Science and Technology for DOE Site Cleanup: Workshop Summary

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SCIENCE AND TECHNOLOGY FOR DOE SITE CLEANUP

WORKSHOP SUMMARY

Kevin D. Crowley, Rapporteur

Nuclear and Radiation Studies Board
Division on Earth and Life Studies

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Preface

The Department of Energy's Office of Environmental Management (DOE-EM) is developing a technology "roadmap" to guide planning and possible future congressional appropriations for its technology development programs. It asked the National Research Council (NRC) of the National Academies to provide technical and strategic advice to support the development and implementation of this roadmap, specifically by undertaking a study that identifies the following:

- Principal science and technology gaps and their priorities for the cleanup program based on previous National Academies reports, updated and extended to reflect current site conditions and EM priorities and input from key external groups, such as the Nuclear Regulatory Commission, Defense Nuclear Facilities Safety Board, Environmental Protection Agency, and state regulatory agencies.
- Strategic opportunities to leverage research and development from other DOE programs (e.g., in the Office of Science, Office of Civilian Radioactive Waste Management, and the National Nuclear Security Administration), other federal agencies (e.g., Department of Defense, Environmental Protection Agency), universities, and the private sector.
- Core capabilities at the national laboratories that will be needed to address EM's long-term, high-risk cleanup challenges, especially at the four laboratories located at the large DOE sites (Idaho National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Savannah River National Laboratory).
- The infrastructure at these national laboratories and at EM sites that should be maintained to support research, development, and bench- and pilot-scale demonstrations of technologies for the EM cleanup program, especially in radiochemistry.

This report addresses the first bullet of this study task. It provides a high-level synthesis of principal science and technology gaps identified in previous NRC reports. The NRC has been advising DOE and its predecessor agencies on the use of science and technology for waste management and environmental cleanup since the mid-1950s. Its published reports have identified, either directly or indirectly, science and technology gaps in the cleanup program. A complete list of NRC reports on waste management and environmental cleanup of DOE sites is provided in Appendix A.

Chapter 2 of this report is based on a discussion paper that was prepared for the March 13, 2007, NRC workshop entitled "Development and Implementation of a Cleanup Technology Roadmap for DOE's Office of Environmental Management." The objective of the workshop was to bring together the key external groups identified in the first bullet of the study task to discuss current site conditions and science and technology needs. The workshop agenda and participants are provided in Appendixes B and C, respectively.

A summary of the workshop presentations and discussions is provided in Chapter 3 of this report. It is intended to update and extend the Chapter 1 summary by providing comments on current cleanup priorities at four DOE sites (Hanford, Idaho, Oak Ridge, and Savannah River). Chapter 3 also provides a summary of workshop presentations and discussions on promoting more effective use of science and technology for DOE site cleanup. This discussion is intended to inform the next study phase, which is described below.

The remainder of the study task will be addressed in a Phase 2 activity that is being carried out by an NRC-appointed committee; the committee membership is given in Appendix D. The committee may also offer additional comments on the first bullet of the study task. The committee is planning to visit the four sites that are the subject of this workshop and their associated national laboratories. The final report from the Phase 2 study is expected to be issued in the fall of 2008.

Acknowledgments

This workshop was organized on very short notice to inform the development of the Department of Energy's technology roadmap. The rapporteur and the National Research Council (NRC) would like to thank the panelists and other participants for making this workshop a success. Special thanks go to Mark Gilbertson and his staff for helping recruit Department of Energy (DOE) panelists; Terry Tyborowski for providing an important congressional perspective on the use of technology for DOE site cleanup; members of the workshop organizing committee (Ed Przybylowicz, Allen Croff, and Carolyn Huntoon) for helping organize and run the workshop; and members of the Phase 2 study committee (Appendix D) for their insights on the workshop discussions. The rapporteur would also like to thank NRC staff, especially John Wiley, Rick Jostes, Greg Symmes, Toni Greenleaf, and Mandi Boykin, for their help with the workshop and this summary. It was truly a team effort.

This summary has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the NRC's Report Review Committee. The purposes of this review are 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 of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain 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:

Patricia J. Culligan, Columbia University
Paul A. Locke, The Johns Hopkins University
John Marra, Savannah River National Laboratory
Andrew M. Sessler, Lawrence Berkeley National Laboratory (retired)

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse, nor did they see the final draft of the report before its release. The review of this report was overseen by the Division on Earth and Life Studies of

the NRC, which was responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered.

This report presents the rapporteur's summary of workshop and does not necessarily represent the views of the workshop participants or the NRC. Responsibility for the final content of this report rests entirely with the rapporteur and the NRC.

Contents

1

Introduction

Beginning with the Manhattan Project and extending through the Cold War, the U.S. government constructed and operated a massive industrial complex to produce and test nuclear weapons and related technologies. At its peak this complex encompassed over 100 distinct sites in 31 states and one territory with a total area of over 2 million acres (see Figure 1). Most of the production and testing activities were carried out at six sites: Hanford, Idaho National Laboratory, Nevada Test Site, Oak Ridge Reservation, Rocky Flats Site, and Savannah River Site (see Sidebar 1). This complex produced large quantities of nuclear explosive materials—plutonium, highly enriched uranium, and tritium—over a period of about four decades.

Starting in the 1980s, large parts of this industrial complex were shut down permanently or placed on standby, and the U.S. government began a costly effort to clean up the materials, wastes, and environmental contamination resulting from weapons production activities. In 1989, Congress created the Office of Environmental Management (EM) within the Department of Energy (DOE) to manage this cleanup effort. To date, this cleanup program has cost U.S. taxpayers about $102 billion. This program is planned to continue for at least another three decades and will ultimately cost several hundreds of billions of dollars.[1] It is the largest single environmental cleanup program in the federal government and arguably the largest such effort worldwide (NRC, 1999g).

From its inception the cleanup program has faced two fundamental technical challenges: (1) to inventory and characterize the vast array of materials, wastes, and contamination resulting from weapons production, testing, and related activities, and (2) to retrieve, treat, remediate, or dispose of these materials, wastes, and contamination. The ultimate goal of this cleanup effort is to reduce

[1] In March 8, 2007, testimony before the House Committee on Appropriations, Subcommittee on Energy and Water Development, Assistant Secretary for Environmental Management James Rispoli reported that the estimated life-cycle cost for the DOE cleanup program had increased to about $235 billion owing to the addition of new projects as well as regulatory and technology development problems with current projects.

FIGURE 1 Location of principal sites within the DOE complex. SOURCE: NRC (2000a).

SIDEBAR 1: THE DOE COMPLEX

Although the DOE complex encompasses over 100 distinct sites, most of the weapons production and testing activities were conducted at six sites:

The *Hanford Site* is located in southeastern Washington state and covers an area of about 1450 square kilometers (560 square miles). Production of materials for nuclear weapons took place here from the 1940s until mid-1989. The site contains several plutonium production reactors, chemical separations plants, and solid and liquid waste storage and disposal sites.

The *Idaho National Laboratory*, first established as the Nuclear Reactor Testing Station, occupies 2300 square kilometers (890 square miles) in a remote desert area along the western edge of the upper Snake River Plain. The site was established as a building, testing, and operating station for various types of nuclear reactors and propulsion systems, and it also manages spent fuel from the naval reactors program. The site was also used to dispose of wastes from Rocky Flats and elsewhere.

The *Nevada Test Site*, which occupies about 3500 square kilometers (1350 square miles) in southern Nevada, was the primary location for atmospheric and underground testing of the nation's nuclear weapons starting in 1951. It is also used for disposal of low-level wastes from other DOE sites.

The *Oak Ridge Reservation* covers an area of approximately 155 square kilometers (60 square miles) and is located about 10 kilometers (6 miles) west of Knoxville, Tennessee. The reservation has three major facilities: the Oak Ridge National Laboratory, the Y-12 Plant, and the K-25 Plant. The laboratory was originally constructed as a research and development facility to support plutonium production technology. The Y-12 Plant was built to produce highly enriched uranium by electromagnetic separation. The K-25 Plant, formerly known as the Oak Ridge Gaseous Diffusion Plant, also was created to produce highly enriched uranium for nuclear weapons. The reservation has waste disposal sites and contaminated buildings and soil.

The *Rocky Flats Environmental Technology Site* was situated on about 2.4 square kilometers (~600 acres) within a 24-square-kilometer (6000 acre) tract near Denver, Colorado, and contained more than 400 manufacturing, chemical processing, laboratory, and support facilities that were used to produce nuclear weapons components. Production activities once included metalworking, fabrication and component assembly, and plutonium recovery and purification. Operations at the site ceased in 1989, and site cleanup was completed in 2006.

The *Savannah River Site*, located near Aiken, South Carolina, covers an area of about 800 square kilometers (300 square miles). The site was established in 1950 to produce special radioactive isotopes (e.g., plutonium and tritium) for use in the production of nuclear weapons. The site contains plutonium and tritium production reactors; chemical processing plants, one of which is still operating; and solid and liquid waste storage sites.

Other Sites. Among the more than 100 other sites, the *Paducah Plant* (Kentucky) and *Portsmouth Plant* (Ohio) contain large gaseous diffusion plants for enriching uranium that will eventually be decommissioned. The *Waste Isolation Pilot Plant* in New Mexico hosts an underground repository for disposal of transuranic waste from defense activities.

SOURCE: Updated from NRC (2000a).

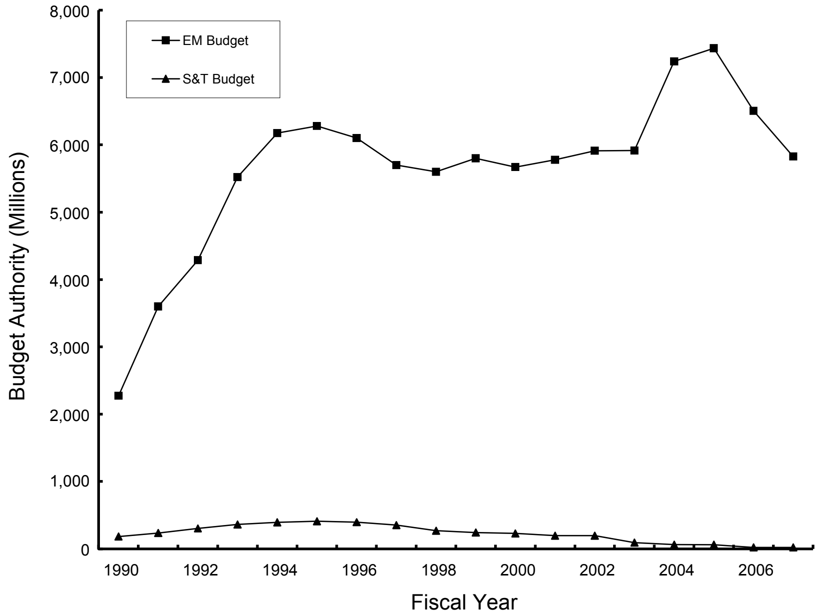

FIGURE 2 Federal budget authority for the DOE-EM cleanup program (squares) and the DOE-EM headquarters-directed science and technology (S&T) program (triangles). After DOE-EM adopted project-based budgeting in the early 2000s, some of the headquarters-directed S&T investments were moved to the sites. The S&T budget shown in the figure does not include these site expenditures. SOURCE: NRC (1999g).

short-term risks to site workers and longer-term risks to the people who live near the sites or utilize site resources.[2]

EM has made major investments in scientific research and technology development to obtain the needed knowledge and tools to meet these challenges. There has been a technology development

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[2] As used in this report, short, medium, and long term refer to time periods on the order of 1 to 5, 5 to 10, and >10 years, respectively. Long term can be further subdivided as follows: it usually refers to periods on the order of one to two decades when used in reference to cleanup and technology development activities and many decades to centuries when used in reference to the behavior of contaminants in the environment or the performance of waste containment and monitoring systems.

program[3] within this office since its creation. However, EM headquarters-directed investments in science and technology activities have varied substantially over the past 18 years (see Figure 2), rising from $184 million in fiscal year 1990 to almost $410 million in fiscal year 1995, followed by a decade-long slide to $21.4 million in fiscal year 2006. This slide was prompted by a variety of factors, including concerns about the effectiveness of the program[4] as well as changing administration priorities. In the past five years the program has focused almost exclusively on short-term technology development needs to support accelerated site cleanup.

There has been recent renewed interest in cleanup science and technology development by both upper DOE management and Congress. This interest was inspired in part by a congressionally mandated National Research Council study (NRC, 2006a) that evaluated DOE's plans for retrieval and onsite disposal of certain wastes stored in tanks at the Hanford, Idaho, and Savannah River sites (Figure 1).

The report from that study recommended that DOE initiate a targeted, aggressive, and collaborative research and development program to support its efforts to retrieve waste and clean and close tanks in which the waste is currently being stored. It further recommended that the program last for 10 years, with funding on the order of $50 million per year. This study prompted DOE to request additional funding for science and technology development for its cleanup program in fiscal year 2007, which in turn prompted Congress to request that DOE prepare a technology roadmap.[5]

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[3] This Technology development program has had several names; Office of Technology Development (1990-1995), Office of Science and Technology (1995-2003), Office of Environmental Cleanup and Acceleration (2003-2006), and Office of Engineering and Technology (May 2006 to present).

[4] See NRC (1999g) for references and discussion.

[5] The fiscal year 2007 House Energy and Water Development Appropriations Bill contains the following language: "Technology Development and Deployment. The Committee recommendation provides $31,389,000, an increase of $10,000,000 over the budget request. The EM technology development program funding has declined over the years, while at the same time many technological challenges continue to face the program. For example, the National Research Council's 2005 report on `Improving the Characterization and Treatment of Radioactive Wastes', recommends that `an improved capability for environmental monitoring would strengthen EM's plans to leave waste and contaminated media at DOE sites', and, `Monitoring systems at EM closure sites have been estimated to be some 25 years behind the state-of-art.' The Committee directs the increase to address the technology short-falls identified by this report. The Committee supports an increased, expanded technology development program, and directs the Department to prepare an EM technology roadmap, that identifies technology gaps that exist in the current program, and a strategy with funding proposals to address them. The report is due to the Committee by January 31, 2007."

