

1. For any given waste, consider first administrative procedures to *simplify* its characterization and treatment, as discussed in **Chapter 2:**

- If the waste is classified, consider declassifying it or destroying its classified attributes to remove the stringent access control requirements that apply to classified materials.
- Consider using a CERCLA *removal action* rather than a *remedial action* to expedite dealing with wastes that present a major risk, for example the 618-10/11 burial ground caissons at Hanford.
- Consider leaving wastes in place if they present little risk or if removing them with currently available technology would present more hazards than leaving them alone, as discussed in **Chapter 4.**

2. For stored wastes, wastes that are likely to be retrieved, e.g., some buried transuranic wastes (TRU), or wastes to be generated in EM facility decommissioning, *consider the trade-offs between utilizing existing treatment capabilities and providing alternative treatments*, as discussed in **Chapter 3**:

- Some facilities, e.g., the Oak Ridge incinerator, offer EM a unique treatment capability that will be lost when the facility is closed. Consider decoupling these facilities from site decommissioning schedules and maintaining them as EM assets until it is certain that they are no longer needed.
- Some new facilities, e.g., the INEEL Advanced Mixed Waste Treatment Facility (AMWTF), the SRS Defense Waste Processing Facility (DWPF), and the Waste Treatment Plant (WTP), which is being built at Hanford, have the technical capability to treat wastes beyond their current scope. Consider using the AMWTF to treat retrieved TRU, remote-handled TRU, and mixed low-level wastes in addition to treating the stored, contact-handled TRU for which the facility was built. Consider encapsulating small volumes of highly radioactive or fissile materials in vitrified wastes at the DWPF or the WTP using the "can-in-canister" approach developed for disposing of plutonium residues in DWPF canisters.
- Shipping the small volumes of orphan wastes is a significant, mainly non-technical challenge recognized in **Chapter 1**, but not addressed in this report. EM might consider that working with regulators and other involved stakeholders to agree, on a case-by-case basis, on the disposition plans for an orphan waste may be an opportunity to improve relations with all stakeholders, a need raised by citizens during the committee's site visits.

Executive Summary

The Department of Energy's Office of Environmental Management (DOE-EM) commissioned this study by the National Academies' Board on Radioactive Waste Management (BRWM) to provide technical advice for its accelerated site cleanup program. EM was established in 1989 to manage the cleanup of waste and environmental contamination that resulted from World War II and Cold War-era production of nuclear materials at more than 100 sites around the country. At one time, EM estimated that completing the cleanup would cost $300 billion and require 70 years. In 2002, as the result of a DOE review of the cleanup program, EM, working with federal and state regulators and local governments, developed an accelerated program for completing its mission by the year 2035 at a total life-cycle cost of about $142 billion.[1] Currently, EM is considering how the schedule and costs might be reduced further without compromising worker safety and public health.

The prospectus and task statement for this study directed the study committee[2] to identify opportunities for improving EM's waste characterization and treatment capabilities. Specifically, the committee was asked to identify opportunities for EM to:

[1]Department of Energy FY 2005 Congressional Budget Request. Assistant Secretary Jessie H. Roberson's FY 2005 Background Information for the Budget Rollout Presentation. Department of Energy. February. Available at http://web.em.doe.gov/budget_docs.html.

[2]The Committee on Opportunities for Accelerating Characterization and Treatment of Wastes at DOE Nuclear Weapons Sites is referred to as the committee throughout this report.

1. make more effective use of its existing facilities and capabilities for waste characterization and treatment, including eliminating self-imposed requirements that have no clear safety or technical basis;
2. improve its treatment and characterization capabilities especially for "orphan" wastes; and
3. invest in new technologies to achieve these improvements.

The committee was not tasked to review or comment on other aspects of the accelerated cleanup program or to address waste issues outside the scope of the EM mission.[3]

To fulfill its task, the committee sought to identify major opportunities that are within EM's ability to implement in the time frame of the accelerated cleanup program and that have the greatest potential for saving time and money without compromising EM's health and safety commitments. The committee visited EM's four largest sites: the Oak Ridge Reservation, Tennessee; the Savannah River Site (SRS), South Carolina; the Idaho National Engineering and Environmental Laboratory (INEEL); and the Hanford Site, Washington. These four sites face EM's biggest waste characterization and treatment challenges, their challenges are mostly inclusive of those at the smaller sites, and they present the biggest opportunities for improvement. Due to time and budget limitations, the committee did not attempt to be comprehensive in identifying all possible opportunities at the four largest sites or to identify specific needs at the smaller sites.

Although recognizing the importance of the many non-technical issues—and challenges—that bear on EM's accelerated cleanup program, the committee did not attempt to pre-judge how non-technical issues, which are noted in Chapter 1, might limit or foreclose valid technical opportunities. Nevertheless, it is clear that for accelerated cleanup to succeed, EM must collaborate with the Environmental Protection Agency (EPA), state regulators, local governments, and other involved stakeholders. All of EM's proposed cleanup activities require the support of regulators and other stakeholders outside of EM and the field offices.

ADMINISTRATIVE OPPORTUNITIES

In initiating this study, EM encouraged the committee to identify opportunities to eliminate self-imposed DOE requirements that have no clear technical or safety basis. The committee found obstacles to accelerated

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[3]For example currently generated and future wastes from the National Nuclear Security Administration, other DOE offices, Nuclear Navy, and others. Some legacy cleanups, e.g., the Formerly Utilized Sites Remedial Action Program managed by the Army Corps of Engineers, are also outside the scope of the EM program and this report.

cleanup in such requirements as continued security classification of Manhattan Project-era equipment being disposed as waste, apparent reluctance by the sites and their contractors to pursue available options under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and excessively strict interpretations by DOE site and contractor personnel of waste characterization and treatment requirements.

Recommendation:
EM headquarters and sites should aggressively pursue opportunities to simplify and expedite waste characterization, treatment, and disposal by

- *working with the responsible classification offices to declassify, to the extent possible, classified materials declared as wastes,*
- *better utilizing the waste removal provisions of CERCLA, and*
- *developing more consistent interpretations among sites of waste acceptance requirements and accelerated cleanup objectives.*

Classified Wastes

EM has a significant opportunity to save time and money by taking aggressive measures to declassify materials and equipment that are to be disposed as waste. The committee became aware of the obstacles imposed by classified Manhattan Project-era waste during open-meeting discussions of decommissioning of the Oak Ridge K-25 gaseous diffusion plant, which presents one of EM's biggest decommissioning challenges. As long as diffusion plant equipment remains classified, only employees with security clearances can work on the program. This results in a reduced labor pool, increased labor costs, extended cleanup time, and significant increase in waste volume due to packaging requirements. The waste must be sent to classified burial grounds with long-term security and surveillance obligations and their associated costs.

DOE's gaseous diffusion equipment at Paducah, Kentucky, and Portsmouth, Ohio, is likely to present inefficiencies similar to those at Oak Ridge—as is classified waste at other sites. EM and its sites should be aggressive in taking appropriate measures to declassify such wastes, for example by destroying their classified shape, composition, or other attributes, as early as possible in the steps of their removal, handling, treatment, and disposal.

Opportunities Under CERCLA

CERCLA provides broad federal authority to respond to releases or threatened releases of hazardous substances that may endanger public health or the environment. In discussions with site and regulatory personnel, the committee became aware of two provisions under CERCLA that could facilitate accelerated cleanup. The first, greater use of DOE's removal authority, would help reduce the planning and approval periods for recovering wastes, and the second would assist EM in removing unexploded ordnance from previous Department of Defense (DOD) operations at INEEL.

Removal Authority. Executive Order 12580, Superfund Implementation, confers removal authority to DOE and other federal agencies under Section 104 of CERCLA. Removal authority can reduce the planning and paperwork phases of a cleanup action—as opposed to *remedial* authority under which DOE conducts most of its site cleanup. DOD is emphasizing the use of removal authority in fast-track cleanup of its closure sites, which closely parallels DOE's accelerated cleanup program.

Munitions Removal at INEEL. During its visit to INEEL, the committee learned that EM resources are being used for clearing military munitions remaining on parts of the site used in the 1940s as a firing range for testing large naval guns and other weapons. DOD, rather than DOE, has statutory responsibility for cleanup actions involving past and present military munitions under the CERCLA National Contingency Plan. EM has an opportunity to save time and money by working with DOD to place a high priority on DOD's recovering and disposing of these legacy munitions at the Idaho site.

Inconsistent Approaches

The semiautonomous operation of the major DOE sites leads them to use different approaches and procedures for cleanup. Although autonomy may offer advantages, the committee found two general areas in which it promotes activities that have no technical or safety basis but reduce efficiencies and increase costs:

1. Overly restrictive interpretation of existing requirements for characterizing and sorting transuranic (TRU) waste, coupled with lack of criteria for remote-handled TRU and wastes intended for Yucca Mountain.
2. Demolishing new or uncontaminated facilities that pose little if any long-term risk.

Characterization, Sorting, and Waste Acceptance. The Waste Isolation Pilot Plant (WIPP) waste acceptance criteria and waste analysis plan comprise a complex set of requirements that must be met by each DOE site to dispose of TRU wastes at WIPP. Each site, working with EM, state officials and the EPA, has written its own procedures to meet these requirements. A previous study[4] found that there are three TRU waste characterization activities that are apparently conducted only for regulatory compliance and do not seem to reduce risk:

1. sampling and analyzing gases from the headspace of waste drums;
2. sampling and analysis of homogeneous wastes; and
3. manual sorting and visual examination to confirm the results of drum radiography.

Based on its own visits to the waste characterization facilities at SRS, Hanford, and INEEL, the committee endorses the previous study's conclusions and suggestions that EM and the sites review these characterization activities for possible modifications, such as reduced sampling frequency, that would remain in compliance with regulations but could save time, money, and the potential risks of operators handling and sorting the waste.

The lack of formal WIPP waste acceptance criteria for TRU wastes that require remote handling is a significant impediment to accelerated cleanup. A priority for EM should be to accelerate negotiations with the State of New Mexico to resolve permitting issues so that sites can proceed with their planning for remote-handled TRU waste packaging and shipping.

Another issue that appears to be slowing down decisions and work planning is uncertainty about the future acceptance criteria for DOE waste intended for the proposed Yucca Mountain, Nevada, repository. Each site is making assumptions regarding how to characterize, treat, and package wastes and even which wastes will be accepted. The sites, EM, the DOE Office of Civilian Radioactive Waste Management, which has overall responsibility for the proposed repository, and the Nuclear Regulatory Commission, which must approve DOE's license application, need to agree on a consistent approach to preparing wastes for disposal in that facility, with one office having oversight authority.

Building Demolition. EM's stated strategy for the accelerated cleanup program is to eliminate the sites' most significant environmental, health, and safety risks as soon as possible and to address less significant risks later. In its site visits, the committee became aware that facilities posing little risk—many are not contaminated or in structural jeopardy—are being dismantled or demolished as near-term priorities. Although the committee appreciates the sites' needs to show visible progress and shrink their operating areas (footprints), as well as save "mortgage" costs, these actions appear to be inconsistent with EM's intent to use its limited resources to achieve the greatest risk reductions first.

[4] *Improving the Characterization Program for Contact-Handled Transuranic Waste Bound for the Waste Isolation Pilot Plant* (NRC, 2004).

IMPROVED AND EXTENDED USE OF EXISTING FACILITIES

The committee believes that the accelerated cleanup can best be kept on track, or further accelerated, if a limited number of facilities with unique capabilities are maintained as corporate resources, instead of being tied to their host site's decommissioning schedules and budgets. Premature closure of these facilities to fit a specific site's schedule could seriously delay the overall EM program because their capabilities cannot be replaced by other DOE or commercial resources. The committee does not suggest automatically retaining or upgrading these facilities, but rather that EM review their unique capabilities and possible needs for those capabilities before committing to decommissioning them.

Recommendation:
EM should consider managing the following facilities as corporate assets for the characterization and treatment of both mainstream and special-case or "orphan" wastes:

- *Toxic Substances Control Act (TSCA) incinerator at Oak Ridge*
- *H-Canyon at Savannah River*
- *T-Plant at Hanford*
- *High-level waste (HLW) calciner at Idaho*
- *Advanced Mixed Waste Treatment Facility (AMWTF) at Idaho*
- *Vitrification Facilities at Savannah River and Hanford*
- *Existing groundwater-monitoring wells at all sites.*

The TSCA incinerator, H-Canyon, and T-Plant are existing facilities that each provide a unique capability, respectively, for treating combustible mixed wastes; reprocessing spent DOE nuclear fuels; and treating large, highly contaminated equipment. Based on presentations to the committee and a previous BRWM study,[5] it appears that upgrading and restarting the INEEL calciner, or converting it to a steam reformer as noted in the next section, would provide a means to treat that site's million gallons of sodium-bearing reprocessing waste.

The AMWTF and the vitrification facilities, in addition to their current missions, offer opportunities for improving and extending EM's capabilities to treat, respectively, TRU wastes that will continue to be recovered from the major sites throughout EM's mission and "orphan" spent fuels and fissile materials that can be encapsulated along with vitrified high-level waste.[6] In addition, the committee noted that many of the existing ground-

[5] *Alternative High-Level Waste Treatments at the Idaho National Engineering and Environmental Laboratory* (NRC, 2000c).

[6] *The Spent-Fuel Standard for Disposition of Excess Weapon Plutonium: Application to Current DOE Options* (NAS, 2000).

water-monitoring wells at the sites are essential resources for characterizing and ensuring the continued safety of the buried wastes and contaminated media that will remain after EM has completed its mission.

TECHNOLOGY INVESTMENTS

In reviewing technologies for possible investment, the committee selected four with applicability to cleanup problems that, if developed, could significantly accelerate cleanup.

Recommendation:
EM should continue developing and deploying new or improved technologies that address limitations in current characterization and treatment capabilities. The committee recommends investments in

- *steam reforming,*
- *improved high-level waste vitrification,*
- *"no-consequence" TRU shipping containers, and*
- *state-of-the-art sensors for environmental monitoring.*

Steam Reforming

Steam reforming is a commercial technology similar to calcination. The process is capable of producing a stable material from a wide variety of waste liquids and slurries, including the sodium-bearing wastes at INEEL. With further development, steam reforming could be implemented by upgrading the INEEL calciner to treat INEEL wastes and to demonstrate the process for treating orphan sludges and slurries throughout the EM complex. Steam reforming is also a promising technology for treating low-activity waste streams from the Waste Treatment Plant being constructed at Hanford. Steam reforming is a lower-temperature alternative to the bulk vitrification planned for these wastes, and thus should encounter fewer waste-component volatility problems.