2

National Research Council Reports on Waste Management and Environmental Cleanup

The National Research Council (NRC) has a long record of advising the federal government on the management and cleanup of wastes resulting from nuclear weapons production.[1] The NRC appointed its first study committee on radioactive waste management and disposal practices in 1955 to advise the Atomic Energy Commission (AEC). In its first two decades of operation, this NRC committee published eight technical reports (NRC, 1956, 1957, 1966, 1970a, 1970b, 1972, 1974, 1975) and one individual paper (NRC, 1958) that examined research and development (R&D) activities and waste management and disposal practices at the large AEC sites.[2]

Starting in 1976, NRC committees began a more intensive examination of disposal practices at these sites, which were then being managed by the Energy Research and Development Administration[3] (ERDA) and later by the Department of Energy (DOE). A 1976 report focused on the shallow land burial of wastes at ERDA sites (NRC, 1976; see also NRC, 1993). Later reports provided reviews of waste management programs, plans, and practices at Hanford (NRC, 1978b, 1985a, 1992c), Idaho (NRC, 1991b, 1994a), Savannah River (NRC, 1981, 1998a) and Oak Ridge (NRC, 1985b). In 1987, the NRC published reports on the management of buried low-level and transuranic waste and contaminated soil (NRC, 1987b) and on management of uranium mill tailings (NRC, 1987c).

During that same time period, other NRC committees were established to advise DOE on the development of what was to become the Waste Isolation Pilot Plant (NRC, 1979c, 1979d, 1980, 1983, 1984a, 1987a, 1988a, 1988b, 1989b, 1991a, 1992b, 1996e, 2000c, 2001e, 2001h, 2002b, 2004). WIPP is now being used to dispose of defense transuranic waste that originated within DOE and its predecessor agencies.

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[1] A complete list of NRC reports on waste management and environmental cleanup of the nuclear weapons complex is given in Appendix A.

[2] Hanford, Oak Ridge, Savannah River, and the National Reactor Testing Station, the latter of which is now part of Idaho National Laboratory.

[3] The AEC was created by the Atomic Energy Act (1946) to control and promote the use of nuclear power. The AEC was abolished by the Energy Reorganization Act (1974) and two new agencies were created in its place: Energy Research and Development Administration (ERDA) and Nuclear Regulatory Commission. A subsequent Energy Reorganization Act (1977) reorganized ERDA into the Department of Energy.

With the creation of DOE-EM in 1989, the focus of NRC work expanded to include environmental cleanup. The first NRC report focusing almost exclusively on environmental cleanup was published in 1989 (NRC, 1989a). That report provided a review of a draft DOE environmental restoration and waste management plan. Also in 1989 the NRC provided a review of a draft DOE plan for applied research, development, demonstration, and testing to support the cleanup program (NRC, 1989c).

In 1994 the NRC established a Committee on Environmental Management Technologies to advise EM on technology development and use. This committee and its successor committees produced a series of reports addressing technology development in five "focus areas" identified by EM: contaminant plumes, landfills, high-level wastes, mixed wastes, and decontamination and decommissioning (NRC, 1995b, 1996a, 1998e, 1999b, 1999c, 1999d, 1999g). During that same period, another NRC committee published a series of reports advising EM on the management of buried and tank wastes and other related issues (NRC, 1994a, 1994b, 1995a, 1996b, 1996c, 1996d, 1997b, 1998b, 2000d).

In 1995 then-Assistant Secretary Grumbly requested that the NRC establish a committee to evaluate the science, engineering, and health basis for EM's Environmental Management Program. The report from that activity, Improving the Environment (NRC, 1995c), included an extensive discussion on the utilization of science, engineering, and technology in the cleanup program. Subsequent NRC reports addressed technology development and selection decision making (NRC, 1998c, 1999e), R&D portfolio development and funding (NRC, 2001g), and the use of peer review in technology development programs (NRC, 1997d, 1999a). The 1999 peer review report was cited by the Office of Management and Budget in its standards for agency peer reviews.

In 1995 Congress created the Environmental Management Science Program (EMSP) to develop new knowledge and tools for the cleanup effort. The program was housed within EM but was jointly managed with the DOE Office of Science. At the request of EM, the NRC undertook a series of studies beginning in 1996 to advise on the implementation of this program. The first three reports focused on the structure and management of the EMSP (NRC, 1996g, 1996h, 1997c). Later reports identified knowledge gaps and research needs on the following topics:

- Contaminated soil and groundwater (NRC, 1998d, 2000a)
- High-level waste (NRC, 2000f, 2001d)
- Deactivation and decommissioning (NRC, 2000g, 2001c)

- Transuranic and mixed waste (NRC, 2002c)
- Excess nuclear materials and spent fuel (NRC, 2003a)

The recommendations in these reports were used by EM and the Office of Science to develop the annual research solicitations for the EMSP. The EMSP was transferred to the Office of Science in fiscal year 2003 and now primarily focuses on soil- and groundwater-related research.

Over the past decade, the NRC has published several reports focused on specific site cleanup problems. These include groundwater cleanup at Hanford (NRC, 2001f) and the Los Alamos National Laboratory (NRC, 2006b); high-level waste processing at Idaho, Hanford, and Savannah River (NRC, 1999f, 1999h, 2000e, 2001a, 2001b, 2005d, 2006a); remediation of the Moab, Utah mill tailings site (NRC, 2002a); and long-term institutional management of early-closure sites (NRC, 2003b). The NRC has also undertaken broader-based examinations of technology development and technology use in soil and groundwater cleanup (NRC, 1994d, 1997e, 2000b). Other recent NRC reports have examined the use of risk analysis in cleanup decision making (NRC, 2005b) and opportunities for accelerating DOE's cleanup efforts (NRC, 2005c).

As illustrated by this summary, NRC studies have examined and reported on a remarkable range of waste management, cleanup, and disposal issues over the past half century. The thousands of pages of information, analyses, and discussions contained in these reports continue to be a valuable resource for DOE managers, technical staff at DOE sites, national laboratory staff, and Congress.

Although some of the older reports are outdated, they still provide an important historical record of the federal government's efforts to manage the environmental legacy of the nation's nuclear weapons production and testing programs. Many and perhaps most of these reports still contain relevant information and advice that can help inform future cleanup efforts.

SCIENCE AND TECHNOLOGY GAPS

This section provides a high-level synthesis of science and technology gaps derived from previous NRC reports. Interested readers are encouraged to read the original reports to obtain more details. Most of the reports published since 1994 can be read online (Web addresses for these reports are provided in Appendix A).

NRC reports identify science and technology gaps using a variety of labels: for example, research needs, technology needs, cleanup challenges, and knowledge gaps. These reports were also written for different audiences—basic researchers, technology program managers, EM management, and Congress—and consequently these needs, challenges, and gaps are written in different styles with different levels of supporting detail. In developing this synthesis, these needs, challenges, and gaps have been combined, reordered, and in some cases reworded to remove specialized jargon and provide a consistent level of supporting detail.

The science and technology gaps were derived primarily from NRC reports on cleanup challenges at the large DOE sites and therefore tend to be biased toward those sites' research and development needs. Some of the identified gaps will require basic research, whereas others will require a combination of applied research and technology development. Some of the gaps can probably be addressed in short time frames (1 to 5 years), whereas others will require medium- (5 to 10 years) and longer-term (>10 years) efforts.

Science and technology gaps have been organized as follows:

- High-level waste and tank cleanup
- Facility[4] cleanup
- Groundwater and soil cleanup
- Waste and contamination containment
- Containment monitoring

These gaps were not prioritized in previous NRC reports, and no attempt has been made to prioritize them here. The comments from workshop panelists in Chapter 3 will serve to update and extend these identified gaps.

To keep this chapter to a reasonable length, no effort was made to include science and technology gaps from NRC reports published before DOE-EM was established. Also, there is no discussion of research gaps for transuranic and mixed waste, nuclear materials, and spent nuclear fuel. These tend to be site- and waste-stream specific needs that are less important in terms of cost and schedule than the other cleanup problems. Additional information on research gaps for these excluded wastes and materials can be found in NRC (2002c, 2003a).

High-Level Waste and Tank Cleanup

There are about 400 million liters (about 105 million gallons) of high-level radioactive waste stored in 225 large underground tanks at the Hanford and Savannah River sites and about 4400 cubic meters

[4] "Facilities" include built structures and the equipment contained within them.

(160,000 cubic feet) of calcined high-level waste stored in bins at the Idaho site.[5,6] The Hanford Site is also storing over 1900 stainless steel capsules containing about 130 million curies of cesium and strontium separated from high-level waste. Most of the tank waste is a multiphase mixture of solids and liquids containing a variety of radionuclides and hazardous chemicals. The tanks themselves are between about 40 and 65 years old, and some have developed leaks. In 2000, DOE estimated that it would cost over $50 billion to complete high-level waste and tank cleanup at its sites.[7]

Figure 3 provides a graphical illustration of DOE's process for high-level waste cleanup at the Savannah River Site.[8] DOE plans to retrieve waste from the underground tanks at the site for treatment, immobilization, and disposal. The sludge waste (a precipitate of metal oxides and hydroxides) will be processed and immobilized in glass for eventual disposal in a geological repository. The salt waste (a mixture of highly alkaline liquid and crystallized waste) will be processed to remove cesium, strontium, and actinides, which will be immobilized in glass. The remaining low-activity salt will be immobilized in grout and disposed of onsite. The tanks, including any residual waste, will be disposed of in place.

DOE is currently retrieving waste from tanks at Hanford and Savannah River, and the sludge waste at Savannah River is currently being immobilized in glass. Several reports (NRC, 1999h, 2001d, 2003c, 2005d, 2006a) have identified opportunities to improve the technical effectiveness and reduce the costs of high-level waste cleanup, as described below.

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[5] In addition, there is sodium-bearing liquid waste in the tanks at the Idaho Site. This waste is not considered to be high-level waste. Its disposition is discussed in Chapter 3 of this report.

[6] All of the high-level waste at the West Valley Site in New York has already been retrieved and vitrified.

[7] DOE, 2000, Status Report on Paths to Closure, http://www.em.doe.gov/pdfs/StatusReportOnPathsToClosure.pdf. The cost estimate cited is characterized in this report as a low-end estimate. DOE has not published an updated estimate since 2000.

[8] A similar process is planned for the Hanford Site, except that the low-activity waste stream will be vitrified for onsite disposal. DOE has not yet decided how it will process the solid calcine waste at the Idaho Site. It might be dissolved and processed in a manner similar to that at Hanford and Savannah River, or it might be processed in a solid state (NRC, 1999h).

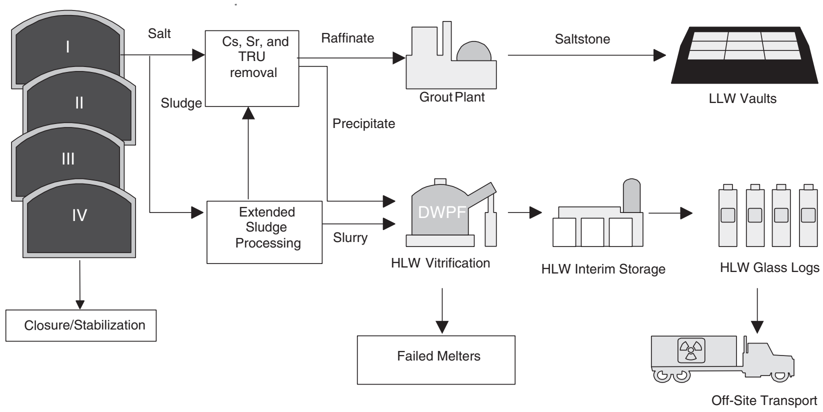

FIGURE 3 Simplified flow sheet for management of tank wastes at the Savannah River Site. Low-level waste (LLW) will be disposed of onsite; high-level waste (HLW) will be stored onsite and eventually disposed of in a geological repository; a disposition pathway for failed melters from the Defense Waste Processing Facility has not yet been established; TRU = transuranic isotopes. SOURCE: NRC (2001d).

Waste Retrieval from Tanks

The high-level waste tanks at Hanford and Savannah River generally have small access ports, and some tanks contain debris and (at Savannah River) cooling coils that further inhibit access and waste retrieval. Many single-containment (also known as “single-shell”) tanks at Hanford have leaked waste into the environment, some double-containment (“double-shell”) tanks at Savannah River have leaked waste into the annulus between the tank walls, and buried waste transfer lines and ancillary equipment (e.g., smaller tanks, valves, and pumps) may also contain waste. Many tanks also contain insoluble residual waste (referred to as “heels”) that is difficult, time consuming, and costly to remove.

Residual waste retrieval from tanks and ancillary pipelines has been identified as an important technology gap in three NRC reports (2001d, 2005d, 2006a; see also NRC, 2003c). These reports recommended the development of physical and chemical cleaning technologies to improve the effectiveness of residual waste removal in tanks, tank annuli, and pipelines, especially technologies that reduce the risks of leakage of wastes to the environment during the removal operations (e.g., by using little or no water to retrieve wastes). Opportunities for expanding the use of robotics technologies for waste retrieval and tank cleaning are discussed in NRC (2005d, 2006a).

The calcine waste at the Idaho Site is a powdered ceramic solid of various sizes and compositions. It was transferred pneumatically to the bins for storage. DOE plans to retrieve the calcine using the same process. However, pneumatic retrieval could be difficult if calcine caking has occurred (e.g., from the addition of moisture to the bins or by particle sintering). A previous NRC report (1999h, p. 22) noted that there will probably be problems in retrieving the calcine waste but that they could be handled. NRC (2006a) reached the same conclusion.

Waste Characterization

High-level waste must be characterized prior to and at several points during processing. Current processing approaches are generally expensive and labor and time intensive. NRC (2001d) recommended that DOE develop innovative methods to achieve real-time and, when practical, in situ physical, chemical, and radiological characterization of high-level waste streams at all phases of processing.

Radionuclide Separations from Salt Waste

Finding reliable and robust high-throughput methods to separate cesium, strontium, and actinides from salt wastes at Savannah River has been a significant science and technology gap. Such separations processes will also be required at the Hanford Site and possibly at the Idaho Site. Several NRC reports have recommended that DOE carry out research to address this gap (NRC, 1999h, 2000e, 2001d).

Immobilization of High-Activity Waste

DOE's baseline approach for immobilizing the high-activity portion of its waste is vitrification in borosilicate glass. While borosilicate glass can probably be used to immobilize all of DOE's high-level waste, there are opportunities to reduce waste volumes and costs through the development of alternate waste forms that allow for higher waste loadings and have less sensitivity to waste stream compositional variations (NRC, 2001d; see also NRC, 1996f). NRC (1999h) recommended that DOE examine a range of technical options for immobilizing high-level waste calcine at the Idaho Site. NRC (2003a) recommended research on the cesium and strontium capsules at Hanford to help ensure their continued safe storage, to identify methods to convert the isotopes to stable glass or ceramic forms, and to understand the long-term hazards of disposition options.