HLW Vitrification

Technology investments that lead to increasing the waste loading or production rate of vitrified high-level tank waste at SRS and Hanford are likely to provide EM with opportunities for large cost and schedule reductions. The committee found two areas for technology investment for EM to improve HLW vitrification:

1. further development of frit and glass-melting chemistry, and
2. new approaches for putting energy into the melters.

Frit development, an ongoing activity for many years, continues to offer opportunities for improved throughput at the SRS Defense Waste Processing Facility (DWPF), and will be necessary to ensure successful vitrification of the much more heterogeneous tank wastes at Hanford. Microwave heating appears to be a very promising method for adding supplemental heat at specific locations in glass melters to help stabilize their operations and increase throughput.

"No-Consequence" Container

For shipping TRU wastes to WIPP, there has long been concern over whether a flammable mixture might arise within the shipping container due to radiolysis or other reactions in the waste and result in deflagration with sufficient energy to breach the containment. In spite of considerable work by EM to ensure that its waste packages meet U.S. Nuclear Regulatory Commission limits on flammable gas concentrations, some few thousand drums will continue to face shipping restrictions. Currently, the only available alternative is to remove the wastes from these drums and distribute them among new drums, with the repacking ratio expected to be 10 to 20 new drums for each original drum.

The concept of a robust no-consequence container that could withstand a worst case hydrogen deflagration is an appealing solution to the problem. Technology to develop this type of container is nearly mature. Further investment to deploy the technology would alleviate the detailed measures the EM sites must now take to ensure that drums facing shipping restrictions due to flammable gas generation can be safely shipped to WIPP.

Sensors for Environmental Monitoring

Sensors and their associated technologies for environmental monitoring are well developed and continue to be improved. However, EM sites currently rely on point measurements (sampling), which are relatively expensive and time consuming. Modern geophysical sensors can provide continuous measurements in time and space that could fill gaps in information between monitoring wells, enable rapid mapping of large areas, deliver information on waste characteristics as well as subsurface hydrogeology, and be developed into long-term monitoring networks. Additional investments in sensor technology and research, particularly in the use of geophysical sensors to understand hydrologic processes, can expedite the transition from hands-on sampling to modern, cost-effective monitoring.

MANAGE-IN-PLACE TECHNOLOGIES

This committee, other NRC committees, EM, its regulators, and many local citizens realize that it is not possible to totally remove all of the legacy waste and environmental contamination from DOE sites. EM's accelerated cleanup plans are predicated on leaving a good deal of buried wastes, subsurface contamination, and some contaminated facilities in place, and transitioning them to DOE's recently formed Office of Legacy Management for long-term stewardship. A scientifically defensible and technically sound approach for characterizing and treating (stabilizing) in-place wastes is essential for EM's accelerated cleanup.

Recommendation:
For waste that EM considers leaving in place, the committee recommends that EM broaden the use of the cocooning concept as currently applied to the Hanford reactors. The cocooning approach provides stabilization and monitoring of wastes left in place, a clear understanding of current benefits and future liabilities for all stakeholders, and the possibility of adapting to changes that will inevitably arise in the future.

In its fact finding, the committee noted that reactor "cocooning" at Hanford is an instructive conceptual approach to managing waste in place. Reactor cocooning involves demolishing and removing all of a reactor's ancillary buildings and the reactor building itself, except for the thick shielding walls around the defueled reactor core, which is left in place. All involved parties (stakeholders) have a clear understanding of future commitments for, for example, monitoring and periodically reentering the remaining structure for inspections and making repairs as necessary and eventually determining its final disposition.

The committee believes that the cocooning concept—stabilize wastes or contamination in place for now; monitor until radioactive decay, other natural processes, or new technologies make ultimate cleanup feasible or unnecessary; adapt to new knowledge; and make responsibilities clear to all stakeholders—can be usefully applied by EM to meet its accelerated cleanup goals.

1

Introduction

In November 1989, the Department of Energy (DOE) established the Office of Environmental Management (EM) to manage the cleanup of waste and environmental contamination from the Manhattan Project and Cold War-era production of nuclear materials at more than 100 sites around the country. The EM cleanup mission is to reduce health and safety risks from legacy[1] radioactive waste and environmental contamination to meet applicable regulations and agreements (DOE, 1996). The cleanup is not intended to remediate the sites to the point of unrestricted reuse ("greenfield").

At one time, DOE estimated that completing the cleanup would cost $300 billion and require 70 years. In early 2002, DOE completed a top-to-bottom review of EM's programs and accomplishments (DOE, 2002a). As a result of the review, EM, working with federal and state regulators and local governments, developed an accelerated program with the goal of completing its cleanup mission by the year 2035 at a total life-cycle cost of about $142 billion (DOE, 2003, 2004). Currently, EM is considering how the schedule and costs might be reduced further, without compromising health and safety.

PROSPECTUS AND STATEMENT OF TASK

EM commissioned this study by the National Academies' Board on Radioactive Waste Management (BRWM) to provide technical advice for its accelerated cleanup program (see Sidebar 1.1).

[1]DOE uses the term "legacy" in reference to sites, facilities, and materials (including waste and environmental contamination) associated with its former research and production activities. See *Linking Legacies* (DOE, 1997).

Sidebar 1.1 KEY EXCERPTS FROM THE STUDY PROSPECTUS

Opportunities for Accelerating Characterization and Treatment of Waste at DOE Nuclear Weapons Sites

In 2001, EM announced that it was changing the paradigm for its cleanup program, focusing on reducing the large risks at its sites to residual levels and managing remaining hazards through long-term stewardship. . .

EM recognizes that, to achieve these "accelerated cleanup" schedule and cost goals, it must make more effective use of its existing cleanup capabilities and wiser investments in cleanup technology R&D. To this end, EM is asking the National Academies to identify opportunities for improving waste characterization and treatment approaches at its sites, and also to identify opportunities for technology R&D to provide for future improvements in characterization, treatment, and disposal capabilities.

. . .

EM is responsible for characterizing, treating, and disposing of thousands of physically and chemically distinct waste streams that are currently in storage or will be generated during site cleanup. . .

Characterizing and treating these waste streams to make them suitable for disposal may be difficult and/or expensive because of their large volumes, physical and chemical complexity and heterogeneity, and radioactivity or toxicity. Because many similar waste streams exist at multiple sites, EM also is faced with the choice of constructing duplicate characterization, treatment, and (in some cases) disposal facilities, or else transporting waste between sites. There are likely to be many opportunities for optimizing the characterization and treatment programs across EM sites to more effectively utilize existing capabilities and to develop new capabilities that can serve multiple sites or purposes.

In its statement of task (see Sidebar 1.2), the committee was asked to identify opportunities for EM to make more effective use of its existing facilities and capabilities for waste characterization and treatment, including eliminating self-imposed requirements that have no clear safety or technical basis; for EM to improve its characterization and treatment capabilities especially for "orphan" wastes;[2] and for EM to invest in new technologies to achieve these improvements.

APPROACH TO THE STATEMENT OF TASK

To help ensure that its accelerated cleanup schedule could be achieved, EM instructed each site to develop a Performance Management Plan (PMP)

[2]Orphan wastes have no generally agreed-upon path for their disposition. Often, but not always, they exist in small quantities, which make them unattractive for inclusion in cleanup contracts. Nonetheless, their presence at a site can interfere with that site's closure.

Sidebar 1.2 STATEMENT OF TASK

The National Academies will identify opportunities for improving the DOE Office of Environmental Management's waste characterization and treatment capabilities, particularly with respect to the following:

- Making more effective use of existing capabilities and facilities for waste characterization, treatment, or disposal and eliminating self-imposed requirements that have no clear technical or safety basis.
- Improving characterization and treatment capabilities to achieve step efficiency improvements or to treat orphan waste streams.
- Recommendations on technology development and demonstration investments that EM should make over the near term to achieve these improvements.

The study will focus on waste streams for which current characterization, treatment, or disposition pathways are difficult and (or) expensive, and for which improvements would help reduce costs, schedules, and hazards to workers, public, or the environment.

that laid out the schedules and strategies ("baselines") for that site's accelerated cleanup. The committee used these as frameworks for information-gathering visits that included EM's four largest sites: the Oak Ridge Reservation, Tennessee; the Savannah River Site, South Carolina; the Idaho National Engineering and Environmental Laboratory; and the Hanford Site, Washington.

Presentations to the committee included an overview of the site's cleanup objectives and its initiatives for accelerated cleanup, as described in the PMP. Site personnel gave details of the initiatives for which they felt the committee's advice would be most useful, including the assumptions and criteria for success underlying each initiative. The committee used these site-specific overviews along with its own collective expertise to identify opportunities for accelerating characterization and treatment that would be practical to implement in the near term (see Sidebar 1.3).

In the course of its information gathering, the committee decided it could best address the statement of task by interpreting "characterization" and "treatment" in the broad context of the sites' cleanup needs. Characterization as discussed in this report includes determining the nature of wastes at DOE sites, (e.g., physical form, and chemical and radioisotopic contents) as well as environmental factors that might change the nature of the waste over time. Similarly, treatment includes actions necessary to prepare waste for shipment, storage or disposal or, more simply, to stabilize waste in place.

Sidebar 1.3 SCOPE OF THIS STUDY

According to the study prospectus and statement of task, the committee restricted its deliberations to the following:

- *Technical issues associated with waste characterization and treatment to support EM's accelerated cleanup program.* The committee focused on providing EM with technical advice while recognizing that non-technical factors will clearly affect the degree to which EM can implement this advice (see the final section in this chapter). The committee did not attempt to assess non-technical factors or examine EM's "risk-based end state" concept for accelerating cleanup (Roberson, 2004).[a]
- *Legacy wastes and contamination under the responsibility of EM at the time of this study.* This includes wastes and contamination that EM will remove and dispose as well as wastes and contamination that EM will leave in place. Current and future wastes from non-EM programs are not considered.
- *Major needs and challenges at the four largest EM cleanup sites according to the sites' presentations and PMPs* (see main text). The magnitude of the EM program as well as the limited time and resources for this study precluded a more comprehensive study.

[a]A separate BRWM study commissioned by EM on the development of risk-based approaches for disposition of transuranic and high-level radioactive wastes was conducted in parallel with this study.

In reviewing existing capabilities and facilities for possibly more effective use or retention, the committee paid special attention to those with applicability to problem or orphan wastes for which an effective disposition path will be needed to achieve accelerated cleanup.

NON-TECHNICAL FACTORS BEARING ON THE COMMITTEE'S RECOMMENDATIONS

In this report the committee identifies opportunities for EM that are technically feasible and aligned with the near-term goals of accelerated cleanup. The committee is aware that many non-technical factors will bear on EM's ability to implement its recommendations. The committee did not attempt to pre-judge how non-technical issues might limit or foreclose valid technical opportunities. Nevertheless it is clear that for accelerated cleanup to succeed, EM must collaborate with the Environmental Protection Agency (EPA), state regulators, local governments, and other involved stakeholders. All of EM's proposed cleanup activities require the support of regulators and other stakeholders outside of EM and the field offices.

Public Concerns

Each of the committee's site visits included opportunities for public participation. During these sessions, citizens and representatives of citizens' groups remarked on generally deteriorating relations with DOE. Public concerns and opposition, which, for example, have led to significant legal challenges to DOE's plans for some of its high-level tank wastes and buried transuranic wastes (NRDC, 2003; PSCC, 2003), can potentially derail EM's accelerated cleanup program. The committee did not examine the impact of public concerns on EM's cleanup plans.

The committee recognizes that public concerns could be significant barriers to EM's implementing the recommendations in Chapter 3, which describes opportunities for maintaining or extending the use of a few existing characterization and treatment facilities at DOE sites. Public concerns would include security, safety, and equity issues. As noted in the study prospectus, optimizing the use of a few centralized facilities may require transporting wastes among sites—although the volumes of the problematic and orphan wastes primarily addressed in this report would be small compared to the ongoing shipments to the Waste Isolation Pilot Plant in New Mexico and those planned for the Yucca Mountain repository in Nevada. The committee did not address public concerns regarding the safety of waste transportation or shipping wastes into their states for treatment.

At the committee's public sessions, several citizens and representatives of citizens' groups suggested that improved communication about site planning, additional stakeholder meetings, and funding of liaison positions would benefit EM's accelerated cleanup efforts at little financial cost to EM. The committee agrees that good public communication and transparency are essential. In Chapter 2 the committee recommends greater use of DOE's removal action authority to expedite cleanup, which formally reduces the public comment period for these actions. The committee did not address how citizens might perceive the shortened comment period, but it would seem that proceeding with actions to reduce risks might be viewed more favorably than protracted discussions. Chapter 4 introduces a concept for managing wastes that EM will leave on DOE sites that the committee believes has technical advantages and may help mitigate public concerns about these residual wastes.

Regulatory Constraints

EM's ability to implement the technical opportunities identified by the committee will be subject to present and future agreements, permits, and regulations among the sites, their host states, and the EPA. In reviewing the sites' PMPs, the committee noted that many of the basic assumptions for achieving accelerated cleanup hinge on regulatory issues that are outside of EM's control; and in addition there are legal challenges such as the recent court rulings in Idaho (NRDC, 2003; PSCC, 2003). The committee also noted that each site has specific agreements with its state and their EPA regions and that these agreements account for some of the variations in the DOE field offices' approaches to site cleanup.

In identifying opportunities for accelerating waste characterization and treatment, the committee was mindful of the main agreements and regulations under which EM and the sites operate, and none of this report's recommendations are intended to circumvent them. However, the committee did not make a detailed examination of laws, agreements, and regulations that might constrain its recommendations. The committee recognizes that the "DOE self-imposed restrictions" discussed in Chapter 2 have in some cases been incorporated into agreements with regulatory or permitting agencies so that the recommended opportunities might not be implementable at all sites. EM's ability to implement recommendations in Chapter 3 on maintaining characterization and treatment facilities, and transporting waste among sites to optimize their use, will be constrained by applicable agreements and regulations, as will its options for leaving wastes in place discussed in Chapter 4.

Economic Factors

As noted at the beginning of this chapter, EM's accelerated cleanup program is directed at reducing cost and schedule to the greatest extent possible without compromising health and safety. For perspective, the committee used estimates provided by EM headquarters and the sites in their presentations and in their PMPs. However, the committee did not attempt to quantify costs or savings that might be associated with the technical opportunities it identified.

Taking advantage of the administrative opportunities to expedite or simplify characterization and treatment described in Chapter 2 and the approaches for managing waste in place identified in Chapter 4 should result in substantial cost savings. Maintaining the facilities identified in Chapter 3 will be very expensive—restarting the INEEL incinerator could cost several hundred million dollars—however, the committee believes that the options it has identified may be less expensive than the alternatives.