Tank Closure and Stabilization

DOE considers it impractical to dismantle and remove tanks after they have been emptied because of costs and worker risks. Instead, DOE plans to characterize and stabilize the residual waste in the tanks. NRC (2001d) identified methods for tank waste heel characterization, especially to estimate radionuclide concentrations, as an important science and technology gap.

Stabilization of this residual waste will be accomplished by filling the tanks with grout. The grout serves several purposes: It encapsulates and stabilizes the residual waste, provides structural support for the tank walls and roof, and acts as a barrier to water infiltration and intruders. NRC (2006a) recommended focused research to improve the fundamental understanding of tank fill materials and also to improve DOE's ability to tailor grout formulations to specific tanks or groups of tanks.

Facility Cleanup

Over 20,000 facilities were constructed to support nuclear weapons production, testing, and related activities, and DOE has identified over 5000 of these as surplus.[9] Additional facilities may be declared as surplus in the future. These surplus facilities include production and test reactors, fuel and target fabrication facilities, chemical processing facilities, and gaseous diffusion plants. Some of these facilities are the most massive reinforced concrete structures ever built and are filled with heavily contaminated process equipment. It could take decades for DOE to complete the cleanup of these facilities.[10]

DOE is following a two-phase strategy for facility cleanup: The first is to deactivate the facility to reduce worker risks and maintenance costs. This includes shutting off nonessential safety and security systems, flushing process lines and equipment, and removing dangerous materials. The second is to decommission the facility. This includes decontamination of the facility and equipment (i.e., removal of radioactive and hazardous chemical contamination) and possibly dismantlement; the decommissioning end state will be

[9] DOE, 1997, Linking Legacies: Connecting the Cold War Nuclear Weapons Production Process to Their Environmental Consequences, DOE/EM-0319.

[10] However, cleanup of the Rocky Flats site was completed ahead of schedule with substantial cost savings; see discussion in Chapter 3.

determined separately for each facility. DOE's most recent low-end estimate of its deactivation and decommissioning costs is about $10 billion.[11]

Facility cleanup will be technically challenging and expensive for several reasons (NRC, 2001c, p. 24):

- Personnel hazards in these facilities—penetrating radiation, airborne contamination, and chemical and industrial hazards.
- Number and size of facilities and bulk of concrete shielding walls.
- Complex, crowded, and often retrofitted equipment arrangements.
- Lack of knowledge concerning the history of operations and contamination.
- Difficulty in identifying and quantifying many of the radioactive and chemical contaminants.
- Lack of decisions on the end states for many facilities.

NRC (2001c) concluded that the following DOE facilities will pose the most difficult cleanup challenges:

- Radiochemical separation facilities at Hanford and Savannah River and the Chemical Processing Plant at Idaho.
- Gaseous diffusion plants at Oak Ridge, Paducah, and Portsmouth (see NRC [1996i] for descriptions of these facilities).
- Plutonium processing plants and Hanford, Savannah River, and Los Alamos.[12]
- Tritium processing facilities at Savannah River.

NRC (2001c) identified specific science and technology gaps; these are described in the following sections.

Contaminant Characterization

Characterization describes the processes used to estimate the types and quantities of contamination present in facilities and equipment that are undergoing deactivation and decommissioning. Characterization is used to make the initial assessment of radioactive and chemical contaminants to guide decommissioning planning. It is

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[11] DOE, 2000, Status Report on Paths to Closure, http://www.em.doe.gov/pdfs/StatusReportOnPathsToClosure.pdf.
[12] DOE has successfully decommissioned and dismantled the plutonium processing facilities at the Rocky Flats Site.

also used to monitor progress in removing contamination during the decontamination process. When decontamination is complete, characterization is again used to assess the effectiveness of decontamination and determine the disposition pathways for wastes, surplus equipment, and possibly the facility itself.

Hundreds of thousands of individual measurements might be required during the decontamination of a facility. Characterization as presently practiced requires workers to enter facilities to collect samples and make measurements. This labor-intensive process exposes workers to radiation and other hazards and is costly. In 2000, DOE estimated that characterization consumed an estimated 15 to 25 percent of facility cleanup budgets (NRC, 2001c, p. 50).

NRC (2001c) identified contaminant characterization for decommissioning as an important science and technology gap. That report recommended that research be undertaken to support development of the following:

- Devices for rapid characterization of low-levels of contamination (radionuclides and Environmental Protection Agency-listed substances) on surfaces of construction materials and equipment, including devices that can detect very-low-energy beta emitters (e.g., tritium) and low-energy photon emitters (iodine-125).
- Minimally invasive methods to characterize contaminant concentrations as a function of depth in construction materials, especially concrete.
- Instruments for remote mapping of radionuclide contamination at low levels that can differentiate specific radionuclides, including beta and alpha emitters.

Materials Decontamination

Like characterization, decontamination is carried out at many stages of the decommissioning process. Initially, it might be used to lower radiation levels to allow workers to access a facility. It might also be used before equipment is disassembled or a facility is dismantled to prevent the spread of contamination. The primary objective of decontamination is to reduce the volume of contaminated waste that requires special handling and to allow the bulk of waste material to be recycled or disposed of without special precautions.

Current decontamination processes are labor intensive and costly. These processes also generate large volumes of secondary wastes and often leave behind unwanted residual contamination. Because of its cost and hazards, cleanup contractors often choose to dispose of contaminated equipment and construction materials rather than decontaminate and recycle them.

NRC (2001c) identified decontamination as an important science and technology gap and recommended specific areas of research needed to improve decontamination technologies, including:

- Research on the chemical and physical interactions between contaminants and construction materials (e.g., steel and concrete) to gain a better understanding of how contaminants bind to and penetrate these materials.
- Research to support the development of biologically based decontamination processes, such as bioleaching agents, biosurfactants, and biocatalysts.

Use of Robotics and Intelligent Machines for Decommissioning

DOE can probably complete its decommissioning program using current approaches, which typically involve direct hands-on work in contaminated facilities. However, this approach is costly and potentially hazardous to workers. The utilization of robotics and intelligent machines in decommissioning could reduce worker exposures and might also reduce project costs (NRC, 1996i).

DOE is making limited use of some robotic technology, for example, as part of the Glovebox Excavator Method used to demonstrate retrieval of some buried transuranic waste at the Idaho Site (NRC, 2005c, p. 43). NRC (2003a) recommended that DOE develop such robotic technologies for retrieval and repackaging of buried waste. Such technologies could potentially be applied to some facility cleanups.

NRC (2001c) recommended research to develop intelligent and adaptable robotic systems that can be used for facility decommissioning. The specific need is to develop actuators (the power component of robotic systems) that can provide real-time information on position, velocity, and force of the robotic tool, as well as software that gives these systems a more humanlike ability to adapt to the variety of tasks likely to be encountered in actual decommissioning projects. NRC (1996i) recommended that DOE undertake focused demonstration of robotic decontamination technologies.

Long-Term Behavior of Contaminants in Construction Materials

NRC (2001c) noted that DOE must determine the final end state of a facility before the decommissioning process can be completed. Possible end states range from complete dismantlement of the facility to unrestricted release of an intact building for other uses. The end state is usually established through a decision-making process that is informed by risk assessment and frequently involves negotiations with local parties. The general lack of understanding of the long-term behavior of contaminants in construction materials like steel and concrete may further limit end-state choices. NRC (2001c) identified long-term contaminant behavior as an important science and technology gap. The report recommended research to provide an improved understanding of long-term contaminant behavior in building construction materials. This includes understanding how the physical and chemical forms of contaminants evolve with time and how they are affected by decontamination activities. This research will help improve knowledge of how such changes might affect the eventual release of contaminants from building materials.

Groundwater and Soil Cleanup

Chemicals, metals, and radionuclides have been introduced into the environment at DOE sites through accidental spills and leaks from storage tanks and waste transfer lines and also through intentional disposal via injection wells, disposal pits, and settling ponds. Releases into the environment generally were not closely tracked, and many release sites were unmarked and forgotten. Some of these sites are being rediscovered as DOE proceeds with its cleanup program.

This environmental contamination occurs in two distinct settings:

- Waste burial grounds. Waste was disposed of in pits, trenches, and auger holes at all major DOE sites. These were unlined and frequently unmarked after closure. There are major burial grounds at Hanford, Idaho, Oak Ridge, and Savannah River, and some of these are leaking contaminants to surface water and groundwater.
- Surface and subsurface contamination. Contamination of surface soils with metals, radionuclides, and hazardous chemicals is a pervasive problem at DOE sites. There is also extensive contamination of the subsurface with chemicals, metals, and radionuclides at all of the major DOE sites.

Groundwater and soil are contaminated with dense nonaqueous-phase liquids, toxic metals, and radionuclides. DOE estimates that its sites contain some 6.4 billion cubic meters (230 billion cubic feet) of contaminated groundwater and 40 million cubic meters (1.4 billion cubic feet) of contaminated soils and debris. The majority of this contamination exists at the Hanford Site (1.4 billion cubic meters [50 billion cubic feet]) and Idaho National Laboratory (4.7 billion cubic meters [170 billion cubic feet]) (see NRC 2000a, Table 2.3), where liquid and solid wastes were dumped or buried or pumped underground through injection wells. DOE's most recent low-end estimate for environmental restoration activities at its sites exceeds $10 billion.[13] The following science and technology gaps for soil and groundwater cleanup have been identified in previous NRC reports.

Remediation Technologies

Three NRC reports (1994d, 1997e, 1999c) have examined the feasibility of active remediation, such as pump-and-treat, for soil and groundwater cleanup. The overall conclusion of these reports is that these remediation approaches have limited effectiveness. One of these reports (1997e) recommended that additional work be undertaken to assess the effectiveness of active remediation technologies, but these reports generally have not recommended further R&D on remediation technologies themselves.

Four NRC reports (1994d, 1997e, 1999c, 2000b) also have examined passive remediation technologies—for example, monitored natural attenuation. Three reports (NRC 1994d, 1997e, 1999c) have recommended that additional work be undertaken on passive remediation technologies, including reactive barriers and in situ bioremediation.

Locating and Characterizing Subsurface Contamination and Characterizing Subsurface Properties

The challenges of locating subsurface contamination are magnified by the wide range of contaminant types (e.g., mixtures of organic solvents, metals, and radionuclides) in the subsurface at many DOE sites; the wide variety of geological and hydrological conditions at these sites; and the wide range of spatial resolutions at which this contamination must be located and characterized, from widely dispersed contamination in groundwater plumes to small isolated hot spots in waste burial grounds. Three NRC reports

[13] DOE, 2000, Status Report on Paths to Closure, http://www.em.doe.gov/pdfs/StatusReportOnPathsToClosure.pdf.

(2000a, 2001f, 2002c) have identified characterization as an important science and technology gap. In particular, these reports recommended that DOE support research to develop new or improved capabilities to:

- Characterize the physical, chemical, and biological properties, including heterogeneity, of the subsurface, especially the unsaturated zone.
- Measure contaminant migration in the subsurface.
- Characterize buried waste in the subsurface, including waste container conditions.

Modeling Contaminant Fate and Transport

Quantitative, or predictive, models are being increasingly utilized to estimate the long-term fate of contaminants in the subsurface and to investigate the potential effectiveness of potential remediation actions. Building such models requires a good knowledge of subsurface characteristics and behavior of natural processes that control contaminant transport. This assembled knowledge is referred to as a conceptual model of the subsurface. NRC (2000a) noted that existing conceptual and predictive models have often proven ineffective for predicting contaminant movement, especially at sites that have thick unsaturated zones or complex subsurface characteristics (e.g., the Hanford and Idaho sites and the Nevada Test Site).

NRC (2000a) also identified conceptual model development as an important science and technology gap. This report recommended basic research focused on the following topics to improve model development capabilities:

- New approaches for conceptual model development for complex subsurface environments.
- New approaches for incorporating subsurface heterogeneity into conceptual model formulations at scales that dominate contaminant flow and transport behavior.
- Development of coupled-process models that account for the physical, chemical, and biological processes that govern contaminant fate and transport behavior.
- Methods to integrate process knowledge from tests and observations into conceptual model formulations, and methods for establishing bounds on the accuracy of parameters and conceptual model estimates from field and experimental data.

Waste and Contamination Containment

When DOE's cleanup program is completed, many sites will still contain substantial surface and near-surface contamination. These include waste burial sites, both historical sites from weapons production activities and new sites developed specifically for onsite disposal of waste from cleanup activities, stabilized underground tanks, abandoned facilities, and other near-surface release sites.

DOE plans to stabilize[14] and cover many of these waste sites with surface barriers, or caps, to limit contact of the waste with surface water. The potential need for such barriers is enormous: There are potentially hundreds of near-surface sites (burial grounds, closed underground tanks, and liquid discharge sites) that will need to be covered with barriers to limit surface water infiltration. These sites occur in both arid and humid environments. The barriers installed on these sites must function for many generations.

The current emphasis in barrier deployment at DOE sites is on low-permeability engineered caps that are constructed of multiple layers of engineered and natural materials for stability, for intrusion prevention (especially by animals), and to limit infiltration. Subsurface barriers are not yet in wide use at DOE sites (except in engineered landfill facilities) but may receive increased attention in the future as DOE completes cleanup of tanks, burial sites, and other waste sites. These could include horizontal or vertical layers of clay, grout, or frozen or fused soil. DOE has experimented with reactive barriers to treat or retard contaminants in contaminated groundwater. Some of these could in principle also be used for waste containment.

Although there has been an increasing emphasis on and acceptance of waste containment and stabilization as "final" corrective actions at DOE sites, both by DOE management and regulatory agencies, there is relatively little understanding of the long-term performance of containment and stabilization systems. Moreover, there is a general absence of robust and cost-effective methods to validate that such systems are installed properly or that they can provide effective long-term protection.

Several NRC studies have called for research to develop improved containment and stabilization systems and to assess their effectiveness (NRC, 1996c, 1999c, 2000a, 2001f; see also NRC, 1997b, 2000d, 2005c). The specific science and technology gaps that

[14] The term "stabilize" has at least two meanings. It describes methods that are used to treat a waste to make it less susceptible to leaching, for example, by producing a chemically resistant waste form. It also describes methods for increasing the structural integrity of a closure system, for example, by in situ grouting or compaction, to improve its long-term performance.

underpin the development of these improved technologies include the following (NRC, 2000a):

- Better understanding of the mechanisms and kinetics of chemically and biologically mediated reactions that can be exploited in containment systems. For example, better understanding of reactions that can extend the use of reactive barriers to a greater range of contaminant types found at DOE sites or that can be used to understand the long-term reversibility of chemical and biological stabilization methods.
- The physical, chemical, and biological reactions that occur among contaminants, soils, and barrier components so that more compatible and durable materials for containment and stabilization systems can be developed.
- The fluid transport behavior in conventional barrier systems to support the design of more effective infiltration barrier systems.
- The development of methods for assessing the long-term durability of containment systems.