Interactions with other DOE Offices, the Sites, and Site Contractors

The DOE Assistant Secretary for Environmental Management commissioned this study, and the committee's recommendations are directed primarily to EM headquarters. In this sense the committee's recommendations are directed "top down." The committee did not attempt to assess the interactions among EM, other DOE offices (Legacy Management, National Nuclear Security Administration), the sites, or site contractors[3] that would ultimately be necessary to implement the recommendations. These relationships may inhibit or possibly help implement the recommendations.

The committee intends and hopes that the opportunities it has identified are useful to the broader audience that is involved with site cleanup, including congressional staff, DOE, the sites, regulators, contractors, and concerned citizens. Changes in the DOE organization that occurred as this report was being completed serve as reminders of the need for a solid scientific and technical basis for site cleanup even as non-technical factors remain in flux.[4]

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[3]Site contractors, through the bidding process, will ultimately determine how technical enhancements recommended in this report might be implemented.

[4]EM Assistant Secretary Roberson resigned, EM reorganized, and the Office of Legacy Management was established.

2

Administrative Opportunities

In initiating this study, the Department of Energy's Office of Environmental Management (DOE-EM) encouraged the committee to identify opportunities for eliminating self-imposed DOE requirements that have no clear technical or safety basis. Accordingly, this chapter identifies institutional barriers and self-imposed requirements that, based on the committee's site visits, are keeping EM from making the most of its current capabilities for accelerating cleanup. The committee found that such obstacles arise from security classification of Manhattan Project-era equipment being disposed as waste, apparent reluctance to pursue available regulatory remedies, and inconsistent and often excessively strict interpretations by DOE site and contractor personnel of waste characterization and treatment requirements. The committee believes that the ability to resolve these obstacles lies within the administrative authority of DOE and EM.[1] By identifying these barriers and self-imposed requirements, this report may provide impetus for positive changes that can significantly accelerate the cleanup program.

Recommendation:
EM headquarters and sites should aggressively pursue opportunities to simplify and expedite waste characterization, treatment, and disposal by

- *working with the responsible classification offices to declassify, to the extent possible, classified materials declared as wastes,*

[1]The committee did not review DOE's legally binding commitments, e.g., Hanford Tri-Party Agreement, Waste Isolation Pilot Plant permit.

- *better utilizing the waste removal provisions of CERCLA, and*
- *developing more consistent interpretations among sites of waste acceptance requirements and accelerated cleanup objectives.*

EM should work with its sites, their contractors, and affected citizens to take advantage of these opportunities to the greatest extent possible.

SECURITY CLASSIFICATION OF WASTES

During the days of the Manhattan Project and the Cold War era most nuclear materials, equipment, and documentation were classified for security reasons—even the existence of the production sites was classified. Today, a significant fraction of the documentation from that era has been declassified, but much material and process equipment remain classified. Some of these classified materials are destined to become waste as part of site cleanup activities. Workers must have security clearance in order to handle, remove, or treat classified wastes—or often just to work in its vicinity. This results in a reduced labor pool, increased labor costs, and extended cleanup time. Requirements for packaging classified wastes increase waste volumes. For disposal, the waste must be sent to a classified burial ground with long-term physical protection obligations and associated costs. In appropriate cases, removing the security classification of some wastes may provide EM with a significant opportunity to save time and money.

The committee became aware of the constraints imposed by classified waste during open-meeting discussions of the decommissioning of the Oak Ridge K-25 gaseous diffusion plant. The K-25 plant presents one of EM's greatest decommissioning challenges (Figure 2.1). The amount, size, and mass of classified Manhattan Project-era equipment in K-25 make removal and disposal a large part of the challenge. Classified equipment at the Paducah, Kentucky, and Portsmouth, Ohio, gaseous diffusion plants is likely to pose similar removal and disposal challenges in the future.

While gaseous diffusion equipment appears to be a primary example of how security classification costs time and money in EM's cleanup activities, the committee expects that there are other examples that were not discussed in its open meetings. In response to committee questions, Idaho National Engineering and Environmental Laboratory (INEEL) representatives acknowledged issues involving the retrieval of classified buried wastes. Presenters at the Savannah River Site (SRS) explained that classified components there are being declassified by physical alteration.

The Atomic Energy Act requires that information relating to nuclear energy and its use in weapons be classified at inception. Atomic energy information remains classified forever, unless officially declassified. Knowl-

FIGURE 2.1 Much of the gaseous diffusion equipment in the K-25 plant at Oak Ridge dating back to the Manhattan Project-era remains classified. Worker access restrictions make the massive job of decommissioning K-25, which includes about 14 million square feet of floor space, more difficult. Photo courtesy of Oak Ridge Operations Office.

edge and technology have evolved greatly since the Manhattan Project and the onset of the Cold War, which has likely rendered the bases for classifying these materials obsolete. Adapting the management of old classified materials, now declared as wastes, to the real security needs of today can streamline their removal, treatment, and disposal (the committee's views on adaptive waste management are developed further in Chapter 4).

DOE (including the National Nuclear Safety Administration) has the authority to declassify and thus, when it can be determined that no security risk is involved, remove obstacles to accelerated cleanup. DOE procedures detail a process for the review and declassification of materials. These procedures are not site-specific and in fact are managed complex-wide owing to the sensitivity and possible impact of the release of the information that is under review.

Aggressive measures to declassify classified wastes as far upstream in the removal, treatment, and disposal sequence as possible should be fully explored and undertaken. In some cases, wastes might simply be deemed unclassified, analogous to formerly classified documents. In other cases, technical measures to destroy classified physical or chemical attributes of the wastes (e.g., crushing, melting, shredding, slagging) could be used based on overall cost-effectiveness. EM headquarters could assign an individual to address the declassification issue complex-wide, in cooperation with the various declassification officers, sites, and contractors. In this manner, all the sites could benefit from the experiences of sites—such as the SRS practice of destroying classified attributes—that have already been successful at declassifying some of their wastes. All possible avenues to render classified wastes unclassified should be explored.

REMOVAL ACTION AUTHORITY

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, provides federal authority to respond to releases or threatened releases of hazardous substances that may endanger public health or the environment. The act provides two kinds of response action:[2]

1. Short-term *removals*, where actions may be taken to address releases or threatened releases requiring prompt response
2. Long-term *remedial response* actions that permanently and significantly reduce the dangers associated with releases or threats of releases of hazardous substances that are serious, but not immediately life threatening.

Currently most EM site cleanups are conducted as long-term *remedial response* actions, which require a much more extensive amount of planning and paperwork than removal actions. During the committee's public discussion in Idaho and, subsequently, at its final public meeting in Washington, D.C. (see Appendix A), representatives of the U.S. Environmental Protection Agency (EPA) advised that EM could conduct some of its cleanup activities more efficiently by using DOE's removal authority, conferred by Executive Order 12580 under Section 104 of CERCLA. A removal action may be time-critical for situations that need attention within six months. However, CERCLA also provides for non-time-critical removals to allow a longer planning period, if necessary. Although there are requirements for public participation in the removal process, they are less than what one typically encounters in the remedial process.

The advice received by the committee is consistent with an earlier study by the General Accounting Office *Greater Use of Removal Actions Could Cut Time and Cost for Cleanups* (GAO, 1996). This study, which included Hanford, Oak Ridge, SRS, INEEL, and the Rocky Flats Plant in Colorado, found that where removal actions were used, they reduced the overall time and cost of planning by 70 to 90 percent compared with other approaches. The report noted that although DOE's policy guidance encouraged use of removal authority, site managers pointed to interagency agreements and environmental restoration contracts as discouraging its use. The report

[2]See http://www.epa.gov/superfund/action/law/cercla.htm

concluded "While not all waste sites may best be addressed through removal actions, there are still opportunities to accelerate DOE's environmental restoration through wider use of this approach" (GAO, 1996, p. 2).

The Department of Defense (DOD) initiative on fast-track cleanup of its closure sites, which strives for expedited cleanup and reuse of property, closely parallels DOE's accelerated cleanup program. A fact sheet from DOD's Office of the Deputy Undersecretary for Environmental Security suggests the use of removal authority for DOD closure sites and gives a step-by-step description of how to conduct a removal action.[3]

The use of the removal actions option under CERCLA by DOE may be constrained by the agreements it has made with the EPA and /or the states.[4] There are no clear lines as to what response actions should be removal or remedial. Although EPA generally supports the use of removal actions to accelerate responses, many of the DOE responses, due to their cost, complexity, and expense, are more appropriately remedial actions. Also, the cleanup work at DOE sites on the Superfund National Priorities List (NPL) is governed by Federal Facilities Agreements (FFAs), which typically have states as co-signatories. One of the concerns that the states have is DOE using the removal action option to forego meeting a pertinent standard that should be addressed. Thus the state may require additional input or action beyond that required by CERCLA. Nevertheless, there are schedule and financial incentives for EM to use DOE's removal authority.

In 1995, EM and EPA jointly endorsed the use of non-time-critical removals for decommissioning DOE facilities (Herman et al., 1995). The committee did not find any evident application of this policy. Recently, the use of time-critical removal action was suggested in a white paper on decommissioning building CPP-627, a former nuclear fuel reprocessing facility at INEEL (Doornbos, 2004). Other use of removal authority by EM and its sites appears sporadic.

DOE's Mound Plant, Ohio, used removal authority to remediate soil contamination at individual potential release sites instead of using the more time-consuming remedial action, feasibility study, and record of decision approach. Mound estimated a life-cycle savings of 25 years and $2 billion (DOE, 1998b). Oak Ridge has conducted a variety of removal actions, but there appears to have been little recent use of removal authority at SRS, INEEL, or Hanford.[5]

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[3]See http://www.dtic.mil/envirodod/Policies/BRAC/Expedit2.html

[4]The EPA Office of Federal Facilities Restoration and Reuse maintains a library of documents that describe these agreements and guidance on their interpretation. See http://www.epa.gov/fedfac/

[5]See http://www.epa.gov/superfund/sites/npl/npl.htm

Recovering and treating waste in the 618-10/11 burial ground caissons at Hanford may be an opportunity for use of removal authority by EM. The caissons contain about 10,000 m^3 of contact-handled transuranic waste (CH-TRU) and about 100 m^3 of remote-handled TRU (RH-TRU), much of it in one-gallon paint cans. The RH-TRU produces radiation levels up to several thousand rads per hour. Some caissons are located near a parking lot currently used by employees of the Energy Northwest nuclear power plant. Removing this potentially high-risk waste would be commensurate with EM's emphasis on accelerated risk reduction. The committee believes that EM should be aggressive in pursuing this and other opportunities to use DOE's removal authority for accelerated cleanup.

REMOVAL OF MUNITIONS AT INEEL

During its visit to INEEL, the committee learned that EM resources are being used for clearing military munitions remaining on parts of the site used as a firing range for testing large naval guns and other weapons. While it is clear that some unexploded ordnance may present a danger to site cleanup operations and thus require the immediate attention of EM, it appears that EM has an opportunity to better engage DOD in removing these munitions. DOD has statutory responsibility for removal actions involving past and present military munitions under the CERCLA National Contingency Plan [Section 300.120(b)(c)].

The Defense Environmental Restoration Program requires that DOD identify, assess, and clean up military munitions contamination at formerly used defense sites (FUDS). Under this program, INEEL has been placed in Risk Assessment Code 2 (serious risk—priority for further action). If EM believes that Risk Assessment Code 1 (high risk—highest priority for further action) is warranted, it should make the case with DOD for higher-priority funding. EM has an opportunity to save time and money by pressing DOD on its statutory responsibility to recover and dispose of these legacy munitions.

INCONSISTENT INTERPRETATION

The semiautonomous operation of the major DOE sites leads to different philosophies and procedures for cleanup. The committee found two general areas in which site autonomy promotes activities that have no technical or safety basis but reduce efficiency and increase cost:

1. Overly restrictive interpretation of existing requirements for characterizing and sorting transuranic waste (TRU), coupled with lack of criteria

for remote-handled TRU destined for WIPP and for high-level wastes and spent fuels intended for Yucca Mountain.

2. Demolishing new or uncontaminated facilities that pose little if any long-term risk.

With the number of EM cleanup sites, many of which face similar problems, uniform solutions to common problems should be sought. However, it will be difficult to achieve these without top-level direction. Recently, EM has utilized a number of integrated (corporate) teams to address such issues, but future implementation of the findings of such teams will require involvement and commitment by top-level officials (DOE, 2002c).

Characterization, Sorting, and Waste Acceptance

The Waste Isolation Pilot Plant (WIPP) waste acceptance criteria and waste analysis plan comprise a complex set of requirements that must be met by each DOE site to dispose of TRU wastes at WIPP. Each site, working with EM, state officials, and the EPA, has written its own procedures to meet these requirements. A previous (NRC, 2004) study found that there are three TRU waste characterization activities that are apparently conducted for regulatory compliance and do not seem to reduce risk:

1. sampling and analyzing gases from the headspace of waste drums;
2. sampling and analysis of homogeneous wastes; and
3. manual sorting and visual examination to confirm the results of drum radiography (Figure 2.2).

These characterization activities are now prescribed by the WIPP permit.

Site presentations and tours of waste characterization facilities at SRS, Hanford, and INEEL led the committee to the same conclusions presented in the previous study. Following the previous study's recommendations, the DOE Carlsbad Field Office applied to the New Mexico Environment Department (NMED) for permit modifications to obtain partial relief from these characterization requirements. The NMED had not acted on the application at the time this report was reviewed for publication.

According to the committee's discussions at the sites visited, the lack of formal waste acceptance criteria (WAC) for waste that requires remote handling (RH-TRU) to be shipped to the WIPP is a significant impediment to accelerated cleanup. Thus, a priority for EM should be to accelerate negotiations with the State of New Mexico to resolve permitting issues so that sites can proceed with their planning for RH-TRU waste packaging and shipping (NRC, 2002a).

FIGURE 2.2 Manual sorting of waste is time consuming and potentially a risk for workers. Photo courtesy of INEEL.

Another issue that appears to be slowing down decisions and work planning is uncertainty about the future WAC for waste intended for Yucca Mountain. There appears to be no complex-wide interpretation of the current waste acceptance system requirements (DOE, 2002b), so each site is making assumptions regarding how to characterize, treat, and package wastes and even which wastes will be accepted. Although the WAC will not be finalized until the site is licensed, the sites, EM, and the DOE Office of Civilian Radioactive Waste Management, which has overall responsibility for the proposed repository, and the Nuclear Regulatory Commission, which must approve DOE's license application, need to agree on a consistent approach to preparing wastes for disposal in that facility, with one office having oversight authority.

Demolishing Facilities that Pose Little Near-Term Risk

The strategy of the accelerated cleanup program is to eliminate EM's most significant environmental, health, and safety risks as soon as possible and to address less significant risks later (DOE, 2003; Roberson, 2004). In its site visits, the committee became aware that many facilities that pose little risk, i.e., they are not contaminated or in structural jeopardy, are being dismantled or demolished as near-term priorities. Although the committee appreciates the sites' needs to show visible progress and to shrink their operating areas (footprints), these actions are inconsistent with EM's intent to use its limited resources to achieve the greatest risk reductions.

Site presentations indicated that some of these facilities had large operating budgets and that demolition would eliminate their "mortgage" costs, thus making more money available for risk reduction. There were no presentations on what such costs would be if the facilities were changed from a standby state to an abandoned state with little maintenance since they would be demolished eventually. Such an abandoned state was referred to as "cold, dark, and dry" in EM presentations to a previous committee (NRC, 2001b).

One example is the CPP-666 building intended for naval fuel reprocessing at INEEL but never put into service. It is uncontaminated, and there is no structural reason to dismantle and demolish it in the near term. There are many facilities and waste storage areas of more immediate concern. With its several-feet-thick shielding walls and reinforced construction, demolishing the building will be expensive and time consuming. It is also possible that some future use will be found for it. Other examples include removing railroad track at Hanford, the unused cooling tower built for the K-Reactor at SRS, and numerous office buildings throughout the complex. The 1995 DOE-EPA policy on decommissioning (Herman et al., 1995) was applied at Oak Ridge in the late 1990s in the transfer of several buildings to the city of Oak Ridge. The committee encourages similar transfers of uncontaminated buildings at other sites.

3

Facilities and Technologies

This chapter deals with facilities and technologies that underpin the DOE Office of Environmental Management's characterization and treatment capabilities. The committee obtained information for this chapter primarily from briefings and documents provided by EM and its contractors during the four site visits (see Appendix A) and from the collective knowledge of committee members. In accordance with its task statement, the committee focused on facilities and technologies with applicability to problematic or "orphan" wastes, for which effective disposition paths are needed to achieve accelerated cleanup. As noted in Chapter 1, the committee was aware of many non-technical factors (public concerns, regulations, economics) that will bear on how EM might implement the technical recommendations set forth in this chapter, but did not attempt to prejudge how these factors might limit or foreclose valid technical opportunities. The committee did not seek a comprehensive list of capabilities and facilities.

From its information-gathering and results from other NRC studies, the committee believes that legacy orphan wastes and "odds and ends" that will continue to arise throughout the EM cleanup fall into seven general categories:

- Low-level and mixed low-level wastes, including combustible and non-combustible materials (NRC, 1999a, 2002b),
- Spent nuclear fuels (SNF) and fuel fragments that require treatment before prolonged storage or disposal (NRC, 2003a),

- Fissile materials (U-235, U-233, Pu-239) that, due to impurities or other factors, cannot be recycled or disposed in the Waste Isolation Pilot Plant (WIPP),
- Radiation sources (sealed sources, Hanford strontium and cesium capsules) that exceed limits for near-surface disposal,
- Sludges, slurries, and tank heels encountered in facility decommissioning that require treatment before disposal (NRC, 1999b, 2001b),
- Large, heavy, highly-contaminated equipment from fuel reprocessing, materials separation, and waste processing, and
- Radioactively and chemically contaminated in situ soils and ground water that require characterization and monitoring (see Chapter 4).

Facilities with unique, currently available capabilities for characterizing and treating many of these wastes are described in the first section of this chapter. The second section describes existing facilities that can be upgraded or their operations extended to treat additional orphans, with the view that upgrades or extended capabilities may be less expensive and more expedient than constructing new facilities. The third section identifies new technologies that would enhance existing capabilities.

Recommendation:
EM should consider managing the following facilities as corporate assets for the characterization or treatment of both mainstream and special-case or "orphan" wastes:

- *Toxic Substances Control Act (TSCA) incinerator at Oak Ridge*
- *H-Canyon at Savannah River*
- *T-Plant at Hanford*
- *High-level waste (HLW) calciner at Idaho*
- *Advanced Mixed Waste Treatment Facility (AMWTF) at Idaho*
- *Vitrification Facilities at Savannah River and Hanford*
- *Existing groundwater-monitoring wells at all sites.*

The basis for this recommendation is the match-up between the seven general categories of wastes that will have to be dealt with throughout EM's cleanup program and EM's already-existing facilities (see Tables 3.1 and 3.2). In considering the continued operation of these facilities as corporate assets versus closing them, EM will need detailed assessments of the liabilities of maintaining them (cost, ensuring safety, meeting regulatory requirements) versus the same liabilities for providing alternatives. While such detailed assessments are beyond the committee's ability, maintaining or extending the capabilities of the recommended facilities are worthy options to consider.

TABLE 3.1 Problem and Orphan Wastes That Can Be Treated in Existing Facilities

Waste Type	Facility	Treatment Capability	Product and Disposal
Combustible mixed low-level waste solids and liquids	Oak Ridge incinerator	Incineration	Stable solids for near-surface disposal
Spent nuclear fuel that requires processing; enriched uranium	Savannah River H-Canyon	Reprocessing, downblending	Recycle or disposal of fissile materials; high-level waste (HLW) is vitrified
Large, highly contaminated objects	Hanford T-Plant	Size reduction, macro-encapsulation	Packaged waste for near surface disposal or WIPP

TABLE 3.2 Wastes That Can Be Treated By Improving Capabilities in Existing Facilities

Waste Type	Facility	Treatment Capability	Product and Disposal
Noncombustible liquids and slurries (high- or low-level)	INEEL calciner	Calcination	Stable granular solids that may be low-level waste, HLW, or TRU waste depending on the original waste composition
High-volume transuranic[a] or low-level wastes	INEEL AMWTF	Characterization, sorting, compaction	Packaged waste for WIPP
Small-volume, highly radio-active sources or fissile materials	Savannah River DWPF; Hanford WTP	Encapsulation in vitrified HLW	Canisters for geologic dis-posal with SNF and other HLW

[a]Including buried TRU that may be retrieved (NRC, 2002b).

CURRENTLY AVAILABLE FACILITIES

The committee believes that the accelerated cleanup can best be kept on track, or accelerated further, if a limited number of facilities with unique capabilities for characterization or treatment are maintained as corporate resources, instead of being tied to their host site's decommissioning schedules and budgets. Premature closure of these facilities to fit a specific site's schedule could seriously delay the overall EM program because these facilities' capabilities cannot be replaced by other DOE or commercial resources.

Oak Ridge Toxic Substances Control Act (TSCA) Incinerator

The Oak Ridge TSCA incinerator is EM's only waste incinerator. It has a permit to burn wastes containing chemically hazardous materials,[1] TSCA materials (e.g., polychlorinated biphenyls [PCBs]), and low-level radioactive liquids and solids. In addition to wastes from within Tennessee, incineration of approved out-of-state wastes, e.g., from other DOE sites, is allowed by the permit. The incinerator thus has a unique capability to treat a wide variety of EM's mixed low-level wastes,[2] which have been identified previously as a potential obstacle for accelerated cleanup (NRC, 1999a, 2002b) (Figure 3.1).

According to Oak Ridge's accelerated cleanup plan, the incinerator is to be shut down in 2006 and to be fully decommissioned in 2008. This closure date will preclude use of the incinerator for some existing wastes from other DOE sites and even for some Oak Ridge site wastes.[3] TSCA mixed wastes along with dioxins and furans now exist at Fernald, Paducah, INEEL, and other national laboratories, according to information presented to the committee. There are no commercial incineration facilities that can serve as replacements.

The committee heard rather different viewpoints about the continued need for this incinerator from Oak Ridge and other sites visited. Oak Ridge personnel stated that it is difficult for incinerator operators to get commitments for shipment of wastes to the incinerator, especially from other sites. This makes forecasting, scheduling, and providing sustained funding to operate the incinerator difficult for Oak Ridge management. Other sites mentioned barriers to sending mixed wastes to Oak Ridge, such as restrictive waste acceptance criteria.

EM's Corporate Projects Initiative on Disposing Waste, Reducing Risk[4] found similar issues as the committee and recommended that the TSCA incinerator be supported as a corporate asset, i.e., funded by sites

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[1]As defined by the Resource Conservation and Control Act (RCRA) of 1976, as amended.

[2]Mixed wastes contain low-level radioactive wastes mixed with RCRA and/or TSCA chemicals.

[3]The committee noted that the large capacity supercompactor, used for crushing metal components from the gaseous diffusion plant decommissioning and which provided another unique treatment capability at Oak Ridge, is being dismantled.

[4]Project teams modeled on those used by for-profit corporations were organized within EM in November 2002 to institute top-down reforms in the cleanup program. They provided their results to EM management in November 2003.

FIGURE 3.1 The TSCA incinerator at Oak Ridge provides EM's only capability for burning mixed low-level radioactive wastes. Photo courtesy of Oak Ridge Operations Office.

sending waste to the incinerator (DOE, 2002c). The EM team found that access to the TSCA incinerator was hindered by regulatory protocol, lack of schedule integration, lack of accurate inventories, and complicated access requirements.

The committee believes that closure of the incinerator should be decoupled from the Oak Ridge cleanup schedule, and the incinerator should be managed and funded as an EM-wide asset until near the end of EM's mission when it is certain to be needed no longer. As a firm closure date approaches, there should be technical opportunities to expand the spectrum of wastes that can be burned. For example, more corrosive materials could be accepted and burned because protecting the interior of the incinerator from corrosion becomes less important as shutdown time approaches.

Savannah River H-Canyon

The H-Canyon reprocessing plant at SRS is the only active reprocessing plant in the United States. At the present it is being used to blend highly enriched uranium (HEU)[5] down to enrichments that are suitable for use in the Tennessee Valley Authority's (TVA's) power-producing reactors. DOE has significant quantities of aluminum-clad fuels and uranium-aluminum alloy fuels that could be reprocessed in H-Canyon, including fuels from domestic and foreign research reactors. Unreprocessed spent fuels from

[5]In enriched uranium the proportion of U-235 has been increased relative to that in naturally occurring uranium, usually for use in weapons or nuclear reactors.

research reactors present a challenge for disposal because of their relatively high uranium-235 enrichment (NRC, 1998). It could also be used to stabilize and store plutonium pending final disposition, as well as to package and ship materials for disposal, e.g., to the Yucca Mountain repository if licensed and constructed, the Nevada Test Site, and WIPP.

According to the SRS Performance Management Plan, H-Canyon will complete its reprocessing mission and safe shutdown will begin in 2015 (SRS, 2002). Shutdown will be completed and deactivation will begin in 2016. This is only a few years after DOE's most optimistic estimate of when the Yucca Mountain repository might open (2010) and some 20 years before EM expects to complete its accelerated cleanup. It seems likely that spent fuels that do not meet Yucca Mountain acceptance criteria will be identified during these 20 years. H-Canyon would have a unique capability to reprocess or otherwise treat these materials.

Hanford T-Plant

The T-Plant was built in 1943 to extract plutonium from uraniuim-238 targets that were bombarded by neutrons in the Hanford production reactors. The plant was shut down as an extraction facility in 1956 and was converted to a decontamination facility for processing and packaging radioactive and hazardous solid waste. The plant was designed for remote operation. It offers large, shielded, operating areas equipped with an overhead crane. The plant provides a unique capability for handling very large, highly contaminated objects, especially transuranic wastes that require remote handling (RH-TRU).

Currently, Hanford is using T-Plant to characterize waste by sampling and radiography, to size-reduce and decontaminate equipment, and to treat waste primarily by macroencapsulation. According to Hanford's final Environmental Impact Statement (EIS) for its solid waste program, T-Plant will be used to store RH-TRU, including K-Basin sludges (ROO, 2004). There are continuing needs and opportunities to use T-Plant for characterizing and treating both on- and off-site wastes that require remote handling.

FACILITIES FOR IMPROVEMENT OR EXPANDED USE

In initiating this study, EM asked the committee to look for opportunities for upgrading or expanding the use of currently existing facilities. While EM and the committee realize that effort and cost to upgrade or expand the capabilities of existing facilities are appreciable, improving existing facilities is likely to offer advantages for accelerated cleanup versus the cost and time required to build new facilities and eventually decommission them. Table 3.2 summarizes the match-up between wastes that EM will need to treat and these facilities.

INEEL Calciner

The fluidized bed calciner at INEEL is an existing facility that has potential extended use in treating the approximately one million gallons of sodium-bearing acidic waste (SBW) from reprocessing naval nuclear reactor fuel at that site, as well as a wide variety of other liquid wastes and slurries. Fluidized bed technology has been used in numerous applications for nuclear materials processing, including purifying uranium ore, producing uranium hexafluoride (UF_6) and uranium dioxide (UO_2) at Oak Ridge, treating power reactor resin wastes at a commercial facility at Erwin, Tennessee, and reprocessing navy fuel by separating zirconium from fission products on a pilot scale. The INEEL calciner was placed in standby condition in June 2000 due to lack of a Resource Conservation and Recovery Act (RCRA) permit and is scheduled for decommissioning (Holmes, 2004).

INEEL has considered both direct calcination and steam reforming (see the following section on technology investments) for producing a dry waste from its SBW and has identified no significant gaps for using these technologies (Holmes, 2004). The existing INEEL calciner, upgraded with "maximum available control technology" (MACT) for controlling emissions to the atmosphere as required for a RCRA permit or modified for steam reforming, can provide either of these capabilities.

Including other options such as direct evaporation and vitrification, very early engineering estimates of the facility cost for treating the SBW range from $200 million to $700 million (Holmes, 2004). Costs of restarting the calciner would likely be in the middle or lower portion of this range. Time and costs for safety reviews and permitting would be substantial. Because in addition to SBW, the INEEL calciner could treat a variety of other problematic wastes and yield a stable product for disposal, the committee believes that it can provide a treatment capability that will benefit EM throughout the remainder of the accelerated cleanup program.

INEEL Advanced Mixed Waste Treatment Facility

The AMWTF is designed, and currently being tested, for characterizing and treating approximately 65,000 m^3 of stored, mixed CH-TRU waste for shipment to the WIPP. The AMWTF is unique in the DOE complex for handling large amounts of mixed wastes. It is potentially also suitable for mixed RH-TRU and mixed low-level waste (LLW). At the time of the committee's visit in March 2004, the facility was undergoing a final series of tests before beginning operation.

The AMWTF was designed to have a high-throughput capacity and the ability to compact 55-gallon drums of waste. Many of its operations are automated. With appropriately placed shielding and some modification, the AMWTF might be able to characterize and treat RH-TRU. In addition, there is no technical reason that the facility could not be used to characterize and treat mixed LLW—although the AMWTF cannot replace the TSCA incinerator as a means of destroying organics or provide such substantial volume reductions as incineration.