Containment Monitoring

Monitoring, defined broadly, refers to methods used to plan for and demonstrate the effectiveness of any remedial action, including waste containment. For example, monitoring is used to collect information to support the development of conceptual and predictive models of subsurface and contaminant behavior. It is also used to demonstrate the effectiveness of efforts to remove, treat, or especially to contain contamination or to gain regulatory approval for such actions.

Monitoring will be especially important to assess the long-term performance of the containment systems that will likely be installed across DOE sites. Such monitoring could in principle be used to assess the performance of containment barriers and provide an early warning of contaminant releases. NRC (2006a, pp. 84-90) identified the characteristics of a good monitoring system; the report also noted that DOE sites have not yet developed plans for postclosure monitoring of underground waste tank closures. The report recommended that DOE begin to plan now for postclosure monitoring so that provisions can be built into closure plans and designs.

Many of DOE's sites will not be cleaned up sufficiently for unrestricted release after the cleanup program is completed (see NRC, 2000d). Those sites (or portions of sites) that cannot be released will be transferred to DOE's Office of Legacy Management once cleanup activities have ended; this office will be responsible for long-term site monitoring and maintenance. DOE's low-end estimate for conducting these long-term stewardship activities is almost $10 billion through 2070.[15]

Two NRC reports have identified postclosure monitoring as an important science and technology gap for tank closure (NRC, 2001d, 2006a). NRC (2001d) recommended the development of in situ and noninvasive methods to monitor the near-field environment within and surrounding the tanks to detect early degradation of barriers or movement of contaminants.

More generally, some NRC reports (e.g., 2000a, 2001f, 2002c, 2005c) have recommended research to develop the following:

- Monitoring methods that can provide measurements of current conditions and detect changes in system behaviors, especially in the unsaturated zone and within and beneath caps and barriers.
- Methods to monitor fluid and gaseous fluxes through the unsaturated zone and within and beneath caps and barriers and for differentiating diurnal and seasonal changes from longer-term changes.
- Validation processes for modeling of containment systems, including determination of the key measurements that are required to validate models, the spatial and temporal resolutions at which such measurements must be obtained, and the extent to which surrogate data (e.g., data from lab-scale testing facilities) can be used in model validation efforts.
- Remote sensing technology to replace point-to-point practices for sampling and analyzing groundwater.

Such monitoring methods have potentially important application to engineered waste disposal facilities like WIPP to help validate their long-term performance (see NRC, 2000c, 2002c).

CLOSING THOUGHTS

A recurring theme from many NRC reports published since the Environmental Management Program was created in 1989 is the importance of science and technology development for DOE's site cleanup mission. This is perhaps best expressed in NRC (1995c, p. 114):

[15] DOE, 2000, Status Report on Paths to Closure, http://www.em.doe.gov/pdfs/StatusReportOnPathsToClosure.pdf.

> Science and technology play a key role in virtually all the activities of EM [Office of Environmental Management]. They help to determine priorities for site cleanup by providing the basis for sound risk assessments, provide the tools for achieving remediation goals, and provide the scientific rationale that reassures stakeholders that the priorities and actions of the Department are in their best interests.

The identification of science and technology as a core continuing need in the cleanup program was identified in the first NRC review of DOE's plans for waste management and environmental restoration (NRC, 1989a, p. 2):

> [DOE's five-year waste management and environmental restoration] plan should make explicit the need and intent to develop a balanced program of basic and applied research, development, and training that embraces the entire thirty-year span of its cleanup effort, not just the first five years.

Other NRC reports have highlighted the importance of science and technology development for improving cleanup capabilities, understanding and reducing cleanup risks, and reducing cleanup costs and schedules. These reports have generally taken a long-term (decadal or longer) view of science and technology development and have encouraged DOE not to ignore longer-term needs in the rush to meet short-term schedules. The following excerpts illustrate many of these points:

> In some circumstances, technologies and processes for safe and efficient remediation or waste minimization do not exist. In other cases, the development of a new technology and processes might substantially reduce the costs of, or risks associated with, remediation and waste management. An effective technology development program focused on such opportunities is an essential element of an overall strategy for reducing the cost and speeding the pace of the Environmental Management Program. (NRC, 1995c, pp. 6-7)

> Many of EM's cleanup problems cannot be solved or even managed efficiently with current technologies, in part owing to their tremendous size and scope. … [A] basic research program focused on EM's most difficult clean-up problems may have a significant long-term impact on the clean-up mission. … Simply put, new technologies are required to deal

with EM's most difficult problems, and new technologies demand new science. (NRC, 1997c, pp. 1-2)

DOE's attempts to clean up contaminated groundwater and soil have been limited in part by technological difficulties. Because of such limitations, new technologies are needed to enable DOE to achieve remediation requirements for groundwater and soil at a reasonable cost. (NRC, 1999c, p. 3)

[W]hile current D&D [deactivation and decommissioning] technologies probably can be made to work in the D&D of [DOE] facilities, there are opportunities to do the job more safely and effectively by developing and using new technologies. … There are strong safety and economic incentives for developing and using innovative D&D technologies that may be achieved through scientific research. The long time frame for completing D&D (50 years or more) allows for substantive research to be completed and applied. (NRC, 2001c, pp. 2-3)

[T]he closing of larger DOE sites will require decades. Problems that are not foreseen or appreciated today are likely to be encountered in buried waste retrievals. … Buried waste retrieval and monitoring of disposal facilities provide opportunities for the long-term, breakthrough research envisioned by Congress [when it created the EMSP], and these opportunities should not be overlooked in DOE's rush to meet short term needs. (NRC, 2002c, p.9)

Ten years or more is a realistic time frame for development, demonstration, and deployment of truly innovative technologies. Such long-term efforts should target both site-specific and complex-wide problems that are intractable or very difficult (e.g., expensive) with current technologies. (NRC, 1999g, p. 21)

3

Workshop Summary

This chapter provides the rapporteur's summary of the presentations and discussions that took place at the March 13, 2007 workshop entitled "Development and Implementation of a Cleanup Technology Roadmap for DOE's Office of Environmental Management." As noted in the Preface, this workshop was organized by the National Research Council (NRC) to bring together regulators and other interested parties to discuss current site conditions and science and technology needs. The workshop agenda and participants are provided in Appendixes B and C, respectively.

OPENING COMMENTS

The organizing committee invited two speakers to provide opening remarks to help establish the context for the day's workshop discussions: Mr. Mark Gilbertson (Deputy Assistant Secretary, Office of Engineering and Technology, Department of Energy Office of Environmental Management [DOE-EM]) provided an overview of DOE's progress in site cleanup, future challenges, and DOE's rationale for requesting the workshop and Phase 2 study (the Phase 2 study is described in the Preface). Ms. Terry Tyborowski (Staff Assistant, House Committee on Appropriations, Energy and Water Development Subcommittee) provided a congressional perspective on technology utilization in DOE's cleanup program.

Mr. Gilbertson noted that EM has made good progress in site cleanup, but great challenges remain. With the successful closure of some smaller DOE sites (e.g., Rocky Flats in Colorado and sites in Ohio), the cleanup program is becoming increasingly focused. Most of the future cleanup work will be carried out at the DOE sites that are the focus of this workshop: Hanford, Idaho, Oak Ridge, Savannah River, Paducah, and Portsmouth. It will cost an additional $100 billion and require several decades to complete the currently planned cleanup programs at these sites.

There are additional DOE sites (operated by the National Nuclear Security Administration, Office of Nuclear Energy, and Office of Science) that could be added to EM's cleanup program in the future. At present there is no indication that the cleanup challenges at these sites are markedly different than what EM already faces at its current sites.

However, there is a substantial amount of new deactivation and decommissioning (D&D) work, particularly at sites like Y-12 at Oak Ridge.

Congress has asked EM to provide its vision for bringing greater technical innovation to bear in its cleanup program. That office is preparing a technology roadmap for Congress that identifies targets of opportunity for the more effective use of cleanup technologies. An abbreviated version of the roadmap is expected to be submitted to Congress at the end of March 2007.[1] The roadmap will be routinely updated in the future as new information becomes available.

EM has requested this National Academies study to help with its roadmap development efforts. EM hopes that this study can help identify opportunities to make targeted investments in technology and to leverage the resources and capabilities of other organizations, including other DOE offices. The primary focus of this workshop is to assess whether EM is missing any technology development opportunities at its sites, specifically with respect to high-level waste cleanup, soil and groundwater cleanup, D&D of facilities, and waste and contamination containment.

The current centralized technology development program within EM for addressing these cleanup challenges is small (about $20 million per year) and focused, unlike the $300 million to $400 million per year investments in the mid-1990s. However, there is a willingness on the part of EM management to expand support if a new vision for technology development can be articulated.

This workshop is the first phase of a two-part study. The second phase of the study[2] will provide advice to EM on leveraging the resources and capabilities of other organizations, including other offices within DOE, and preserving critical assets at the national laboratories so that they are available to support the long-term cleanup mission. EM does not need to manage the national labs to have access to their capabilities. However, EM does need to provide and manage resources for people, programs, and facilities, and it needs to keep national laboratory staff working on its problems.

EM now spends between $150 million and $200 million per year at national laboratories for direct and indirect technical support of its cleanup projects. It is not clear, however, that these investments are being managed in a strategic manner. The transfer of the EM Science Program to the Office of Science is a case in point. When the Office of Science contacted the sites for advice on high-level waste research, site responses focused on short-term needs. The Office of Science interpreted this response as an indication that the sites did

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[1] A draft version of the roadmap was delivered in mid April 2007.
[2] As noted previously, the Phase 2 study is described in the Preface.

not have any longer-term needs that could be addressed by the EM Science Program. Consequently, the Office of Science decided to focus that program on subsurface research instead. EM has reengaged the Office of Science to correct this miscommunication.

A member of the audience asked Mr. Gilbertson if EM was providing direct support to the national laboratories. Mr. Gilberston responded that most EM support to the national laboratories is presently being done through cleanup contractors. There might be opportunities to provide funding directly to the labs in the future, but EM wants advice on capabilities and infrastructure that should be supported. He noted that EM also invests about $20 million per year in university research activities.

Another audience member asked whether the cleanup technology roadmap addresses buried waste and spent fuel and nuclear materials management. Mr. Gilbertson noted that buried waste is addressed in the roadmap under soil and groundwater cleanup needs. The current draft of the roadmap does not address management of spent fuel or nuclear materials.

An audience member suggested that EM will need to provide a continuous source of funding if it wants to maintain capabilities at the national laboratories. Mr. Gilbertson agreed that critical capabilities need to be looked after by EM, but that there were other federal agencies that could provide some of the needed funding. For example, the Department of Homeland Security has picked up some of the research and development (R&D) on sensors that was formerly funded by EM.

Ms. Tyborowski began her remarks by noting that the Energy and Water Development Committee is frustrated by the lack of utilization of new technology in EM's cleanup program. The committee has received complaints from companies about EM's resistance to the use of company-developed technologies. At the same time, there is a legacy of pauses, stops, and reevaluations of cleanup projects because technology does not get inserted at the right time. The committee does not understand the reasons for the resistance to new technology utilization.

The Energy and Water Development Committee agrees that there is a need for more innovative technology in the cleanup program. The committee is also happy to see that EM is rebuilding its technology programs and is ready to support increased technology investments. EM's cleanup work needs to be done smartly by taking advantage of new technologies, rather than the current focus on "fast" and "cheap." EM's use of design-build projects to cut costs and save time is not working. The committee agrees with a Government Accountability

Office[3] report that there should be a gauge of technology maturity before a cleanup project moves forward.

The Energy and Water Development Committee is encouraged that the National Academies are looking at technology development needs. The Academies can speak independently, and its reports cannot be edited by the administration. It would be helpful to Congress if the Academies could identify the barriers for inserting new technologies into the cleanup program. It would also be useful to have advice on technology investment priorities and criteria (e.g., safety and mortgage cost reduction) for prioritization.

During the question and answer session following Ms. Tyborowski's formal remarks, a national laboratory staff member offered comments about barriers to new technology deployment. He noted that cleanup projects are contract driven: contractors get paid to execute the contracts and are penalized if contract obligations are not met. There are few incentives in current contracts for the deployment of new technologies. Also, there is often not enough money to do all of the necessary planning up front, which requires that projects be implemented in stages. It is hard to predict "show-stopper" problems until they are encountered during project execution, and by that time there is pressure to spend additional time and money to solve the problem rather than select another technology.

A cleanup contractor listed several obstacles for getting new technologies used in the cleanup program: lack of continuity of site contractors; use of performance-based contracts that lack incentives for contractors to use new technologies; and the cost of paperwork for revisions to agreed-upon work, especially for safety documentation. In short, contractors have zero or negative incentives for using new technologies.

Another contractor noted that new technologies such as caustic side solvent extraction, which will be used to process salt waste at Savannah River in place of in-tank precipitation, have taken years to reach maturity. He suggested that EM should look to the nuclear industry for mature technologies to add to its cleanup toolbox.

A state regulator expressed support for the development of the cleanup technology roadmap. She noted that the closure of tanks at the Savannah River Site will be carried out from 2010 to 2022, and that not all of the tools necessary to close the tanks are available at present. She commented that there is still time to develop such tools

[3] Department of Energy: Major Construction Projects Need a Consistent Approach for Assessing Technology Readiness to Help Avoid Cost Increases and Delays, GAO-07-336, March 27, 2007, available at http://www.gao.gov/cgi-bin/getrpt?GAO-07-336.

and that regulatory drivers can provide the necessary pressure and incentives to do so.

Another state regulator noted that without continued regulatory pressure, cleanup progress tends to stall. He commented that regulators have the flexibility to allow EM to introduce new technologies into its cleanup projects.

CLEANUP CHALLENGES AT FOUR DOE SITES

Panel sessions were organized for each of the four large DOE sites: Hanford, Idaho, Oak Ridge, and Savannah River. For each panel session a DOE staff member initiated the discussion by providing comments on site science and technology gaps and/or the underlying site technology needs and cleanup challenges. The panelists were then invited to provide comments on these DOE-identified gaps (or the underlying technology needs and cleanup challenges) and to identify other gaps that require attention. The DOE speakers and panelists were also encouraged to comment on the science and technology gaps identified in the workshop discussion paper—particularly with respect to the current relevance of those identified gaps to their sites. Following panel comments, questions and comments from the audience were invited.