Hanford and SRS Vitrification Facilities

Technology referred to as "can-in canister" (CIC) was developed by DOE in the late 1990s as an option for disposing of a portion of DOE's excess plutonium (Gray et al., 1999). The concept included stacking plutonium-ceramic "hockey pucks" in slender stainless steel cylinders ("cans") and mounting the cans onto a rack, which could be placed in an empty canister designed for disposal of vitrified high-level waste. Molten vitreous HLW poured into the canister would encapsulate the cans, and the filled canister would eventually be disposed in a geologic repository, e.g., Yucca Mountain if licensed and constructed. The concept was developed for the Defense Waste Processing Facility (DWPF) at SRS, and it was demonstrated in nonradioactive tests. The CIC approach was canceled in 2002 because of the estimated cost of a new facility for making the plutonium-ceramic pucks (Siskin, 2002).

The DWPF and the Waste Treatment Plant (WTP), which is under construction at Hanford, could provide CIC capability for relatively small-volume problematic or orphan wastes, especially those that are highly radioactive (such as the Sr-90 and Cs-137 capsules stored at Hanford) or that contain fissile materials. One such fissile material is the U-233 stored at Oak Ridge. Currently Oak Ridge has about one metric ton of separated U-233 (Rushton and Forsberg, 2001). Based on the previous plan for disposing of plutonium, this amount of U-233 could be disposed in about 40 DWPF canisters of HLW glass (Gray, 1999). Given the large number and variety of enriched-uranium research reactor fuels, it is likely that some will not meet Yucca Mountain acceptance criteria for direct disposal. The CIC approach could provide a disposal route for these fuels.

Current Monitoring Wells

Buried wastes and subsurface contamination have been monitored throughout the operation of DOE sites by the use of wells drilled in selected locations to provide samples of the groundwater. Many of these wells are being plugged (usually by grouting) and abandoned in connection with facility closures or the capping of waste disposal areas. Nevertheless, the need to monitor and treat groundwater plumes will continue for an extended period of time. The committee therefore includes currently existing groundwater-monitoring wells among facilities that are essential to EM's characterization capabilities.

The committee observed that the DOE and contractor staff responsible for decommissioning and capping are different from those with long-term site responsibility, so that it is not clear whether plugging and abandoning existing wells is being weighed against future monitoring needs. Because capping is intended to provide a low-permeability barrier against surface water infiltration, drilling new wells through the caps is a poor technical option—yet a decision to remove a monitoring well from such a location forecloses essential characterization capability. The need to continue long-term monitoring of buried wastes and contaminated media is discussed in Chapter 4.

NEAR-TERM TECHNOLOGY INVESTMENTS

This section addresses the portion of the committee's statement of task that requests recommendations about technology investments that EM should make to enhance its characterization and treatment capabilities significantly. In reviewing technologies for possible investment, the committee selected four that are directly relevant to EM's larger characterization and treatment challenges and that are well enough developed that additional EM support should lead to near-term payoffs.

Recommendation:
EM should continue developing and deploying new or improved technologies that address limitations in current characterization and treatment capabilities. The committee recommends investments in

- *steam reforming,*
- *improved high-level waste vitrification,*
- *"no-consequence" TRU shipping containers, and*
- *state-of-the-art sensors for environmental monitoring.*

Steam reforming is a commercially developed technology that can potentially treat a wide variety of orphan wastes. High-level waste vitrification is EM's single most expensive waste treatment process. Incremental technology improvements can produce large schedule and cost advantages. The "no consequence" container is a nearly developed technology that can greatly simplify characterization and reduce repackaging of flammable-gas-generating-TRU wastes. New sensor technology can be rapidly deployed to reduce costs and increase the knowledge gained in environmental monitoring. Monitoring systems at EM closure sites have been estimated to be some 25 years behind the state-of-art (INEEL, 2003).

Steam Reforming

Steam reforming is a fluidized bed technology that has great potential for treating a wide variety of wastes, slurries, and sludges—including low-activity tank waste at Hanford, sodium bearing waste at INEEL, and many of the potential orphan wastes listed at the beginning of this chapter. In a typical steam reforming process, superheated steam along with the material to be treated and co-reactants are introduced into a fluidized bed reactor where water evaporates, organic materials are destroyed, and the waste constituents are converted to a granular, leach-resistant solid. Steam reforming is in commercial use at Erwin, Tennessee, for treatment and destruction of radioactively contaminated ion exchange resins, oils, and solvents from commercial nuclear power plants.

In the steam reformer, superheated steam is directed through a bed of refractory particles, which are partially suspended by the steam so that collectively they behave like a fluid. The fluidized particles provide a large surface area to promote heat transfer and chemical reactions. In addition, the particles may have a chemical composition or coating that catalyzes the reactions. The process does not require elevated pressure and typically operates at 600-750°C, which is well below the temperature required for incineration or vitrification. The relatively lower temperatures reduce problems associated with equipment corrosion and radionuclide volatility.

Chemical conditions in the reactor can be controlled to enable a variety of reactions. RCRA and TSCA organics can be converted to water and carbon dioxide by a combination of the steam and oxidizers. Carbon- and iron-based reductants can convert nitrates and nitrites directly to nitrogen (Cowan et al., 2004). Clay or other inorganic materials can be added to convert radionuclides and bulk waste constituents such as sodium, potassium, sulfate, chloride, phosphates, and nonvolatile heavy metals to a stable ceramic form for disposal. In tests with radioactive materials, steam reforming has produced a waste form that indicated a good ability to stabilize cesium and technetium (Jantzen, 2004). These short- and long-term hazardous radionuclides are volatile in conventional waste vitrification processes and are readily leached from grouts.

The most important near-term potential application is for providing supplemental processing capacity for the low-activity waste (LAW) stream from the

Hanford WTP. Waste compositions are expected to change significantly as wastes from different tanks or blends of tanks are fed to the WTP. Some additional process development and chemistry studies will likely be required to optimize the operating conditions for these various waste compositions.

As noted in the previous discussion of the INEEL calciner, converting that unit to a steam reformer for treating sodium-bearing waste appears straightforward, based on the committee's limited fact finding. The technology has high potential for application to other waste types where radioactively contaminated liquids are to be treated—for example liquid phases from decontamination operations or from groundwater-pumping operations. Wastes that may contain materials such as mercury and acidic gases pose technical issues that also need to be addressed.

High-Level Waste Vitrification

Treating HLW is the most expensive, long-term component of the EM cleanup, amounting to over one-third of the total life-cycle cost of the program (DOE, 2000b). The DWPF has been vitrifying high-level tank sludges at SRS since March 1996. The glass melter has been replaced once and more than 1.4 million gallons of waste have been vitrified. In May 2003, a change in the composition of the frit material used to form the glass allowed a 25 percent increase in waste loading, i.e., the amount of waste that can be incorporated into a given quantity of the glass product (Occhipinti, 2004). Hanford's WTP is scheduled to be in operation by 2011 after its $5.7 billion construction is completed.

Technology investments that lead to increasing the waste loading or production rate of vitrified high-level tank waste at SRS and Hanford are likely to provide EM with opportunities for large cost and schedule reductions. In addition to opportunities for incremental technology improvements while the DWPF is operating, such as the improved glass-forming frit, there are opportunities to deploy major new technologies each time a melter is replaced—about every five years. Lessons learned at the DWPF and new commercial technologies can be deployed in the WTP in the early phases of construction. The committee found two broad areas for technology investment for EM to improve HLW vitrification:

1. continued development of frit and glass melting chemistry, and
2. new approaches for putting energy into the melters.

Frit Development. Waste vitrification involves trade-offs among waste loading in the glass, viscosity of the melt (so that it is pourable), and quality (durability and homogeneity) of the product glass (NRC, 1999a). Simply increasing the melt temperature, which would improve all three, is generally not possible due to melter corrosion and radionuclide volatility. The only other option is to tailor the glass-forming frit composition closely to the waste composition to improve the match-up among the glass-forming chemicals and the waste components. SRS has increased its waste loading, but at the expense of throughput (pounds of waste vitrified per hour), pressure, and pour stream instabilities. Hanford has a frit composition for the initial waste feed but is challenged by a much wider range of waste compositions than SRS. Therefore the committee believes that continued investments in frit and glass chemistry provide an important opportunity for enhanced vitrification capability.

Microwave Heating. Microwave technologies may provide a straightforward means of delivering additional energy to SRS and Hanford melters. Small transmitters could be installed at strategic locations around the melter, with essentially all electronic components outside the melter cell to allow hands-on maintenance. At SRS, the higher waste loading has led to pour stream instabilities, which might be remedied by heating the bellows around the pour spout (Occhipinti, 2004). The higher loading can also lead to precipitation of metals from the waste into the relatively cold area near the bottom of the melter. Accumulations in this area can short-circuit the electrodes that power the melter. Using microwave energy to heat this area might help keep the metals dissolved in the molten glass and improve the overall homogeneity of the product. Additional development will be needed to assess this approach.

Unlike the SRS design, the Hanford WTP does not include an evaporator to remove excess water from the waste slurry entering the melter, but rather relies on heat from the melter itself. This raises issues concerning heat transfer through the "cold cap" of unmelted waste and frit that floats between the molten glass in the melter and the incoming aqueous slurry. Microwave heating may be an effective means to evaporate excess water without resorting to air "bubblers," which are inserted into the molten glass and pass air through the melt to disrupt the cold cap. Bubblers inserted into the melt raise issues that include changes in glass chemistry, corrosion, and radionuclide volatilization.

No-Consequence Container

For shipping TRU wastes to WIPP, there has long been concern over whether a flammable gas mixture might arise within the shipping cask due to radiolysis or other reactions in the waste and result in deflagration with sufficient energy to breach the containment. The U.S. Nuclear Regulatory

Commission (USNRC), which licenses the shipping casks (referred to as TRUPACT-II casks), dealt with the flammable gas issue by requiring that hydrogen and other flammable gases comprise less than 5 percent by volume of the total gas inventory in any confined space within the cask, e.g., a drum or bag within a drum (NRC, 2001a). This requirement caused severe problems at sites, including the need to sort and rupture plastic bags within the waste, and to repackage waste to meet per-drum limits on radioactive materials. There was also considerable work by EM to reassess the shipping requirements derived from the USNRC limit. Revision 19 of the Safety Analysis Report for Packaging for the TRUPACT-II reduced, but did not eliminate, the concern about hydrogen generation (Curl et al., 2002).

WIPP representatives believe that even with additional revisions under the "Quick to WIPP" concept (hydrogen removal from the containers before shipment and a shorter shipping period to reduce time available for gas generation), some few thousand drums will continue to face shipping restrictions due to flammable gas concerns. Currently, the only available alternative is repackaging the contents of a problematic drum, with the repacking ratio expected to be 10 to 20 new drums for each problematic one (Italiano, 2004).

The concept of a robust "no-consequence container" that could withstand a worst-case hydrogen deflagration is an appealing solution to the problem. A problematic drum would simply be placed in the no-consequence container, which could then be loaded into the TRUPACT-II and shipped. Since 2001 DOE has funded testing of the Arrow-Pak design of a no-consequence container.[6] Based on earlier EPA-approved "no-migration" macroencapsulation containers, the new container has an increased wall thickness. Tests showed that the Arrow-Pak container would conservatively withstand a worst-case deflagration.

While the Arrow-Pak has demonstrated the no-consequence concept, there are technical issues remaining. These include determining the best container design and construction materials based on cost and compatibility with WIPP waste handling and disposal requirements. Currently, WIPP managers and operators are working on better ways to evaluate the containers and the limits on their contents and to prepare for implementation. However, the committee cautions against setting the performance requirements higher than required to meet WIPP's permit requirements, and thus increasing cost unnecessarily. Continued EM investment in the no-consequence container can resolve the problem of shipping flammable-gas-generating TRU wastes to WIPP.

[6]Arrow-Pak is manufactured by BOH Environmental, LLC.

Sensors for Environmental Monitoring

An improved capability for environmental monotoring would strengthen EM's plans to leave waste and contaminated media at DOE sites and transition the responsibility for their long-term management to DOE's new office of Legacy Management (see Chapter 4). Sensors and their associated technologies for environmental monitoring are well developed and continue to be improved. Previous studies of science and technology needs found opportunities for new sensor technology in most aspects of EM's work (NRC, 2001b, 2002b, 2003a). INEEL recently developed a science and technology roadmap, which listed sensors and sensor systems as key capabilities for long-term site stewardship (INEEL, 2003). Similar needs were raised to the committee in its fact-finding visits (Provencher, 2004).

Environmental monitoring at EM sites currently relies heavily on sampling and analyzing groundwater.[7] This practice provides individual point measurements that are used to monitor contaminant source areas, evaluate the effectiveness of hydrologic barriers and treatment walls, identify changes in site conditions, and characterize subsurface and waste heterogeneity. Modern, noninvasive geophysical sensor techniques, such as electromagnetic and electrical methods, seismic methods, and ground-penetrating radar can substantially improve current practices and lead to cost-effective means to implement long-term monitoring after site closure. Geophysical sensor technology can provide continuous measurements in time and space that could fill knowledge gaps between monitoring wells; enable rapid mapping of large areas, including soundings to depth; deliver information on waste characteristics as well as subsurface hydrogeology; and be developed into long-term monitoring networks (EPA, 2000).

An example of new technology is real time, long-term monitoring using geophysical sensors developed at INEEL. This technology is currently being employed at a waste storage area located at the Ruby Gulch Superfund site in South Dakota (Versteeg et al., 2004). At this site contaminant breakthrough has not been controlled, so there is not yet a quantitative link between the response of the geophysical sensors and contaminant concentration.

EM investment in a systematic geophysics program would benefit all of the legacy sites by closing current knowledge gaps that are barriers to implementing modern sensor technology. These gaps include uncertainties in how hydrostratigraphy (i.e., subsurface formations that influence groundwater movement) affects measurement signals, the relationship between measurement scale and process scale, and the long-term robustness of in

[7]Costs for groundwater analyses across the DOE complex have been estimated at around $300 million per year (INEEL, 2003).

situ geophysical sensors. The types of tests needed to extend current knowledge include

- evaluation of signal response in sites of varying hydrostratigraphy to better understand measurement sensitivity and noise;
- comparison of different geophysical techniques to see how signals can be enhanced, which methods work better for different problems, and what synergy can be gained by combining two or more complementary methods;
- controlled experiments, e.g., Daily et al., 2004, to validate geophysical measurements and make these sensors more widely applicable; and
- in situ monitoring experiments, e.g., Versteeg et al., 2004, to investigate sensor signal quality and reliability over time.

These tests could be conducted as part of ongoing site characterization and remediation projects, supplemented with additional sites to cover a range of settings. For example, nonintrusive geophysical characterization was part of the Pit 9 investigation at INEEL (see Sidebar 3.1). Subsequent excavations conducted to retrieve Pit 9 waste provided actual sampling data to compare with and help verify the geophysical measurements.

Sidebar 3.1 PIT 9 AT INEEL

INEEL's Radioactive Waste Management Complex (RWMC) was established in 1952 for disposal of solid low-level radioactive waste generated onsite. Wastes from other DOE sites were also buried there, including transuranic waste from Rocky Flats. Wastes were disposed in pits, trenches, soil vaults, an above-ground disposal pad, a transuranic storage area release site, and three septic tanks. One of the trenches contained in the complex is Pit 9, a 1-acre site that was used primarily to dispose of wastes from Rocky Flats between 1967 and 1969. DOE estimates that Pit 9 contains about 7,100 cubic meters (250,000 cubic feet) of sludge and solids contaminated with plutonium and americium.

At the time of the committee's visit, March 2004, INEEL had successfully completed a pilot-scale excavation of portions of Pit 9 (Figure 3.2). To ensure safety, a containment structure was erected over the area to be excavated and the excavation and waste retrievals were done with remotely operated equipment. This procedure, referred to as the Glovebox Excavator Method (GEM) allowed the use of both non-invasive geophysical measurements and actual sampling of the excavated material for characterizing the waste.

FIGURE 3.2 The glovebox excavator method (GEM) was a pilot project for retrieving waste at INEEL. While successful, it also demonstrated the cost and difficulty of retrieving some types of wastes at EM sites. Photo courtesy of INEEL.

4

Manage-in-Place Technologies

The Department of Energy's Office of Environmental Management, this committee and other NRC committees,[1] and many citizens who are concerned with DOE site cleanup realize that it is not possible to totally remove all of the legacy waste and environmental contamination from the EM sites. In its accelerated cleanup program, EM intends to leave much of its buried waste and other "in-place" waste and contamination at DOE sites. However, ensuring that left-in-place wastes in fact remain in place is a responsibility that continues for potentially very long times. In assessing step improvements in efficiency in waste characterization and treatment, the committee found that options to characterize and treat (stabilize) wastes in place offer significant opportunities for accelerating EM's program. In this chapter, the committee provides advice on technical and scientific approaches for optimizing the trade-offs between short-term expediency and long-term liabilities.

COCOONING APPROACH TO MANAGING WASTE IN PLACE

In its fact finding, the committee noted that reactor "cocooning" at Hanford is an instructive conceptual approach to managing waste in place. Reactor cocooning, also known as Interim Safe Storage (ISS), involves demolishing and removing all of a reactor's ancillary buildings and the reactor building itself, except for the thick shielding walls around the

[1]See, for example, NRC, 1999b, 2000a, and 2003b.

defueled reactor core. A roof that is expected to last for about 75 years is built over the remaining structure, which is sealed, and the door is welded shut. A minimal but prudent amount of external monitoring is maintained, and the structure is reentered for inspection every five years. It is expected that the roof will have to be replaced one or more times before the residual radioactivity in the reactor core will have decayed sufficiently, and/or new technology developed, so that final disposition (removal, abandonment, a combination of these, or a currently unknown option) can be undertaken. Reactor cocooning has support from Hanford's regulators and other stakeholders.

The committee believes that the cocooning concept can be adapted and applied to other left-in-place wastes and facilities. Conceptualizing left-in-place wastes as cocooned can facilitate EM's accelerated cleanup in terms of both simplifying the technical work itself and gaining acceptance by stakeholders. According to the cocooning concept,

1. Needs for characterization and treatment are greatly reduced compared to the handling, characterization, and treatment necessary if the waste were removed—but characterization and treatment are not totally eliminated;
2. Immediate advantages versus long-term liabilities (monitoring, rebuilding, eventual disposition) are displayed clearly to all stakeholders, including EM, contractors, regulators, state governments, communities, and other interested parties;
3. The waste is stabilized in a scientifically responsible way that meets today's regulatory requirements and uses well-established technologies, but does not foreclose future disposition options;
4. Monitoring and modeling are ongoing, providing verification that the waste is safely stabilized in the same sense as periodically inspecting cocooned reactors; and
5. Future remedial activities are adapted to new developments in science, technology, regulation, and the changing (usually decreasing) risk of the waste with time.

The concept of cocooning is to adaptively manage wastes that do not pose immediate health or environmental threats and to avoid actions that involve costly or inappropriate treatment activities and result in little gain. Radioactive decay generally serves to reduce the hazard over time. New technologies as well as new knowledge to inform better decision making for the wastes' eventual disposition can emerge during the cocooning period. Simply leaving wastes in place without an adequate monitoring program and periodically revisiting characterization and treatment options cannot be considered cocooning.

Recommendation:
For waste that EM considers leaving in place, the committee recommends that EM broaden the use of the cocooning concept as currently applied to the Hanford reactors. The cocooning approach provides stabilization and monitoring of wastes left in place, a clear understanding of current benefits and future liabilities for all stakeholders, and the possibility of adapting to changes that will inevitably arise in the future.

In its site visits, the committee noted instances where the time and money that were being spent on engineered trench caps appeared unwarranted, cap design appeared inappropriate and/or the projected performance of caps, and also engineered liners, appeared overly optimistic. The trench cap at the SWSA-6 site at Oak Ridge is one case in point.[2] In 1989, a multi-million dollar high-density polyethylene (HDPE) cap was placed over SWSA-6, despite the fact that continued lateral groundwater flow through the buried waste, the primary cause of contaminant transport from this site (ORO, 2002), rendered the cap insignificant as a hydraulic barrier. Maintenance and repair of the cap ceased in 1996, reducing its reliability even as a protective barrier between the underlying waste, ecological receptors, and site workers.

Another example is the Environmental Remediation Disposal Facility (ERDF) at Hanford,[3] where risk-assessment analyses assume that leachate from the facility will not reach groundwater for 1000 years (DOE, 2000a). These analyses presuppose that the ERDF's engineered cap and liner will remain effective for close to 1000 years.[4] There are no data to support such expectations of longevity. Furthermore, the ERDF cap includes a layer of compacted clay despite concerns that, in arid and semi-arid regions, such layers might desiccate and crack over time, reducing the cap's effectiveness as a barrier to water infiltration (Suter et al., 1993). Continued monitoring, with repair and some rebuilding as necessary, would be more reasonable expectations.

Rather than installing unwarranted or inappropriate barriers, and/or over-rating barrier performance without adequate scientific basis or means, the cocooning concept would lead site managers to use more cost-effective and scientifically justifiable barrier designs, and help ensure that all stake-

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[2]Solid Waste Storage Area 6 (SWSA 6) was used for the disposal of solid low-level radioactive waste in trenches, auger holes, and silos.

[3]The ERDF is a massive trench, opened in 1996, to collect and dispose of 16 million tons of waste and contaminated media from the Hanford site cleanup. Currently it contains 4 million tons. The facility uses a double liner system to contain and collect water. It is located near the center of the Hanford site, which is about 240 feet above the groundwater table.

[4]See http://web.em.doe.gov/profiles/han.html

Sidebar 4.1 APPLICATION OF THE COCOONING CONCEPT TO EM'S ACCELERATED CLEANUP

By analogy to reactor cocooning at Hanford, the cocooning concept applied to managing left-in-place waste encourages the use of established, cost-effective technology while making long-term responsibilities clear to all stakeholders.

- Characterization. Historical records, real-time field analyses, and geostatistical techniques for optimizing sampling locations can produce timely results, data adequate to locate the waste, and enough information to determine practical ways to stabilize and isolate it. Expensive invasive characterizations are generally not necessary.
- Reducing waste leachability: Compaction and/or grouting increase density and decrease porosity of buried waste and its immediate surroundings, thus minimizing the amount of leachant that can contact the buried waste. Less established practices, like in situ vitrification, are not likely to offer widespread advantages.
- Trench caps and barriers: Current knowledge and material properties indicate that RCRA and CERCLA cover systems or barriers might achieve a design life of hundreds of years provided that the design is appropriate for the site conditions and performance monitoring and repair are kept up. Inappropriate designs can compromise barrier performance in a short period of time even when a barrier is constructed from materials known to be indefinitely durable.
- Monitoring. For this long-term responsibility, current sampling capabilities (e.g., wells) are important assets. New investments in state-of-art technologies (e.g., sensor networks) are recommended (see Chapter 3).
- Modeling. Interpretation of monitoring data through models built on basic physical and chemical principles (conceptual models) can build confidence in the isolation system among all stakeholders and facilitate the transfer of site responsibility from EM to other entities.

holders recognize their continuing responsibilities for maintaining barriers and managing the left-in-place wastes (see Sidebar 4.1).

The following sections outline the steps for managing waste in place according to the cocooning concept.

CHARACTERIZATION

The purpose of characterization is not to characterize a site or waste area group[5] as thoroughly as possible, but to gather sufficient information to make decisions. Characterization needs for managing left-in-place wastes include knowledge of the waste boundaries, including its footprint area and

[5]Waste Area Group (WAG) is an EM designation for waste disposal areas throughout the DOE complex.

vertical limits, the local subsurface hydrostratigraphy and the waste properties. The use of geophysical methods (described in Chapter 3), real-time field analyses and decision support, and geostatistical techniques for optimizing sampling locations can produce timely results and reduce overall costs (Ditmars, 2002; NRC, 2003c). One example of a successful application of geophysical methods is the Argonne National Laboratories' Adaptive Sampling and Analysis Program (ASAP), which is based on noninvasive surveys and computer analyses to facilitate decision making. The ASAP led to an estimated saving of $40 million for characterization of radioactive soil contamination at the Fernald Site (Ditmars, 2002).

Detailed characterization of buried waste, such as the Glovebox Excavator Method (GEM) used for Pit 9 at the Idaho National Engineering and Environmental Laboratory (INEEL), is time consuming and difficult (see Sidebar 3.1). The committee does not consider such detailed characterization routinely necessary for sound decision making. The use of remote sensing, historic photos, and discharge from groundwater seeps at WAG-4,[6] Oak Ridge, where waste burial records were lost due to fire, is an example of an approach to characterization that the committee felt to be reasonable (Huff et al., 1996). In the case of groundwater plumes, characterization approaches need to recognize that plumes are unlikely to be stationary, either spatially or temporally (Read et al., 2004).

Site characterization should be commensurate with the complexity of the site and/or waste in question. For example, hydrogeologic characterization of the Oak Ridge site might justify more effort than is needed at the Savannah River site, because waste migration in the fractured bedrock underling Oak Ridge will be more complex than waste migration in the Coastal Plain sediments underlying the SRS. Hanford's Data Quality Objectives program provides advice on obtaining sufficient, but not unnecessary data, to define the risk at the site, demonstrate the need for remedial action, and support the rational for selecting a remedial action alternative.[7] Similar advice is provided by the EPA Office of Federal Facilities Restoration and Reuse.[8]

[6]WAG-4 (or SWSA 4) at Oak Ridge was used from 1951 to 1959 for disposal of liquid and solid radioactive wastes in trenches and auger holes. The currently in-progress remediation project includes construction of a 30-acre multi-layer cap, installation of 2400 linear feet of upgradient and 1200 linear feet of downgradient diversion trenches, a groundwater treatment plant, and a road relocation.

[7]http://www.hanford.gov/dqo/keyelements.html

[8]http://www.epa.gov/fedfac/

BASIS FOR MANAGING WASTE IN PLACE

Only after waste and its surroundings are adequately characterized can scientifically based decisions about leaving it in place be made. Although the decision to leave waste in place is site specific, the committee provides the following broad guidelines and suggests that if one or more guidelines are met leave-in-place should be considered. These guidelines are largely compatible with the EPA (1997) "rules-of-thumb" for when it is appropriate to contain wastes, rather than retrieve them:

- *There is currently no clear disposition pathway for the waste if it were retrieved*, e.g., contaminated soils at the Oak Ridge Corehole 8 site,[9] and irradiated lithium-aluminum targets used for tritium production and now buried at Hanford and the Savannah River Site (SRS),
- *The waste poses little threat when left in place, but will expose workers to risk if it is moved*, e.g., calcined waste from nuclear fuel reprocessing now stored in large silos at INEEL,
- *With current technologies, it is technically infeasible to remove all of the waste*, e.g., the deep (> 60 m below ground surface) trichloroethylene plume in groundwater beneath WAG-1 at INEEL,[10]
- *The subsurface area that is affected is very large*, e.g., large groundwater plumes at each of the sites, such as the tritium plume beneath the 1,500 acre low-level burial grounds at Hanford's 200 East area,
- *The threat posed by the waste will diminish to acceptable levels within the next few decades*, e.g., tritium groundwater plumes at SRS,
- *Removing the waste will cause greater risk or damage to ecosystems than the risk posed by the waste itself*, e.g., contaminated sediments in the Clinch River system at Oak Ridge and Par Pond at SRS (Whicker et al., 2004).

The committee also recognizes that there are times when the risk posed by existing buried waste is unacceptable, for example due to its toxicity or location. The 618-10/11 caissons at Hanford, described in Chapter 2, are examples of waste that should not be left in place.

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[9]Corehole 8 is an area of groundwater contamination beneath the Oak Ridge National Laboratory (ORNL). The plume emanates from soil contaminated due to a broken pipe on a waste tank, which is located near the ORNL cafeteria.

[10]WAG-1 is also referred to as Test Area North (TAN). Located on 102 acres in the north-central portion of INEEL, TAN supported the Aircraft Nuclear Propulsion Program between 1954 and 1961 and reactor safety tests through the 1980s. Except for one facility that manufactures armor for military vehicles, TAN is now undergoing facility deactivation and decommissioning and environmental restoration.

STABILIZATION

The committee considers buried waste or contaminated soil to be stabilized when the waste or soil does not release unacceptable levels of contaminated liquids or gases into the environment and is not accessible to ecological and biological receptors at risk through direct contact. In cases where existing buried waste or contaminated soil is not already stable, strategies that involve leachability reduction, hydraulic isolation and/or physical isolation can help achieve stabilization. In the case of contaminant plumes, stabilization means that the plume is either contained in a controlled area where is does not pose an unacceptable risk to human health or the environment or it is treated at discharge points to prevent the unacceptable release of contaminants. Stabilization can be achieved by physical, chemical or biological treatment (Wentz, 1995).

Reducing Leachability

In order to minimize the flow of water through waste materials, and thus minimize leachate generation, the cumulative permeability through the wastes and associated barriers should be less than the surroundings. For permeability reduction in place, in situ grouting (Conner, 1990) or dynamic compaction (Massarsch, 1999) is adequate in many situations but may not eliminate all of the permeable pathways through the waste when used for large-scale applications. As an example, grouting could be considered for the "Corehole 8" contamination discussed during the committee's Oak Ridge site visit. Although this contamination is in an area near buildings that are in active use, it does not pose a threat at the land surface. Excavating the contamination would expose the waste and put workers at risk. In situ grouting could reduce both cost and risk. Less established practices for reducing waste leachability, such as in situ vitrification, are suitable only under select situations, and are not likely to offer widespread advantages for EM's accelerated cleanup.