Savannah River Site

Cleanup challenges and technology needs at the Savannah River Site were reviewed by Panelist Pat Suggs (Chemical Engineer, DOE Savannah River Operations Office, Salt Processing Division). She noted that the primary objective of the cleanup program at the site is to meet federal facility agreement commitments for waste retrieval and tank closure, solidification of high-level waste at the Defense Waste Processing Facility (DWPF), and processing and disposal of low-activity waste at the Salt Processing Facility. While meeting these regulatory commitments, DOE-EM is also trying to preserve working tank space, which is in very short supply, for its current and future waste processing operations (e.g., operation of the H Canyon,[4] DWPF, and the Salt Waste Processing facility [SWPF]).

EM's principal high-level waste cleanup challenges include:

[4] DOE-EM has proposed to extend the operation of the H Canyon at the Savannah River Site through 2019 to process 26 metric tons of highly enriched uranium and 2 metric tons of plutonium, mostly from aluminum-clad spent fuel that is now being stored at the site.

1. Removal of residual high-level waste from tanks and waste transfer lines:
   - Removal of sludge “heels” (i.e., the sludge remaining after bulk waste retrieval is completed) from tanks, especially tanks with internal obstructions such as cooling coils.
   - Removal of waste from the spaces (annuli) between the inner and outer tank containments in tanks that have leaked.
   - Removal of residual waste from transfer lines between tanks and other facilities.
2. Reduction of sludge mass to be sent to the DWPF for immobilization in glass.
3. Improvements in waste processing to preserve working tank space to support future site operations.

Savannah River is examining a number of technologies for meeting these cleanup challenges. For residual waste removal, the site will employ an oxalic acid cleaning technology in two tanks. However, the use of oxalic acid can cause hydrogen generation and can have downstream processing impacts. The site hopes to develop an alternate technology that does not have these impacts for future tank cleaning operations. The site also hopes to employ new mechanical cleaning technologies in tanks with cleaning coils, especially technologies that use little or no added water.

Recent analytical projections indicate that there is more mass such as aluminum, iron, and nickel in the sludge waste in the tanks than initially anticipated. These projections are based on samples of sludge waste sent to the DWPF for vitrification. Under worst-case projections, it could take 12 years to process the additional sludge mass, and this processing could produce an additional 2000 canisters of vitrified (glass) waste. EM currently spends about $500 million per year on its high-level waste operations at the site, so the incentive for reducing excess sludge mass is very high. EM has not yet identified clear final technologies for sludge mass reduction. The site has some historical experience with tank farm aluminum dissolution by sodium hydroxide that could be used to reduce sludge mass. The site plans to involve industry and other national labs/DOE sites to identify alternative technologies.

For waste processing improvements, the site hopes to implement technologies to improve waste throughput in the DWPF, possibly through a combination of higher waste loadings in glass (current waste loadings are 37 to 38 percent), new melter technologies, and relaxing current compositional standards for glass products. The site will also examine approaches for speeding up the preparation of sludge batches to be fed to the DWPF and for minimizing the addition of water during sludge processing.

Panelist David Wilson (Bureau Chief, South Carolina Department of Health and Environmental Control) commented that high-level waste cleanup was the highest priority for the state of South Carolina; getting the tanks closed is “paramount” to the state. Cleaning tanks with cooling coils, tanks with waste in the annuli, and waste transfer lines are significant technical challenges. The state is also interested in the disposition of surplus plutonium, which is being consolidated at the site. Some of this surplus plutonium could be used in mixed oxide fuel, but some may have to be processed through the DWPF. Disposition of this material is a significant concern to the state.

Panelist Shelly Sherritt (Federal Facilities Liaison, South Carolina Department of Health and Environmental Control) reiterated the state’s interest in tank closure and also noted the state’s interest in minimizing the quantity of radionuclides left onsite from high-level waste cleanup. The state is relying on the SWPF to remove radionuclides from the tank waste, but the state does not want Savannah River to “put all of its eggs” in the SWPF basket. An important lesson from the site’s transuranic waste cleanup program is that targeted technologies can be used in innovative ways to meet cleanup goals. This approach is now beginning to be extended to the high-level waste cleanup program, for example, through the use of new technologies to treat the waste in Tank 48 (from the unsuccessful in-tank precipitation process) to remove about 800,000 curies of radioactivity.

Other technology needs at the site include advanced technologies for characterizing and stabilizing residual waste in the tanks; technologies to improve waste storage in tanks to minimize risks and chip away at the conservatism that limits operational flexibility; advanced soil and groundwater remediation technologies; and low-worker-risk technologies for characterizing retrievable transuranic waste that is now being stored in soil-covered drums on pads.

Panelist John Marra (Associate Laboratory Director, Savannah River National Laboratory) noted that the high-level waste at Savannah River is relatively uniform in composition and that there are established disposition pathways for this waste. The site has encountered surprises in processing some of this waste (e.g., the recent analytical projection of a larger-than-anticipated sludge mass in the tanks), and the limited working space in the tanks continues to hinder operational flexibility. The current operating environment is conservative from a safety standpoint, which further limits operational flexibility. The carbon steel construction of the tanks limits options for in-tank processing of waste as well as waste retrieval.

The site has been very successful in maintaining the high-level waste tanks in a safe condition, which tends to promote a status quo operating mentality that can prevent progress from being made. In particular, there is a tendency to wait for “best” cleanup solutions that are more complex and time consuming to implement.

The Savannah River National Laboratory receives $60 million to $70 million per year for EM-related work; much of this funding is project directed. In the past the lab received direct funding to work on EM problems, but direct funding was eliminated when the cleanup work was “projectized.” It is difficult to sustain R&D programs in the absence of direct funding.

Questions and Discussion

Questions from the audience covered a wide range of cleanup and closure challenges, some of which were not mentioned by the panel is its initial round of comments. Ms. Suggs was asked whether current EM investments in tank cleanout technology development were sufficient to meet site needs. She responded that current investments were project directed and were being made in real time. This work is also being carried out in real tanks because the site does not have a cold test facility (a realistic mock-up of an actual tank). Additional funding can always be used, but such funding is hard to find. Dr. Marra commented that cleanup schedules and budgets require that technology development be done in parallel with actual cleanup.

The panel was questioned about the level of technology development for cleanout of tanks with cooling coils. Ms. Suggs noted that tank cleanout is the site’s first priority to meet regulatory milestones. She reiterated that oxalic acid and other methods are being tried. Dr. Marra commented that there is debris in many tanks (e.g., measuring tapes, spent zeolite from ion exchange columns), which also makes cleanout difficult. Ms. Sherritt commented that the state of South Carolina will not approve closures of tanks that contain too much residual waste. She also noted that the schedules for cleanout of Tanks 18 and 19 are being adjusted so that EM can try new retrieval technologies.

Ms. Suggs was asked whether the lack of knowledge about tank waste composition was hindering progress in the program. She responded that characterization is carried out on an as-needed basis. The contractor samples the waste that is removed from tanks to obtain characterization information.

Ms. Suggs was also asked to elaborate on needs for post closure monitoring. She noted that DOE plans to monitor the tanks after closure but has not yet developed detailed plans to do so. She speculated that monitoring might involve instrumentation in the tank annuli.

Dr. Marra suggested that EM might also want to try some new monitoring approaches, for example, placing instrumentation directly into the grouted tanks. He commented that it is hard to find funding for monitoring technology development.

An audience member asked Ms. Suggs to elaborate on technology priorities for D&D of site facilities. She responded that the site's priorities are worker protection and characterization of hot spots. EM needs to determine whether it is better to fix contamination in place or remove it. The audience member asked whether current technologies were sufficient for containing contamination in place. Ms. Suggs commented that EM was testing some technologies (e.g., phosphate cements), but additional technologies might be needed. Dr. Marra commented on the importance of leveraging technology development from other organizations in other parts of the world.

An audience member asked whether retrieval of buried waste was an important site cleanup challenge. Ms. Sherritt noted that EM must retrieve transuranic waste stored on pads, but this was not as critical an issue as high-level waste retrieval. A regulatory decision has already been made to leave waste in place in the burial grounds at the site.

Finally, an audience member asked whether the time frame for technology development and deployment ("10 years or more") described in the workshop discussion paper (which is incorporated into Chapter 2 of this report) was realistic. Dr. Marra commented that 10 years is not a bad number for deployment of innovative technologies. He pointed out that the success of such deployments can be enhanced through the use of test facilities. He offered as an example the deployment of new waste processing and vitrification technologies in the DWPF. While that facility was being designed and constructed, the site operated a pilot facility at a cost of about $30 million per year to work on technology issues. Ms. Suggs commented that it takes three to four years to develop simple technology. She commented on the importance of early and sustained technology investments so that contractors have the technology when they need it.

Idaho Site

Panelist Scott Van Camp (Assistant Manager, DOE Idaho Operations Office) opened the discussion with a short presentation of the Idaho Site's cleanup challenges and technology needs. The Office of Nuclear Energy is the landlord of the site; EM is responsible for site cleanup. This cleanup is proceeding under several agreements, including a 1995 settlement agreement with the state of Idaho. This settlement dictates cleanup requirements and milestones. EM has initiated the Idaho Cleanup Project to accelerate compliance with some of the agreement milestones.

The Idaho Site's principal cleanup challenges include the following:

1. Waste retrieval and treatment:
   - Calcine retrieval (from bins) and treatment.
   - Sodium-bearing waste treatment.
   - Tank closure.
   - Spent nuclear fuel management, including treatment of sodium- and epoxy-bonded fuels.
2. Soil and groundwater cleanup:
   - Retrieval of targeted waste.
   - Monitoring of installed caps.
   - Monitoring of contamination migrating through fractured basalt 200 to 700 feet (60 to 210 meters) below the surface.
   - Long-term stewardship of groundwater contamination and radioactive waste left in place.
3. D&D of highly radioactive structures.

Calcine waste retrieval and treatment is the primary cleanup challenge at the site. About 4400 cubic meters (160,000 cubic feet) of highly radioactive granular calcine waste is being stored in stainless steel bin sets inside reinforced concrete silos. The waste must be remotely retrieved and processed into a waste form that is suitable for eventual disposal in a geological repository. The site is testing a retrieval technology for breaking up clumped waste and vacuuming it out of the bins. The site has not yet selected technologies for processing the waste for storage and disposal. The settlement agreement stipulates that by 2035 the calcine waste must be put into a form that is ready to be transported to a repository.

The sodium-bearing waste challenges are more schedule than technology driven. There are about 900,000 gallons (3.4 million liters) of mostly liquid waste being stored in stainless steel tanks at the site. This waste will be retrieved and processed using steam reforming to produce a dry granular waste form. The waste may eventually be disposed of in an underground repository in New Mexico (the Waste Isolation Pilot Plant). The settlement agreement stipulates that the sodium-bearing waste be removed from the tanks by 2012 and transported out of the state by 2018.

The tanks at the site are constructed of stainless steel, so the high-level waste did not have to be neutralized for storage.

Consequently, the tanks contain only minor amounts of solids. This greatly simplifies the process for retrieving waste and cleaning the tanks. Once the tanks are emptied, they will be filled with grout. The site has already begun to grout some of the smaller tanks.

DOE has an agreement with the state of Idaho for the retrieval of targeted waste from the Radioactive Waste Management Complex at the site. Current technologies for carrying out this retrieval are labor intensive. Caps will have to be installed over waste burial sites, and their long-term performance will have to be monitored. Contamination in the vadose zone and groundwater will also have to be monitored over the long term.

The site contains many highly contaminated facilities (reactors and chemical processing facilities) that must be deactivated and decommissioned. The primary technical challenge is to characterize and remove contamination in the high background radiation environments in these facilities. Additionally, there are pipelines and other structures under a facility at the site that have high radiation fields (up to 1600 rads/hour). Technologies are needed for remote remediation of this waste, otherwise the facility might have to be demolished to access and remediate the contamination.

Spent nuclear fuel is also being stored at the Idaho Site. Some of this fuel contains organic (epoxy-bonded fuel) and reactive (sodium-bonded fuel) components. These components must be removed as part of fuel processing for storage and disposal. Less expensive methods are needed for this processing.

Some spent fuel has already been put into canisters ("canned") for storage and eventual disposal. Technologies are needed for nonintrusive characterization of canned fuel that may have damaged cladding.

Panelist Nick Ceto (Program Manager, Office of Environmental Cleanup, Hanford/Idaho National Laboratory Project Office, U.S. Environmental Protection Agency [EPA]) identified the primary technical challenge at the site as characterizing and managing chemical and radioactive contamination in the vadose zone and burial grounds. Additional technologies are needed for characterizing and retrieving buried wastes that do not rely on visual inspection and that do not raise worker safety issues.

Additional work on in situ stabilization technologies also is needed. Caps are a favorite DOE technology, but they are not a favorite technology of EPA or the public. Their long-term effectiveness is unknown, and they have limited effectiveness when contamination is located in the deep vadose zone. More work is needed on assessing the effectiveness of capping technologies as well as other technologies to characterize and stabilize waste in the deep vadose zone.

Conceptual model development for groundwater is a technical challenge across DOE sites. These models work well when the subsurface is homogeneous and flow is by matrix processes. The models work poorly for complex sites like Idaho and many other DOE sites where fracture flow dominates.

Technology development to address these issues is important, and EM has time to carry out R&D to address many of its problems. EPA advocates the use of life-cycle baselines that include technology development activities. Having an agreed-upon baseline that includes technology development activities can provide a rallying point for regulators and stakeholders.

There is a tendency at DOE sites and national laboratories to “reinvent the wheel,” and not enough emphasis is placed on information sharing and using already available tools in site cleanup. EM needs to be more thoughtful about when to delay cleanup to allow time for technology development and when to move forward. Leaving technology development to cleanup contractors is not appropriate: There is not sufficient continuity for long-term work, and parochial business interests can interfere. EM should have the leadership responsibility for funding and managing its R&D activities.

Panelist Kathleen Trever (Coordinator, State of Idaho, Idaho National Laboratory Oversight Office) noted that DOE-EM and regulators were working together to make a difference at the site but that the long time frames to solve some of the cleanup challenges do not match up well with institutional and political realities. Frequent changes in administrations and DOE management make it difficult to sustain support for technology development over 10-year time frames. A good example of this difficulty was the development of a roadmap for the vadose zone. A great deal of effort was put into developing this roadmap, but then EM’s priorities shifted and the roadmap was never implemented.

Buried waste retrieval and D&D of facilities will be carried out at the site over the next 10 years. These D&D activities will place workers in high-hazard environments. DOE-EM might ask workers about their safety concerns and use their answers to focus its R&D work.

Stabilization of residual contamination is another important cleanup challenge. Evaluating the long-term performance of caps and grout is a specific technology challenge. Some work is already being carried out on grout performance, but additional work is needed to ensure that this stabilization technology works as anticipated.

R&D can help ensure that the nation does not repeat the waste and environmental management problems of the past. This is especially important if society continues to rely on nuclear power and the United States decides to reprocess spent fuel. DOE’s biggest cleanup challenges revolve around the tank farms and wastes generated from previous reprocessing activities.

Questions and Discussion

An audience member commented that the impediments to introducing the steam reforming technology (for immobilization of sodium-bearing waste) at the site were "nontechnical," and he asked about the status of that technology. Mr. Van Camp noted that steam reforming came out on top after an evaluation of several technologies. The technology selection process was identified by the Defense Nuclear Facilities Safety Board as a model project for DOE. Ms. Trever noted that a pilot plant in Colorado helped sort through some of the technical issues associated with this technology. Previous commercial experience with the technology was also helpful for getting regulatory approvals. DOE management was opposed to vitrification at the Idaho Site because of its costs and problems with implementation at the Savannah River and Hanford sites. Mr. Van Camp noted that the Savannah River Site is using the Colorado pilot plant for testing another waste form.

Another audience member asked EPA and DOE panelists why their cleanup priorities were different. Mr. Van Camp noted that DOE technology needs for buried waste cleanup ranked below other cleanup needs. Mr. Ceto commented that both DOE and EPA were concerned about vadose zone contamination. He also noted that the management of buried waste in the Subsurface Disposal Area being conducted under CERCLA (Comprehensive Environmental Response, Compensation and Liability Act) is of interest to both EPA and the state, but the state works most closely with DOE on spent fuel management issues.

The panel was asked to comment on the risks from transuranic waste in piping beneath a facility at the site and whether it was contributing to contamination of the vadose zone. Ms. Trever responded that the extent of contamination or the risks are presently unknown.

Mr. Ceto was asked to elaborate on his comments about the vadose zone. He responded that his major concerns were uncertainties in characterization and lack of technologies to retrieve or stabilize contamination. Ms. Trever commented that another concern was how contamination moves in the vadose zone and what methods were available for remediating it.

An audience member asked Mr. Van Camp how EM planned to dispose of classified wastes at the site. Mr. Van Camp noted that special nuclear materials are being disposed of in several ways:

Some are being sent to the Nevada Test Site or Oak Ridge, and some waste was being disposed of onsite.

Another audience member noted that in recent congressional testimony Assistant Secretary Rispoli estimated that remediation of the burial grounds at the Idaho Site could cost $250 million per acre. He asked the panel to comment on opportunities for removing or stabilizing this buried waste. Mr. Van Camp responded that DOE and regulators are currently in discussions about how much waste will be retrieved. Mr. Ceto commented that there is a preference in CERCLA for waste treatment and permanent remedies. Ms. Trever noted that some combination of retrieval, stabilization, and caps was likely to be needed. She reiterated her earlier comment about the importance of assessing and addressing worker safety concerns in technology development programs.

Mr. Ceto also commented that buried waste is a “very big issue” across the DOE complex and that in situ stabilization technologies are ripe for research at all sites. He noted that the public has a hard time understanding the difference between pre-1970 versus post-1970 wastes, which have the same characteristics but are managed differently (land disposal was used for pre-1970 waste, but deep geological disposal is required for post-1970 waste). It is important to explain to the public why it is acceptable to leave waste behind regardless of its origin. The public is interested in waste consolidation under small caps.

There was an exchange between an audience member and the panel over the use of monitoring to improve subsurface models. Mr. Van Camp noted that there are a large number of monitoring wells at the Idaho Site and that data from these wells are used to assess and improve site models.

Finally, an audience member commented that subsurface R&D was being done by the Office of Science and other federal agencies and asked Mr. Van Camp how the site accesses this work. Mr. Van Camp noted that the sites work through Deputy Assistant Secretary Gilbertson’s office to access work at other offices. Cleanup contractors also have mechanisms to access this work. Ms. Trever commented that site access to this work is “hit or miss.” The Idaho National Laboratory has a vadose zone research program, but the program is not fully operational. It is not clear whether or how information from this and other programs is factored into site cleanup decisions.

Oak Ridge Reservation

The Oak Ridge Reservation is a multimission site. DOE’s Office of Science manages the Oak Ridge Office, which includes the Oak

Ridge National Laboratory (ORNL) and East Tennessee Technology Park (ETTP). The National Nuclear Security Administration manages the Y-12 National Security Complex. DOE's Office of Environmental Management is responsible for remediation at ETTP (including D&D of the former gaseous diffusion complex) and for cleanup of the watersheds in which ORNL, Y-12, and associated waste disposal facilities are located. ORNL and Y-12 are undergoing modernization and construction of new facilities, and Y-12 is undergoing a footprint reduction. At these sites there are many surplus and dilapidated buildings that are not yet within EM's scope of work but that need to be demolished before soil and groundwater cleanup can be completed.

Panelist David Adler (Environmental Management Program Manager, DOE Oak Ridge Office) opened the discussion by reviewing the site's cleanup challenges and technology needs, which he summarized as follows:

1. Deactivation and decontamination of facilities:
   - Beryllium characterization and monitoring.
   - Characterization, decontamination, and demolition.
2. Groundwater and soil cleanup:
   - Characterization and remediation of mercury.
   - Cleanup of groundwater plumes.
   - Preventing the release of contaminants during deactivation and decontamination.
   - Performance assessment, monitoring, and verification to support closure.

The Oak Ridge Reservation contains hundreds of facilities that will eventually need to be deactivated and decommissioned. At present EM is responsible for only a subset of these facilities. Some buildings are in poor structural condition, many contain worker hazards (e.g., high radiation fields [>100 rads/hour], chemical and biological contamination), and some are located near occupied buildings or populated areas. In some facilities, equipment, piping, and duct work contain pyrophoric and other hazardous materials (e.g., mercury and lithium dioxide). Many of these facilities have already been deactivated and do not have water or process waste lines. At present EM is spending about $10 million per year for surveillance of facilities at the site and may have to spend additional monies just to make the facilities safe enough for workers to decommission.

Beryllium was used extensively at the Oak Ridge Site and is present in numerous facilities that are slated to be demolished. It is a significant inhalation hazard, causing respiratory inflammation at low concentrations and permanent lung damage at high concentrations. Some workers are especially sensitive to beryllium. Current techniques for measuring beryllium in air involve sampling for laboratory analysis, which can take days to produce results. The site needs real-time, field-deployable beryllium monitors that provide accurate measurements at picogram levels. Such monitors do not exist at present, and their development is an important site technology need.

The site has other technology needs to improve the safety and cost effectiveness of D&D activities at the site:

- Remote characterization technologies and technical approaches for cleanup of highly contaminated, deteriorated structures that have confined spaces or are otherwise unsafe for human entry. In particular, sensors are needed for making accurate, real-time measurements in extremely high radiation fields. There may be technologies outside DOE that could be applied at the site.
- Decontamination technologies and tools, including cost-effective remote decontamination processes and robotics technologies; dry decontamination technologies that can be used to remove high levels of contamination with minimal secondary wastes; decision tools for determining optimal decontamination approaches; and technologies and approaches for removal of equipment containing high levels of radioactive and hazardous contamination.
- Demolition technologies and tools for understanding, predicting, and preventing the release of contaminants during facility demolition; technologies and approaches for real-time monitoring during facility demolition; and technologies and approaches for demolition of highly contaminated structures near operating facilities and populated areas. The demolition of tall (>100 feet [30 meters]), highly contaminated off-gas stacks is a good example of the site's demolition challenges. These stacks are too contaminated internally and too close to operating facilities to be knocked down. Dismantling them brick by brick would be expensive and potentially hazardous to workers.

Groundwater and soil contamination are other cleanup challenges at the site. Large quantities of mercury were released to the environment during facility operations, and small amounts are still being released at present. Mercury has been found at depths exceeding 20 feet [6 meters] at the Y-12 facility and is present in water, in some cases above drinking water standards. Mercury has also been found in sediments, the floodplain, and fish in the Upper East Fork Poplar Creek. Cleanup of mercury using traditional methods (excavating and dredging), although very effective, is expensive and time consuming, as are conventional techniques for mercury sampling. Current sampling techniques can also miss hot spots.

The site has identified the following needs for characterizing and remediating mercury contamination at the site:

- Identification of mercury sources, physical and chemical forms, and transport mechanisms and pathways.
- Identification and evaluation of technologies to reduce methylmercury concentrations in fish.
- Effective systems for treating mercury-contaminated groundwater.
- Identification and evaluation of in situ approaches for treating mercury in soil.
- Evaluation of phytoremediation-based technologies for removing mercury from soil and water.
- Evaluation of the use of plants to monitor (e.g., using surface reflectivity measurements) mercury stability and bioavailability in the environment.

There is extensive contamination of groundwater beneath the industrial areas on the site with uranium and other metals, solvents, and exotic isotopes. The sources of contamination are not well known, and the complex subsurface geology makes it difficult to identify flow paths. Natural attenuation through microbial degradation could be a potentially important tool for remediating organic groundwater contaminants (e.g., trichloroethylene plumes) at the site.

The site has identified contaminant characterization, evaluation, monitoring, and enhancing natural attenuation as important technical needs. There is also a need for decision tools for remediation of contamination in fractured rock and low-permeability soils that are characteristic of the site. “When to remediate and when to wait” is an important technical issue for the site.

The site plans to use caps and other engineered barriers to close burial pits and other contaminated areas. The estimated cost of long-term monitoring of these closures is in the hundreds of millions of dollars. Long-term monitoring is an important technology need, and monitoring approaches at the site could be improved.

Panelist Susan Gawarecki (Executive Director, Oak Ridge Reservation Local Oversight Committee, Inc.) noted that the major cleanup challenges identified by the Oak Ridge Oversight Committee are deactivation and decommissioning, soil and groundwater contamination, and long-term stewardship. These priorities were similar to the list presented by David Adler.

There are many impediments to the use of new technologies at the site. EM's intolerance of technology failures is an example of such a challenge. Technologies do not always work well the first time, as exemplified by the in situ vitrification demonstration (the first demonstration of this technology at the site resulted in unexpected ground motion from an underground steam explosion).

Contractor incentives can be another impediment: Cleanup contractors who are incentivized to reduce costs will prefer "tried and true" technologies and will resist the use of untried new technologies. The change of contracting approach at the site (from a reservation-wide management and operation contractor to a management and integrating contractor) has also been an impediment because it has severed the direct ties that existed between the cleanup program and ORNL.

Several groups at the site are promoting the use of new technologies. The stakeholder-driven End Use Working Group has developed a community consensus on "end uses" of land and facilities at the site, which in turn has helped accelerate cleanup. The Long-Term Stewardship Working Group (under the Oak Ridge Site Specific Advisory Board) is promoting long-term surveillance of cleanup remedies and documentation of remediation actions. The Office of Science sponsors the Field Research Center at the site which is researching and developing new groundwater remediation technologies.

Outside organizations are potentially good sources of technologies for the site's cleanup program. For example, the Department of Defense might be a source of technologies for remediating shock-sensitive materials disposed of in burial pits at the site. Also, EPA has a technology innovation website that could be useful, and other industries (surveying, mining, petroleum) also might have useful technologies.

Dr. Gawarecki cited the cleanup of the site's gunite tanks as a good example of how innovative technologies can be used to tackle difficult cleanup problems. Panelist Phil McGinnis (Program Manager, Oak Ridge National Laboratory) elaborated that the tanks were used as a test bed for over 100 technologies related to waste retrieval, pretreatment, and robotics. The use of these technologies allowed the tanks to be emptied and grouted over a decade ahead of schedule. Mr. McGinnis also commented that the big driver for the cleanup program over the next decade was D&D of facilities. Many facilities have not had proper maintenance and surveillance and will be very expensive to decontaminate and demolish. The technical challenges include underwater cutting and demolition and approaches for demolishing large contaminated facilities without spreading contamination. New containment technologies will be needed to enable this demolition work. Many of the needed technologies have been identified in the current EM cleanup technology roadmap, but the site needs tools now to optimize surveillance and maintenance to lower its facility cleanup costs.

Remediation of contaminated groundwater is another important cleanup challenge at the site. Monitored natural attenuation is a potentially good way to perform low-cost groundwater cleanup. The site has a strong science program (Natural and Attenuated Bioremediation Research Program, which is sponsored by the Office of Science and is now part of the Field Research Center) that can help promote the development of such approaches.

Panelist Dale Rector (Assistant Director, Emergency Services Coordinator, Tennessee Department of Environment and Conservation, DOE Oversight Division) reminded the audience that EM is undertaking accelerated cleanup of the Oak Ridge Reservation and plans to complete that process by 2015. Only waste management and monitoring will remain after site cleanup is completed.

He commented that the site has many technical needs. There is a need for better quality assurance and quality control for characterization of waste during facility cleanup. The site is geologically complex (a fractured karst system), but current site groundwater models do not account for this complexity. Consequently, soil and groundwater remediation plans that are based on such models may not be realistic.

The Y-12 site has received funding for a bioremediation project in 2007, but bioremediation may not be a long-term solution because reactions are reversible once treatment stops. The State Regulators Consensus Working Group has prepared a report about the use of bioremediation. DOE should use state regulators as partners in its bioremediation projects.

Questions and Discussion

An audience member asked whether facilities that enter the EM cleanup program in the future would increase the scope of the site's cleanup challenges. Mr. Adler responded that D&D of hot cells would be an added technical challenge.

Another audience member asked what kinds of remote handling technologies are needed for facility cleanup and also what the technical gaps are for demolishing facilities. Mr. Adler responded that effective dry decontamination technologies that can be applied remotely would be particularly useful. Some of these technologies may already exist and just need to be transferred to site applications. The site also needs systems to rapidly scan thousands of miles of piping from the gaseous diffusion plants that contain deposits of uranium.

Dr. Gawarecki noted that workers cannot manually remove material from the gaseous diffusion plant because the structure is unstable. At present, workers are only going after high-risk objects. Also, sorting of materials removed from facilities is a challenge. It is important to avoid commingling lightly contaminated materials with more heavily contaminated materials, especially those containing uranium and technetium.