Isolation: Caps and Barriers

The purpose of isolation is to separate buried waste from people and the environment and to control fluid (water and/or gas) migration into or from the waste. Isolation methods, such as caps and vertical walls, are usually intended to prevent fluid migration (Bedient et al., 1999) and can be used as the sole stabilization strategy or to augment leachability reduction techniques that reduce liquid migration through the waste but do not attain targeted end goals. However, caps are also a way to restore the appearance of the environment and encourage the return of local ecology, and consideration of these factors should also be a part of a cap's design (NRC, 2003b). Furthermore, appropriate cap designs in humid climates can be different than those in arid and semi-arid climates. For example, low-permeability covers are suitable in humid climates, while evapotranspiration covers are suitable in arid climates (Parker, 2004).

Although current knowledge indicates that properly designed surface caps might have design lives of hundreds of years, this assumption is predicated on continued monitoring and repair of the cap (see Sidebar 4.2). Furthermore, it is hard to anticipate site-specific environmental stresses and conditions, such as subsurface deformations or the health of local vegetation, which might adversely affect the integrity of a cap (Parker, 2004). The cocooning concept will enable an adaptive approach to using surface caps that confirms their service life through continued monitoring and/or extends it through repair or even rebuilding when necessary. Whenever possible, existing monitoring wells should be preserved when installing caps. The design of caps that are able to incorporate performance monitoring systems is also important.

Caps alone are insufficient when subsurface water can leach the buried waste (e.g., WAG 6 at Oak Ridge). Additional means of controlling water movement into and/or out of the waste will be needed. These means could include vertical barriers (e.g., soil-bentonite walls, sheet pilings), vertical (French) drains and/or permeable reactive barriers.

Plume Stabilization

For plumes that cannot be isolated or contained in a suitable area using engineered or natural hydraulic, physical, chemical or biological methods, and need control before the discharge point, reactive barriers and in situ redox manipulation are an option. Several DOE sites are already making use of this technology for both organic and inorganic plumes, as well as mixed plumes (e.g., the In Situ Redox Manipulation (ISRM) permeable treatment zone for chromate contamination at Hanford). Permeable reactive barriers can both capture a plume and treat it in situ. Although these barriers require monitoring and periodic repair/replenishment, they are one of a few solutions for treating mixed waste and limiting plume discharge to surface sources (see Sidebar 4.3).

MONITORING AND MODELING: CONTROLLING FUTURE LIABILITIES

Continued monitoring to improve conceptual understanding of subsurface contaminant behavior and, hence, theoretical modeling efforts, are essential to maintaining the safety of human health and the environment at legacy waste sites. Demonstrating, through observation, that the fundamental concepts of contaminant migration are understood scientifically can lead to greater public confidence that the sites are indeed safe. Many of EM's technology needs are related to modeling the fate and transport of subsurface

Sidebar 4.2 LONGEVITY OF SYNTHETIC CAPS AND LINERS

HDPE is a material that is used as a hydraulic barrier in caps and liners (Figure 4.1). It undergoes UV degradation when exposed to daylight, as it is at SWSA-6. It is vulnerable to puncture and burrowing mammals and can be uplifted if gas emissions from the underlying waste are not vented. HDPE is only recommended as a cover system when no other liner is practical (Daniel and Koerner, 1993). Multilayer caps can be effective in controlling water and gas flow into and out of underlying waste, isolating waste from bio-intruders, and restoring the appearance of a site. However, there are many mechanisms that adversely affect the performance of multi-layer cover systems (Daniel and Gross, 1996; Parker, 2004). As a result, EPA's draft guidance document on landfill covers[a] presently considers a design life of hundreds of years feasible for cover systems, but only provided that performance monitoring and long-term maintenance of the systems are sustained.

[a] This report is accessible at http://hq.environmental.usace.army.mil/epasuperfund/geotech/index.html.

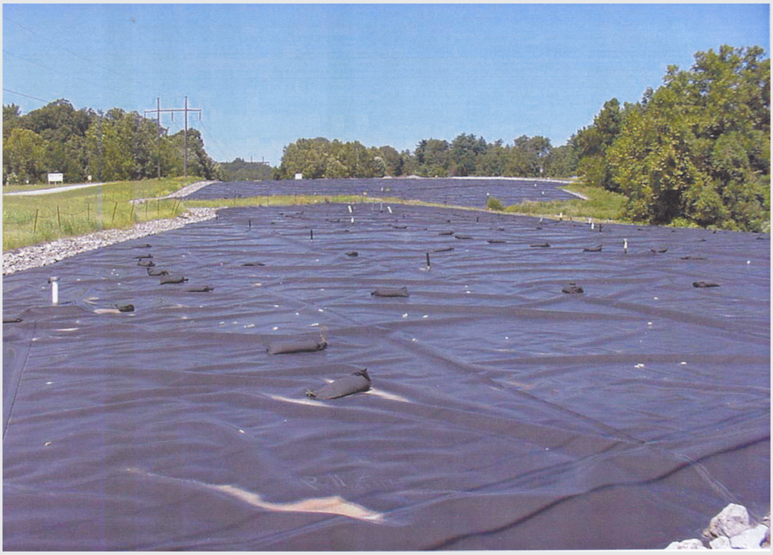

FIGURE 4.1 Trench caps made of high-density polyethylene (HDPE) are expected to last at least one hundred years. There are no field data to confirm this expectation, rather experience has shown punctures, tears, and deformations. Photo courtesy of Oak Ridge Operations Office.

Sidebar 4.3 COCOONING VERSUS MONITORED NATURAL ATTENUATION

Monitored natural attenuation (MNA) relies on natural processes (chemical and biological breakdown of contaminants, radioactive decay, dilution, and dispersion) to achieve remediation goals within a time frame that is reasonable compared to that offered by active methods (EPA, 1999a, 1999b). MNA requires very detailed site characterization, which can be more expensive and time consuming than required for active technologies.

Cocooning is distinct from MNA. Cocooning is not a final remediation, but rather waste stabilization that allows for future remediation options. Further, cocooning does not require extensive, in-depth site characterization. Finally, although cocooning of nonaqueous phase liquids (NAPL), such as oils, and radionuclide contamination might be feasible, MNA is not expected to remediate NAPL and has not been demonstrated for most radionuclide plumes other than tritium (NRC, 2000b, 2003b). The committee recognizes that natural attenuation processes could contribute to remediation goals for some left-in-place wastes. However, the number of cases in which MNA will be a viable alternative to cocooning is likely to be limited.

contamination (Colwell, 2004). The committee observed that in some instances, e.g., the East Tennessee Technology Park at Oak Ridge, privatization of parcels of land is planned while underlying groundwater remains contaminated. This is a case in which the cocooning approach and specific monitoring plans could help to prevent contaminants from becoming a health hazard.

Monitoring

Better use of existing capabilities and adaptive use of new technologies can reduce the financial and time burdens of monitoring efforts. Both stabilized wastes and contained plumes require monitoring. Although wells for monitoring should be preserved, hydraulic receptors, such as French drains, seeps, and rivers that integrate large areas, should also be used in monitoring schemes. A good example of the use of hydraulic receptors for monitoring is the use of seeps at WAG-4 Oak Ridge. These seeps were used to identify specific trenches that were contributing most to radionuclide release in order to focus remediation efforts on smaller areas (Huff et al., 1996).

The use of “key indicator species” to monitor the effectiveness of stabilization strategies for leave-in-place wastes is also valid. The monitoring of fall Chinook salmon in the Columbia River is a good example of this approach at Hanford. The committee recognizes that no single species is likely to be indicative of ecological health at a site. Appropriate key indicator species should be identified in consultation with qualified experts, including those with local environmental knowledge.

For monitoring the conditions of contaminant source areas, such as stabilized tanks and trenches, noninvasive geophysical techniques should be pursued more aggressively, as discussed in Chapter 3. The committee believes that simple measurements, using durable low cost sensors that monitor, for example, changes in fluid and material resistivity, could provide useful, first-order information on how cocooning is performing. Long-term monitoring programs that routinely involve the collection and laboratory analysis of a large number of samples should be avoided. However, reasonable triggers for this activity might be unexpected monitoring results from in situ sensors, changes in site information and conditions, or improvements in conceptual understanding. The committee encourages the development of complex-wide networked information systems, such as the U.S. Geological Survey's (USGS) Water Watch project,[11] which could provide real time information on environmental conditions at sites that would be valuable to decision makers and other stakeholders.

Modeling

Modeling is another important component of a viable leave-in-place strategy. In addition to data collection, monitoring involves interpretation of data. Modeling can provide a focus for this interpretation if handled in an appropriate manner. However, as noted in an earlier report (NRC, 1990a), modeling is only as good as the modeler's assumptions and interpretations. Because our current ability to accurately predict subsurface flow and transport, especially in a complex setting like the vadose zone, is limited (Lenhard et al., 2004), the purpose of modeling should be to develop concepts of waste behavior that can be tested and updated. These new concepts can enhance the judgments and decision making of personnel responsible for ensuring that the waste remains safe.

Since a key feature of models is incorporation of long-term knowledge of a site, modeling is important for transition from EM to long-term management of left-in-place wastes. Models can help ensure that known geohydrological features and anticipated processes for waste and water movement at a site are not lost, and that the limitations of assumptions and model parameters are well understood. Changes in site personnel often result in loss of essential historic data (Versteeg et al., 2004). This should be anticipated and avoided.

[11]Waterwatch provides real-time maps of water flow in streams and rivers throughout the United States. See http://water.usgs.gov/waterwatch/

ADAPTIVE APPROACH

The management of left-in-place wastes can benefit from changes in knowledge over time. As an example of how advances in technology have changed site remediation practices in just over a decade, the committee cites the fact that the number of projects at Superfund sites that used "innovative technologies" for contaminant remediation, e.g., air-sparging, bioremediation, dual-phase extraction, permeable reactive barriers, phytoremediation, chemical treatment, in-well air stripping, went from zero to more than 90 from 1985 to 1999 (EPA, 2002). Although the service life of cocooning will vary with the waste, its location, and the threat it poses, periodically reexamining its condition and newer stabilization and treatment options on the order of decades is appropriate.[12] This length of time is understandable to stakeholders and, through adaptive management, provides opportunity for using future technology advances to ultimately reduce the costs and risks to society.

As noted at the beginning of this report, the EM cleanup is not intended to remediate all sites for unrestricted future uses ("greenfield"). After EM has completed its work, the Office of Legacy Management, created by DOE in 2004, will assume the long-term responsibility for closed sites—according to DOE's current planning. For managing the very-long-term responsibilities that are inherent in radioactive waste management, the BRWM has long advocated an adaptive or flexible approach: "[T]ime to assess performance and a willingness to respond to problems as they are found, remediation if things do not turn out as planned, and revision of the design and regulations if they are found to impede progress toward the health goal…" (NRC, 1990b, p. viii). This theme has been echoed in more recent reports on management of high-level waste (NRC, 2001c, 2003d) and excess nuclear materials (NRC, 2003a). Adaptive management is also appropriate for chemical, biological, and hazardous waste, and for classified materials that are now designated as waste as noted in Chapter 2.

According to its task statement, the committee has sought near-term opportunities to support EM's accelerated cleanup program. The next step, the responsible, long-term management of wastes and contamination that remain after EM cleanup, can best be undertaken through an adaptive approach.

[12]For example, experience has shown that several mill tailings caps designed to last for 1000 years required maintenance within 10 years (INEEL, 2003).

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Appendix A

Presentations to the Committee

Washington, D.C., October 27–29, 2003

Overview: EM Accelerated Cleanup, Patrice Bubar, Department of Energy, Office of Environmental Management (DOE-EM)
Study Vision: EM Accelerated Cleanup, Patrice Bubar, DOE-EM
Environmental Management Technology Development and Demonstration Program, Mark Gilbertson, DOE-EM
Hanford Waste Streams: Issues and Opportunities, Matt McCormick, DOE Richland Operations Office (DOE-RL)*
Savannah River Site: EM Accelerated Cleanup, Charles Anderson, DOE Savannah River Operations Office (DOE-SR)*
Cleanup Issues and Opportunities at the Idaho National Engineering and Environmental Laboratory (INEEL), Kathleen Hain, DOE Idaho Operations Office (DOE-ID)*
Oak Ridge Environmental Management Program Overview, Mildred Ferré, DOE Oak Ridge Operations Office (DOE-OR)*

Oak Ridge, Tennessee, January 20–21, 2004

Oak Ridge Accelerated Cleanup Program, Gerald Boyd, and Steve McCracken, DOE-OR

*By telephone.

EM Corporate Project Team: Disposing Waste, Reducing Risk, Mildred Ferré, DOE-OR

East Tennessee Technology Park (ETTP) Closure Project, Donna Perez, DOE-OR

Melton Valley Closure Project, Robert Sleeman, DOE-OR

Balance of Reservation Closure Project, Mildred Ferré, DOE-OR

Historical Overview of the Oak Ridge Reservation, Steve Stow, American Museum of Science and Energy, Oak Ridge

Combined Stakeholders' Presentation, Susan Gawarecki, Oak Ridge Reservation Local Oversight Committee, Inc. (LOC); David Mosby, Oak Ridge Site Specific Advisory Board (ORSSAB) and Oak Ridge City Council; Norman Mulvenon, LOC Citizens' Advisory Panel, ORSSAB and Stewardship Committee; Bill Pardue and Lorene Sigal, Stewardship Committee; and Ellen Smith, Oak Ridge Environmental Quality Advisory Board and LOC

Roundtable Discussion: New Technology Opportunities for DOE Waste Characterization and Treatment, Elizabeth Phillips, DOE-OR; Paula Kirk, Bechtel Jacobs Co.; and Tom Early, University of Tennessee-Battelle

Tour of the Oak Ridge Reservation

Augusta, Georgia, January 22–23, 2004

Savannah River Site (SRS) Overview, Rick Ford, DOE-SR

Accelerating EM Cleanup, Charles Anderson, DOE-SR

Nuclear Materials to Disposition, Kevin Hall, DOE-SR

SRS Facilities Deactivation and Decommissioning Scope, Alice Doswell, DOE-SR

Closure of Waste Sites, Alice Doswell, DOE-SR

Integrated Regulatory Strategy, Alice Doswell, DOE-SR

Waste Disposition Project, Doug Hintze, DOE-SR

SRS Transuranic (TRU) Waste Program, Joe D'Amelio, Westinghouse Savannah River Company (WSRC)

Defense Waste Processing Facility Accelerated Waste Throughput, John Occhipinti and Joe Ortaldo, WSRC

Savannah River Technology Center (SRTC): Support for Accelerated Cleanup, Todd Wright, SRTC[1]

Citizens for Nuclear Technology Awareness (CNTA), Todd Crawford, CNTA

SRS Citizens' Advisory Board (CAB), William Lawless, CAB

Tour of the Savannah River Site

[1]Now the Savannah River National Laboratory.