An audience member asked about technology “lessons learned” from cleanup of the gunite tanks at the site. Mr. McGinnis commented that the tanks were used as a test bed to evaluate scabbling, robotic, and bottom scraping technologies and also skid-mounted technologies for cesium removal. Dr. Gawarecki credited the DOE-EM program manager for the success of the tank cleanup effort. An audience member who is familiar with this cleanup effort credited regulatory pressures and escalating cleanup schedules for helping promote the use of these new technologies on the tanks.

Another audience member commented about public concerns that cleanup of contaminated facilities could result in the disposal of contaminated materials in landfills or their recycling to the marketplace. She stated that there should be no uncontrolled releases of contaminated materials from site cleanup. Dr. Gawarecki commented that she was satisfied that recycling of decontaminated nickel would not pose any risk to the public.

A federal regulator in the audience asked what the state expected from performance monitoring at the site over both the short and long term. Mr. Rector responded that over the short term, the state was promoting the use of automated equipment such as air monitors. Over the longer term, he noted that there are about 40 million pounds (18 million kilograms) of uranium buried in trenches at the site that will require some kind of monitoring forever.

Hanford Site

Hanford is managed by DOE-EM, and cleanup activities are currently being conducted by two different EM organizations: The Office of River Protection, which was created by Congress, is responsible for retrieving, processing, and immobilizing high-level waste, closing tanks, and remediating or stabilizing subsurface contamination associated with tank leaks. The Richland Field Office is responsible for the remainder of site cleanup, including soil, groundwater, and facility cleanup.

Panelist John Morse (Senior Technical Advisor for Soil and Ground Water Remediation, DOE Richland Office) opened the discussion by reviewing the Richland Field Office's cleanup challenges and technology needs. He noted that the office has three cleanup priorities:

1. Contaminants that have reached or have the potential to reach the Columbia River.
2. Contaminants that have the potential to migrate through the vadose zone to groundwater.
3. D&D of site facilities.

Radioactive and chemical contamination exists at over 1500 locations on the site and in about 80 square miles (200 square kilometers) of groundwater. Some groundwater contamination has reached the Columbia River. The groundwater contaminants of primary concern include carbon tetrachloride, chromium, strontium, technetium, and uranium, the latter of which has been found to be more mobile in some environments than anticipated.

The site is evaluating and deploying several technologies to sequester strontium and uranium contaminants. For example, near the Columbia River, an apatite barrier is being used to sequester strontium, and polyphosphate is being used to sequester uranium. In addition, phytoremediation is being evaluated to remove strontium from the shallow soil (vadoze zone), and in situ reductive techniques are being tested for reducing chromium (VI) to chromium (III).

DOE's Office of Science recently awarded a five-year grant to scientists at Pacific Northwest National Laboratory to develop an improved understanding of uranium geochemistry and also to develop improved fate and transport analysis methods. There is a 5-square-mile [13-square-kilometer] carbon tetrachloride groundwater plume beneath the Central Plateau in the 200 West Area that is the result of past discharges of an estimated 500 to 1000 metric tons of carbon tetrachloride, a significant portion of which is believed to still be in the vadose zone. A standard approach (pump and treat) is currently being used to contain this plume. More effective technologies are needed.

Although groundwater contamination at the site is extensive, most subsurface contaminants are being held up in the vadose zone, especially beneath the Central Plateau. Some of these contaminants (e.g., uranium and technetium) are migrating toward groundwater.

Locating, characterizing, and remediating or stabilizing this contamination are important technical challenges.

The Richland Field Office has already begun to deactivate and decommission production reactors and fuel fabrication facilities and laboratories along the Columbia River. There are large fuel processing facilities (canyons) and waste management facilities on the Central Plateau that will be the subjects of future cleanup decisions. The Central Plateau is heavily contaminated and will require long-term stewardship even after facility cleanup is completed.

Panelist Steve Wiegman (Senior Technical Advisor, DOE Office of River Protection) described the Office of River Protection's cleanup challenges. There are 53 million gallons (200 million liters) of high-level waste and 177 underground tanks on the Central Plateau at the site. The tanks, which have carbon steel shells, have exceeded their design lives, and some single-containment (i.e., single-shell) tanks have leaked waste into the subsurface. EM is moving the waste from these tanks into newer double-containment (i.e., double-shell) tanks that have not leaked any waste.

At present the site has no capabilities for treating its high-level waste, but the WTP (Waste Treatment Plant) is being constructed on the Central Plateau for this purpose. When completed, it will be the largest chemical treatment plant in the world. Completion of the WTP has been delayed because of seismic concerns and other technical issues. There will be more extended storage of waste in aging tanks than anticipated because of this delay.

The Office of River Protection has identified the following cleanup challenges:

1. Minimize the impacts of WTP delays on emptying the tanks.
2. Develop additional methods to immobilize low-activity waste streams from the WTP. The site is investigating several immobilization technologies, including bulk vitrification and steam reforming.
3. Develop simpler tank-side processes for solid-liquid separations during tank waste retrieval operations.
4. Develop alternate ways of dissolving waste in the tanks (e.g., fractional crystallization) to enable in-tank separation of some chemical components.
5. Develop improved tank waste retrieval methods. Hanford has a cold test facility that is used for realistic testing of waste retrieval technologies. The delay in completing the WTP provides additional time to develop and test new technologies.
6. Improve waste processing efficiencies and waste loading in glass.

7. Develop improved methods to characterize waste and contaminated equipment, the latter to support tank farm closure. There are hundreds of miles of piping and other equipment that must be characterized.
8. Develop interim technologies to reduce surface water infiltration in the tank farms. Infiltration around the tanks can drive subsurface contaminants deeper into the vadose zone and groundwater.
9. Develop methods to characterize and remediate the vadose zone beneath the tanks.

Panelist Nancy Uziemblo (Environmental Specialist, Washington State Department of Ecology, Nuclear Waste Program) noted that the site has many cleanup challenges: groundwater, soil, vadose zone, tanks, buildings, waste sites, and cribs. More progress has been made in site cleanup in the past five years than at any time previously, largely in response to regulatory pressures. It is important to the state of Washington that funding for site cleanup continues so that this progress can be sustained.

Put simply, the state's goal is cleanup and closure: The state wants DOE to empty each tank and then close it. The goal is to remove as much waste as possible from these tanks. Regulators need to be involved early in the planning for tank closure, and it is important that they and EM pursue the same goals.

Innovative technologies will be needed to complete site cleanup. However, technology development should not take funding away from site cleanup activities. There needs to be a balance between looking for "best" solutions versus proceeding with currently available and adequate technologies and approaches.

Panelist Nick Ceto (Program Manager, Office of Environmental Cleanup, Hanford/INL Project Office, EPA) characterized the greatest cleanup challenge at the site as "vadose zone, vadose zone, vadose zone." Most of the radioactive and hazardous materials that were released into the ground at the site are now in the vadose zone. Uranium and technetium in the vadose zone are of particular concern because they are mobile. Remediating (e.g., flush and collect) or stabilizing contamination in the vadose zone, especially in the deep vadose zone, is a difficult technical challenge. Examples of specific cleanup challenges include the BC Cribs on the Central Plateau, where the magnitude of intentional discharges of contaminants exceeded the leaks from the tanks, and the 618-10/11 burial grounds located north of the 300 Area, which contain intensely radioactive transuranic waste, some of which has contaminated the local groundwater.

The site has several other cleanup challenges: tank waste retrieval, which has the potential to exacerbate vadose zone and groundwater contamination if not done carefully; cleanout and closure of the K-Basins in the 100 Area; and disposition of transuranic waste. The definition of transuranic waste is not risk based (the definition is based on concentrations and half-lives), and DOE has the option of petitioning EPA if it wishes to change its approach for managing this waste for specific cleanup projects.

Panelist Dirk Dunning (Program Coordinator, Oregon Office of Energy, Nuclear Safety Division) highlighted plutonium migration in the vadose zone as a critical problem at the site. Plutonium beneath the Plutonium Finishing Plant on the Central Plateau is moving in ways that are not predicted by current site models. Plutonium beneath the Z Cribs near the plant has migrated to depths between 20 and 100 meters (65 and 330 feet) and is moving toward groundwater. Remediating or stabilizing this material will be difficult because it is so deep. Advances in understanding of plutonium geochemistry in the past seven to eight years suggest that plutonium bonds to some soil components and is slightly soluble in subsurface environments.

The geology beneath the Hanford Site is complex, containing permeable horizontal sedimentary layers, less permeable vertical clay dikes that cut across these layers, and other lateral and vertical discontinuities. This complexity affects the movement of subsurface contamination. Contaminants migrate laterally within the sediment layers and then move vertically when they reach the dikes. Current site models are totally inadequate for predicting this behavior and therefore cannot be used for estimating risk. New models populated with field data are needed—and needed quickly.

The site also requires new decision tools for high-level waste cleanup. In particular, the site needs tools that can help EM make decisions about double-shell tank maintenance and capacity management so that the tanks will be available when the WTP is operating.

Panelist Susan Leckband (Chair, Hanford Advisory Board) focused her comments on sharing information and implementing technology in the cleanup program. Many DOE sites have common problems, but the site personnel do not get together to share concerns. The loss of funding for the Technical Focus Areas that provided cross-site communication is partly to blame for this problem. DOE-EM should be a facilitator of information sharing rather than a gatekeeper.

EM also needs to develop a process for continuous implementation and sharing of new technologies. The Hanford Advisory Board has developed a flowsheet for the Central Plateau that identifies the entry points for new technologies during the cleanup process. The board is working on a similar flowsheet for groundwater cleanup.

Panelist Terri Stewart (Initiative Lead for Environmental Biomarkers, Battelle Pacific Northwest National Laboratory) focused her comments on soil and groundwater cleanup challenges at the site. Conceptual model development should be at the top of the list of science and technology gaps in the workshop discussion paper. At the Hanford Site, conceptual model development is needed to promote better understanding of contaminant behavior near the Columbia River and beneath cribs and tank farms on the Central Plateau where contamination enters the subsurface flow system. This improved understanding leads to improved remediation, especially cost-effective in situ remediation.

Hanford has had some success in understanding contaminant (especially cesium, strontium, uranium, and technetium) behavior beneath the tank farms because of an EM-funded research project at Pacific Northwest National Laboratory that engaged scientists from across the United States. The project was successful for several reasons: It involved good researchers; it combined basic and applied research; it used “translators” who were able to work with the researchers and cleanup contractors to communicate needs and results in meaningful ways; and the researchers had access to site- and field-relevant samples. This project produced 140 publications and provided important insights into key processes that control contaminant movement in the subsurface.

The site would benefit from additional research on how natural subsurface systems work and how to take advantage of those systems to stabilize and immobilize contaminants. The site also needs sampling and characterization tools that provide volumetric information to support conceptual model development and postclosure monitoring. Postclosure monitoring is at least three decades away, so there is still time to develop the necessary knowledge and technologies. However, factoring postclosure concepts into current activities is important to ensure that a life-cycle perspective drives today’s decisions.

Dr. Stewart concluded her remarks by asking, “What should be the mission of science on a life-cycle basis in the cleanup program?” She observed that to be effective, science and technology development should not be driven by short-term needs alone.

Panelist Roy Gephart (Geohydrologist, Battelle Pacific Northwest National Laboratory) focused his comments on high-level waste cleanup challenges at the site. The Hanford Site holds 60 percent by volume and 40 percent by radioactivity of DOE’s nationwide inventory of high-level waste. There are 89 different waste composition "envelopes" that the WTP will eventually need to process. DOE knows what is in the tanks in a broad sense but lacks detailed information. Completion of the WTP has been delayed until 2018—30 years after the Tri-Party Agreement was signed—which provides adequate time for a well-considered science and technology program focused on waste characterization through processing.

There are four major factors that will determine schedule and life-cycle costs for EM's high-level waste program at the Hanford Site: waste volume to be processed, waste form loading, waste form predictability and consistency, and facility operational effectiveness. Controlling life-cycle costs is a key decision driver when carrying out short- and long-term science and technology investments. Examples of specific technical challenges include the following:

- Predicting non-newtonian fluid dynamics in waste processing, especially when particles are introduced (e.g., settling velocities, slurry mobilization, turbulence, scaling, and filtering).
- Understanding the chemistry of multiphase, high-salt systems during extended storage and processing and its effects on tank corrosion, gas generation, and transfer line plugging.
- Understanding the chemistry of the liquid-glass transition to help predict the properties of glass melts. Particular technical challenges are predicting the properties of glass melts made from composition data alone and from the bismuth phosphate waste streams.

There is great value for predicting waste formulations, waste loadings, and melter operations by developing a sound scientific understanding of these issues instead of relying solely on empirical knowledge.

Mr. Gephart ended his remarks by observing that none of this science will be done without the continuity and retention of an experienced scientific staff. He suggested that DOE needs to demonstrate a sustained commitment to funding research programs so as to maintain a qualified scientific staff to support the growing science and technology needs of DOE's tank cleanup mission.

Questions and Discussion

A regulator in the audience asked about the performance requirements for containment monitoring and what strategies were needed to carry out such monitoring. Mr. Ceto commented that monitoring requirements were site specific. Under CERCLA, monitoring performance goals are established up front. Mr. Weigman noted that EM has conducted a performance assessment for in-place disposal of the emptied single-shell tanks. This has helped EM think about how to monitor tank closures. The site is also examining electrical methods to monitor for tank leaks during waste retrieval. If tanks can be cleaned out thoroughly, the long-term risks shift to the vadose zone (from the contaminants discharged from past tank operations or resulting from tank leaks).

An audience member commented on several issues raised by the panelists. He observed that there is no pilot facility for the WTP at Hanford, even though the DWPF pilot facility at Savannah River was considered a success. A pilot facility that was able to reduce the required length of WTP operations, even by a small amount, could easily pay for itself. He also suggested that the EM would benefit from having core expertise in fluid dynamics to help deal with subsurface model complexities, hydrothermal processing (e.g., for steam reforming) to widen the range of waste processing and waste form choices, and multidisciplinary optimization under uncertainty to help manage the tank farms and the WTP. He also commented that current subsurface models at the site combine sophisticated hydrodynamics with overly simplistic chemistry.

Mr. Dunning responded to the last point, noting that the U.S. Geological Survey is using multiple constructs for system models. Mr. Wiegman noted that model uncertainties increase as one moves from the waste form through the vadose zone and into the groundwater. Consequently, one needs to do a good job in making the waste form.