Idaho Falls, Idaho, March 8–9, 2004

Accelerating INEEL Cleanup: Management Overview, Richard Provencher, DOE-ID
Idaho Nuclear Technology and Engineering Center (INTEC) Overview, Frank Holmes, DOE-ID
INTEC Waste Programs Review, Joel Case, DOE-ID
Characterization and Treatment of Sodium Bearing Waste, Joel Case, DOE-ID
Tank Closure, Keith Lockie, DOE-ID
INEEL Spent Nuclear Fuel Program, Ronald Ramsey, DOE-ID
Calcine Characterization and Pneumatic Retrieval Issues, Gregory Duggan, DOE-ID
Closing the Smaller Facility Areas and Deactivation and Decommissioning (D&D), William Leake, DOE-ID
Radioactive Waste Management Complex Review, Herbert Bohrer, DOE-ID
Environmental Science and Technology Roundtable, William Owca, DOE-ID; Russel Hertzog, James Herzog, Robert Lenhard, Paul Meakin, Gregory Stormberg, Kevin Kostelnik, Melinda Hamilton, Fredrick Colwell, Matt Anderson, Roger Mayes, Jay Roach, Nicholas Soelberg, INEEL
Public Comments, David Kipping, Willie Preacher, Beatrice Brailsford
Tour of the Idaho National Engineering and Environmental Laboratory

Richland, Washington, March 10–11, 2004

Hanford Cleanup Overview, Keith Klein, DOE-RL
Hanford Project Management Plan Update and Projectization, Jeff Frey, DOE-RL
Office of River Protection (ORP), Steve Wiegman, DOE-ORP
Accelerate Stabilization and Deinventory of Nuclear Materials at the Plutonium Finishing Plant, Suzanne Clarke, DOE-RL
Accelerating Waste Disposal, Mark French, DOE-RL
Accelerate Central Plateau Cleanup, Larry Romine, DOE-RL
Impacts of Residual Radioactive Waste on Hanford Groundwater, Michael Thompson, DOE-RL
EM Corporate Project Team: Disposing Waste, Reducing Risk, Todd Shrader, DOE-ORP
Public Comments, John Price
Tour of the Hanford Site

Washington, D.C., May 12–14, 2004

Removal Authority in Accelerated Cleanup, James Woolford, U.S. Environmental Protection Agency

DOE Office of Civilian Radioactive Waste Management: Current and Future Interfaces with EM, Christopher Kouts, DOE Office of Civilian Radioactive Waste

DOE Office of Legacy Management: Current and Future Interfaces with EM and with Continuing-Mission Sites, Mark Gilbertson, DOE-EM

Commercial and Other Opportunities for Disposition of EM Waste, Doug Tonkay, DOE-EM

Close-out Comments on the Study, Mark Frei, DOE-EM

Information presented to the committee during its site visits is available from the Board on Radioactive Waste's Public Access File for this study. http://www7.nationalacademies.org/brwm/

Appendix B

Biographical Sketches of Committee Members

Milton Levenson, Chairman (NAE), is nationally recognized for his ability to apply creative new insights to major engineering challenges in the nuclear industry and for his organizational and leadership skills. Currently an independent consultant, Mr. Levenson is a chemical engineer with more than 50 years of experience in nuclear energy and related fields. His technical experience includes work related to nuclear safety, fuel cycle, water reactors, advanced reactors, and remote control. His professional experience includes research and operations positions at the Oak Ridge National Laboratory, the Argonne National Laboratory, EPRI (formerly the Electric Power Research Institute), and Bechtel. He was elected to the National Academy of Engineering (NAE) in 1976. Mr. Levenson is a fellow and past president of the American Nuclear Society, a fellow of the American Institute of Chemical Engineers, and recipient of the American Institute of Chemical Engineers' Robert E. Wilson Award in Nuclear Chemical Engineering. He is the author of more than 150 publications and presentations and holds three U.S. patents. Mr. Levenson is a member of the National Academies' Board on Radioactive Waste Management (BRWM). He served as chairman or committee member in several recent studies by the BRWM and the Board on Radiation Effects Research. He received his B.Ch.E. from the University of Minnesota.

Cynthia Atkins-Duffin is an authority on the physical and chemical behavior of actinide and fission product elements. She is program leader in applied energy technologies at Lawrence Livermore National Laboratory.

She was deputy materials program leader in the Chemistry and Materials Science Directorate from 1999 to 2002, and deputy director of the Glenn T. Seaborg Institute for Transactinium Science from 1996 to 1999. Earlier she was principal investigator in the hydrology and radionuclide migration program within the nuclear weapons program. Dr. Atkins-Duffin's honors include the Chemistry and Materials Science Directorate Award, 2001; the Energy Directorate Award, 2000; and the American Institute of Chemists Award for Outstanding Undergraduate in Chemistry. She has authored or coauthored more than 40 refereed publications and given about 80 presentations. Dr. Atkins-Duffin received her Ph.D. in inorganic chemistry from Purdue University and her B.S. in chemistry from Worcester Polytechnic Institute.

Patricia Culligan is an authority on applying geoengineering principles to understand and control the migration of contaminants from waste disposal sites. She is associate professor of civil engineering and engineering mechanics at Columbia University. Her research centers around understanding the behavior of miscible contaminants and nonaqueous phase liquids in soil and fractured rock, and determining the effectiveness of in situ remediation strategies for the cleanup of waste sites. In addition, she has interest and experience in the design of land-based disposal sites for waste materials. Dr. Culligan has received numerous awards including the Arthur C. Smith Award for Undergraduate Service (1999) and the National Science Foundation CAREER Award (1999). She is also the author or coauthor of more than 50 journal articles, book chapters, and refereed conference papers. Dr. Culligan received her B.Sc. from the University of Leeds, England, and her M.Phil. and Ph.D. from Cambridge University, England.

Robin Dillon-Merrill specializes in risk and decision analysis. The focus of her research is using programmatic risk analysis to improve project and operational management in complex, resource-constrained environments, which are typical of the Department of Energy (DOE) projects. She is assistant professor at the McDonough School of Business at Georgetown University, Washington, D.C. Dr. Dillon-Merrill has applied her work in the selection of a new tritium supply facility for DOE and assessing options for unmanned space missions for the Jet Propulsion Laboratory. She has coauthored papers with the nation's leading risk and decision analysts. Dr. Dillon-Merrill received her Ph.D. in engineering risk analysis from Stanford University, and her M.S. and B.S. degrees (with highest distinction) from the University of Virginia.

Lloyd A. Duscha (NAE) is a nationally recognized authority on managing large engineering projects. He has more than 40 years of experience, including 25 years in executive management positions with the U.S. Army Corps of Engineers. Mr. Duscha was elected to the NAE in 1987. He is a fellow of the American Society of Civil Engineers and the Society of American Military Engineers. He has served on numerous committees at the National Academies including the Board on Infrastructure and the Constructed Environment, the Committee to Assess the Policies and Practices of the DOE to Design, Manage, and Procure Environmental Restoration, Waste Management, and Other Construction Projects; he was principal investigator for the Project on Assessing the Need for Independent Review of DOE Projects; and he chaired the Committee on Long-Term Research Needs for Managing Transuranic and Mixed Wastes at DOE Sites. Currently Mr. Duscha is serving on the Committee to Review and Assess DOE Project Management. Mr. Duscha earned his bachelor's degree in civil engineering, with distinction, from the University of Minnesota, where he was awarded the Board of Regent's Outstanding Achievement Award.

Thomas Gesell is an authority in health physics and environmental radiation monitoring, both of which must be considered in assessing waste characterization and treatment options. He is professor of health physics, director of the Technical Safety Office, and director of the Environmental Monitoring Program at Idaho State University. Previously, he worked for the DOE Idaho Operations Office as deputy assistant manager for nuclear programs and director of the Idaho National Engineering and Environmental Laboratory (INEEL) Radiological and Environmental Sciences Laboratory. Dr. Gesell was a faculty member of the University of Texas School of Public Health in Houston for ten years. He is a fellow of the Health Physics Society and a member of its Board of Directors. He is a vice president and member of the Board of Directors of the National Council on Radiation Protection and Measurements (NCRP). Following a six-year term as a member of the U.S. Environmental Protection Agency Science Advisory Board's Radiation Advisory Committee, he now serves as consultant to that committee. Dr. Gesell has served on two committees of the National Academies Board on Radiation Effects Research. He was a consultant to the President's Commission on the Accident at Three Mile Island. Dr. Gesell received his B.S. in physics from San Diego State University and his M.S. and Ph.D. degrees in physics with specialization in health physics from the University of Tennessee.

Carolyn L. Huntoon is recognized for improving management practices and technical approaches to DOE site cleanup problems as the former DOE assistant secretary for Environmental Management. She held this Senate-confirmed position from July 1999 until July 2001. She is currently an independent consultant in the fields of energy and aerospace. Before moving to DOE, Dr. Huntoon served in various scientific and management positions at the National Aeronautics and Space Adminsitration (NASA), including Director of the Johnson Space Center in Houston, Texas, and special assistant to the administrator of NASA in Washington, D.C. In addition, she served as an executive in residence in the George Washington University Project Management Program and spent two years at the White House in the Office of Science and Technology Policy. She is a fellow of the American Astronautical Society, the American Institute of Aeronautics and Astronautics, and the Aerospace Medical Association. Dr. Huntoon has been awarded the Secretary of Energy's Gold Medal, and the Outstanding Leadership, Exceptional Service, Scientific Achievement, and Distinguished Service Medals from NASA. Dr. Huntoon received her undergraduate degree from Northwestern State College, Natchitoches, Louisiana, and her M.S. and Ph.D. degrees from Baylor College of Medicine, Houston, Texas.

Barry Scheetz is recognized for his expertise in the chemistry of cementitious systems for waste forms and environmental remediation. He is professor of materials, civil, and nuclear engineering at Pennsylvania State University. His work includes environmental waste management programs such as remediation of mine lands by the use of industrial by-products, focusing on large-volume usage of fly-ash-based cementitious grouts. Other programs include developments of radioactive waste forms based on vitrifiable hydroceramics and sodium zirconium phosphate structures. Dr. Scheetz received a national internship from the Argonne National Laboratory in 1972, and he was a National Academy of Sciences visiting scholar to China in 1989. He served as a member of the BRWM Committees on Idaho National Engineering and Environmental Laboratory High-Level Waste Alternative Treatments, and Cesium Processing Alternatives for High-Level Waste at the Savannah River Site. Dr. Scheetz is the author of more than 160 scientific publications and holds 46 U.S. and foreign patents. He received a B.S. in chemical education from Bloomsburg State College, and an M.S. in geochemistry, and Ph.D. in geochemistry and mineralogy from Pennsylvania State University.

Laura Toran is recognized for her expertise in hydrologic flow and transport in fractured and porous media as applied to problems of groundwater contamination. She is associate professor at Temple University where she was appointed to the Weeks Chair in Environmental Geology in 1997. She began her career as a Wigner fellow at Oak Ridge National Laboratory (ORNL). Later, Dr. Toran worked in the Environmental Sciences Division at ORNL on characterizing and modeling radioactive waste and mixed waste, including an investigation on waste remobilization and nuclear criticality for the U.S. Nuclear Regulatory Commission (USNRC). She serves as a consultant to the U.S. Army Corps of Engineers on the cleanup of a uranium-contaminated site near Philadelphia. Dr. Toran has been a National Science Foundation panelist and served on the editorial board of the journal Water Resources Research. She is on the editorial boards of the journal of Ground Water and Hydrogeology. Dr. Toran received her Ph.D. in geology from the University of Wisconsin, Madison, and her B.A. in geology, magna cum laude, from Macalester College, Minnesota.

Raymond G. Wymer is a specialist in radiochemical characterization and treatment technology for radioactive waste management and nuclear fuel reprocessing. He retired as director of the Chemical Technology Division of Oak Ridge National Laboratory (ORNL) and continued his career as a consultant for ORNL, the U.S. Department of State, and the DOE. Currently he is a member of the BRWM Committee on Optimizing the Characterization and Transportation of Transuranic Waste Destined for the Waste Isolation Pilot Plant. He has served on several other BRWM committees and chaired the Committee on Prioritization and Decision-Making in the Department of Energy. Dr. Wymer also served on the USNRC's Advisory Committee on Nuclear Waste from 1997 to 2003. He is a fellow of the American Nuclear Society and the American Institute of Chemists, and has received the American Institute of Chemical Engineers' Robert E. Wilson Award in Nuclear Chemical Engineering and the American Nuclear Society's Special Award for Outstanding Work on the Nuclear Fuel Cycle. Dr. Wymer received a B.A. from Memphis State University and an M.A. and Ph.D. from Vanderbilt University.

Appendix C

Acronyms

AMWTF	Advanced Mixed Waste Treatment Facility at INEEL
ASAP	Adaptive Sampling and Analysis Program
BRWM	Board on Radioactive Waste Management
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CH-TRU	contact-handled transuranic waste
CIC	can-in-canister
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DWPF	Defense Waste Processing Facility at SRS
EIS	Environmental Impact Statement
EM	DOE Office of Environmental Management
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility at Hanford
FFA	Federal Facility Agreement
FUDS	formerly used defense sites
GEM	Glovebox Excavator Method

HDPE	high-density polyethylene
HEU	highly enriched uranium
HLW	high-level waste
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
ISRM	In Situ Redox Manipulation
ISS	Interim Safe Storage
LAW	low-activity waste
LLW	low-level waste
LM	DOE Office of Legacy Management
MACT	maximum available control technology
MNA	monitored natural attenuation
NAPL	nonaqueous phase liquid
NMED	New Mexico Environment Department
NPL	National Priorities List
ORNL	Oak Ridge National Laboratory, Tennessee
PCB	polychlorinated biphenyl
PMP	Performance Management Plan
RCRA	Resource Conservation and Recovery Act
RH-TRU	remote-handled transuranic waste
RWMC	Radioactive Waste Management Complex at INEEL
SBW	sodium-bearing acidic waste
SNF	spent nuclear fuel
SRS	Savannah River Site, South Carolina
SWSA	solid waste storage area at Oak Ridge
TAN	Test Area North at INEEL
TRU	transuranic waste
TSCA	Toxic Substance Control Act
TVA	Tennessee Valley Authority
USGS	U.S. Geological Survey
USNRC	U.S. Nuclear Regulatory Commission
VOC	volatile organic chemicals

WAC	waste acceptance criteria
WAG	waste area group
WIPP	Waste Isolation Pilot Plant in New Mexico
WTP	Waste Treatment Plant at Hanford