Another audience member asked the DOE panelists to comment on technology needs for spent nuclear fuel and excess nuclear materials, especially cesium and strontium capsules. Mr. Morse noted that technology needs were not significant relative to other site needs. DOE is using standard engineering for sludge cleanup in the K-Basins and is examining possible waste forms for dry storage of the cesium and strontium capsules. Eventually, those capsules and the site's spent fuel will be disposed of in a geological repository. Mr. Wiegman commented that EM may end up shipping the cesium and strontium capsules directly to the repository. An audience member noted that these discussions ignore the uncertainties for disposal of high-level waste. Mr. Wiegman commented that the site's high-level waste would eventually need to be disposed of in a repository, and the sooner that happened the better. But regardless of when that occurs, vitrification and some onsite storage will still be required.

An audience member asked the panel how to interpret the apparent lack of focus on D&D at Hanford: Are there no needs, or has the site not yet looked at them? He also commented that lessons learned from D&D of the U Plant at Hanford are potentially applicable to Savannah River, which has similar kinds of facilities. Mr. Morse commented that Hanford is now performing facility D&D. There are

3000 buildings at the site that present a range of difficulties. Some innovative technologies have been applied.

A regulator in the audience asked whether EM is using risk-based performance approaches for designing remedial actions, and he suggested that there should be multiagency efforts to establish such approaches. He also asked how EM handles knowledge management so that project managers can take advantage of past experience. Mr. Ceto commented that risk is an important consideration in CERCLA cleanups and that removal actions can be used for high-risk problems.

An audience member asked if Hanford was confident that it had the necessary barrier technologies it needed for site closures. Mr. Morse responded that the site has an active program on barriers and continues to collect data from field lysimeters and test beds like the Hanford Cap. The site has accumulated 10 to 12 years of data. The site is a year away from emplacing its first barrier, which will be monitored. Mr. Dunning observed that subsurface heterogeneity at the site complicates the use of barriers, especially for contaminants in the deep vadose zone. The ratio of lateral to vertical transport in the subsurface of the Hanford Site is 1000:1 because of the horizontal layering and vertical dikes. This makes it difficult to estimate barrier "shadow zones" in the subsurface. Assuring long-term barrier performance is also a challenge: The Collins Ranch barrier[5] was expected to last for 500 years, but it is failing and will need to be replaced in about 20 years. Mr. Gephart observed that 60 percent of solid waste at the site is pre-1970 waste. What to do with that waste is a "sleeping dog issue" because of its mixture of transuranic and nontransuranic waste. Mr. Dunning noted that this pre-1970 waste contains a large amount of plutonium.

PROMOTING THE EFFECTIVE USE OF SCIENCE AND TECHNOLOGY

For its final session the workshop organizing committee invited presentations on promoting the effective use of science and technology in the DOE-EM cleanup program. David Maloney (Director, Technology—Nuclear Group, CH2M Hill) provided a cleanup contractor's perspective, and David Kosson (Chair, Department of Civil and Environmental Engineering, Vanderbilt University) and Chuck Powers (Professor, Department of Civil and Environmental Engineering, Vanderbilt University) provided

[5] Collins Ranch is a Uranium Mill Tailings Remedial Action Project disposal cell near Lakeview, Oregon.

perspectives from CRESP (Comprehensive Risk Evaluation with Stakeholder Participation).

Perspectives from a Site Cleanup Contractor

Dr. Maloney described technology program "lessons learned" on the development and use of new technologies in cleanup of the Rocky Flats Site, a 6000-acre (24-square-kilometer) weapons components production facility near Denver, Colorado. About 600 acres (2.4 square kilometers) of the site was industrialized. The site was shut down in 1989, and cleanup was completed in 2006. The site is now a wildlife refuge.

The original schedule and costs for closure of the Rock Flats Site were 2060/$37 billion. EM and the cleanup contractor (Kaiser Hill) were able to reduce the closure schedule and costs to 2010/$7 billion and later to 2006/$6 billion through contracting and technology innovations. Even though the site was closed on an accelerated schedule, the cleanup contractor, with EM support, was able to successfully incorporate new technologies into its cleanup activities. In fact, the closure schedule and cost targets could not have been met without the continuous improvements made possible through the development and use of new technologies.

Several factors were responsible for promoting the use of new technologies in site cleanup. Most notably, cleanup was carried out under a performance-based (rather than milestone-based) contract. Also, EM provided about $30 million in funding over eight years to address contractor-identified technology development needs and also encouraged the contractor to tap the expertise in EM's technology development organization. There was an estimated 30:1 return on this investment in terms of cost savings to the cleanup program.

Based on the Rocky Flats experiences, Dr. Maloney identified three factors that promote greater technology use and impacts in the cleanup program: risk-based planning, technology integration, and project integration. Risk-based planning must be carried out throughout the cleanup project using PRA (programmatic risk assessment). This is a probabilistic statistical method for estimating technology, schedule, and other risks in the baseline for a cleanup project. It is carried out at a detailed activity level (typically at Work Breakdown Structure levels 7, 8, and 9) and uses Monte Carlo techniques to develop a distribution of risk estimates. It can be used to identify at-risk activities and to help focus resources (and technology planning) on identified technology risks before they become actual problems.

Like PRA, technology development must be integrated throughout the entire cleanup project and must be carried out as a partnership between the contractor and DOE. Technology innovation must be built into project baselines (i.e., "prebaselined"), and the expectation of continuous technical improvement should be reflected in project costs and schedules.

Proactive planning for off-baseline technology alternatives should be pursued for activities that are identified as "high risk" by PRA; multiple technology pathways (i.e., incremental improvements to current baseline technologies and off-baseline technology development) should be investigated until the identified risks are under control, and on-ramps should be established to bring successful new technologies into the cleanup program. On ramps are especially important for long-duration and multi-component projects. The design and engineering of such projects should be able to accommodate new or improved technologies during their life cycles. This is more costly up front but less costly over a project's life.

Contracts and regulatory standards can promote or inhibit technology innovation. Contracts that promote innovation are performance based (rather than milestone based) and provide schedule and cost targets through project completion, transfer schedule control to contractors, and transfer of responsibility and risks for technology use to contractors. Contractors in turn may transfer some of this risk to subcontractors such as technology vendors. Many technology vendors are risk averse, so such risk transfer can sometimes be difficult. Cost sharing between contractors, vendors and DOE can be a way to overcome this aversion. National laboratories also act as contractors and can be incentivized by DOE to take risks.

Technology innovation is also promoted by performance-based (rather than technology-based) regulatory standards. In performance-based regulatory regimes, regulators in many cases are willing to consider the use of alternate technologies if credible performance bases can be established. However, cleanup contractors must take the initiative for requesting consideration of off-baseline approaches.

Finally, technology innovation can also be promoted through predictable funding mechanisms. These include "local banking" of funds for technology development at sites that are under the control of the technology program manager working with the line project manager and can be accessed without an extensive proposal process. These funds can be awarded as grants or as part of a cost-sharing arrangement depending on risk. There can also be a "fenced bank" that is reserved for technology development at the site and possibly retained by the contractor for additional technology development activities through project completion.

Questions and Discussion

In response to a general comment from an audience member, Dr. Maloney observed that under the performance-based completion contracts described previously, technology innovation is enhanced when DOE manages the contract rather than the contractor. Project managers, not DOE, should be responsible for determining the project's technology needs.

Another audience member asked Dr. Maloney to provide examples of innovative technologies that helped make the Rocky Flats cleanup program a success. Dr. Maloney identified three: a new technology to remove plutonium from surface-contaminated objects saved the project at least $105 million; the use of Standard Waste Boxes, which hold 10 times the volume of waste drums, and the use of a high-efficiency neutron counter (Super HENC) to assay the boxes, saved about $146 million; and implementation of passive reactive barriers at the site saved about $155 million in completion and stewardship costs.

A regulator in the audience commented on the importance of tying cleanup plans to land end uses and asked whether cost estimates for different end-use scenarios at Rocky Flats had been estimated. Dr. Maloney responded that he never saw comprehensive cost estimates for industrial versus residential versus wildlife refuge scenarios.

Another audience member asked Dr. Maloney to compare the contracting approach at Rocky Flats to those at Hanford and Idaho. Dr. Maloney responded that the Hanford contract had performance-based incentives but also contained milestones. It would have to be "opened up" to be fully effective. Idaho has a closure contract, but the necessary culture change in management had not yet been fully realized. An audience member commented that Hanford is currently using a technology-based approach. A performance-based approach would simplify environmental impact statements because only one case would need to be examined. Dr. Maloney commented that the Hanford Site has limited flexibility to consider alternatives because it has committed to making glass waste forms (for its tank wastes).

A DOE staff member from Hanford commented that Rocky Flats used hands-on approaches for D&D at the site. Such approaches would not translate to other sites with larger and more extensive facilities. Dr. Maloney noted that Rocky Flats used some remote control equipment, but even the hands-on approaches are difficult. Building 771 at Rocky Flats was characterized as the most dangerous building in the world before it was successfully taken down. It was easy in hindsight, but that was certainly not the case when the work was being planned and executed.

Perspectives from CRESP

Drs. Powers and Kosson briefly described three CRESP projects that provide some lessons learned on technology development and use in cleanup programs. The first was a project at Amchitka Island, Alaska, in which CRESP worked with affected groups (e.g., local Aleut populations) and regulators as an “integrating independent organization” to develop consensus on all of the technical factors relevant to site closure and monitoring of a site that had been used for three underground nuclear tests between 1965 and 1972.

The second CRESP project was a December 2006 workshop on cemetitious materials at the Savannah River Site in conjunction with Savannah River National Laboratory. The objectives of the workshop were, first, to develop a common understanding among DOE, regulators, site operators, researchers, and other stakeholders concerning the state of the science, current practices, and knowledge gaps, and second, to identify opportunities to improve the use of cementitious materials for waste management and reduce long-term uncertainties associated with their use.

The third CRESP project involved a merit review of the C-Tank Farm Closure Performance assessment at the Hanford Site. The objective of the review was to evaluate whether the performance assessment appropriately considered the processes that could result in future health impacts after tank farm closure and recommended improvements to the performance assessment to make it a more effective risk communications vehicle.

Several lessons learned from these projects were identified: process is as important as technology, and public involvement is essential to a credible process; cleanup project success requires an accepting public and persuaded regulators and DOE decision makers; and all of these require a carefully constructed, ongoing, iterative process of engagement. Developing an enduring trust with affected parties should be a central element of technology development and deployment programs.

CLOSING COMMENTS

Workshop organizing committee members Allen Croff and Carolyn Huntoon identified some key messages from the workshop discussions: There was generally good agreement among the workshop panelists on site cleanup challenges and R&D needs. These include the following needs, listed generally in order of decreasing importance:

- High-level waste and tank cleanup was a prominently identified cleanup challenge at Hanford, Idaho, and Savannah River; little or no relevant headquarters-directed R&D is being sponsored at national laboratories.
- Both soil and groundwater contamination are substantial problems at all four sites. Vadose zone contamination is an especially difficult problem at the western sites. There does not appear to be much vadose zone or groundwater R&D within EM.
- Deactivation and decommissioning: Specific needs include early planning for stabilization and R&D on remote handling, paying special attention to worker safety. Also, end-state identification continues to be a challenge.
- Buried waste: Specific R&D needs include balancing the extent of contaminant removal with the cost and the ecological impacts and also waste retrieval and stabilization.
- Spent nuclear fuel and excess nuclear materials stabilization and packaging.

R&D is also needed to better understand the long-term performance of engineered barriers such as caps and grout. Improving long-term monitoring effectiveness is another important R&D need, especially to support the transition of sites from the EM cleanup program to the Office of Legacy Management.

Several other general observations were offered:

1. Congress has expressed support of technology development but wants prioritization and removal of impediments to new technology deployment from the private sector. Such impediments include aversion to, and penalties for, technology risk taking by cleanup contractors, as well as the long lead times required for technology deployment.
2. EM senior management is also supportive of increased R&D investments.
3. The possible future transfer of additional sites and facilities to the EM cleanup program will likely lead to new R&D needs, although it is presently unclear what these might be.
4. The panelists identified examples of the successful application of new technologies in the cleanup program. Some also identified the continuing need for developing technology alternatives for high-risk cleanup problems and the need for cooperation across DOE sites.

5. There is a need to balance cleanup speed with completeness (i.e., "fast" cleanup versus "good" cleanup). Methods to help strike this balance are needed.

Workshop organizing committee Chair Ed Przybylowicz commented on EM's R&D management challenges. He observed that these challenges are not that different from large industrial organizations that have centrally funded and business-unit-funded technology development programs. The challenges include (1) creating a governance process to effectively manage technology development and sharing; (2) communicating technology needs, both internally (across sites) and externally (with Congress and the public); and (3) managing the development of high-risk technologies, including knowing when to cut off funding for technology development when a technology is no longer viable or needed.

Deputy Assistant Secretary Mark Gilberston was invited to offer closing comments. He noted that the future success of EM's technology development programs depended on the following factors:

- Improving knowledge management.
- Better sharing of ideas, concepts, and information on technology development. The EM program is more focused than previously. Cross-site activities and public communication need to be encouraged.
- Balancing basic and applied research and technology development. There is still an important role for new science within the EM cleanup program. How to rebuild the science program, either through expanded investments in the Office of Science or by other means, is an important challenge.
- Assuring continuity of funding for technology development.
- Tying technology development to cleanup baselines, especially to develop additional alternative technologies for high-risk baselines.

FUTURE PLANS

This workshop summary will be used by DOE to inform the development of its technology roadmap for Congress. It will also be used by the EM Roadmap Committee (Appendix D) to carry out Phase 2 of this study. The committee's final report, which will address the study task outlined in the Preface, is expected in the fall of 2008.

Appendix A

National Research Council Reports on Waste Management and Environmental Cleanup of the DOE Nuclear Weapons Complex

NRC. 2006b. Plans and Practices for Groundwater Protection at the Los Alamos National Laboratory: Interim Status Report. http://books.nap.edu/catalog.php?record_id=11781.

NRC. 2006a. Tank Waste Retrieval, Processing, and On-Site Disposal at Three Department of Energy Sites: Final Report. http://books.nap.edu/catalog.php?record_id=11618.

NRC. 2005d. Tank Wastes Planned for On-Site Disposal at Three Department of Energy Sites. http://books.nap.edu/catalog.php?record_id=11415.

NRC. 2005c. Improving the Characterization and Treatment of Radioactive Wastes for the Department of Energy's Accelerated Site Cleanup Program. http://books.nap.edu/catalog.php?record_id=11200.

NRC 2005b. Risk and Decisions about Disposition of Transuranic and High-Level Radioactive Waste. http://books.nap.edu/catalog.php?record_id=11223.

NRC. 2005a. Improving the Regulation and Management of Low-Activity Radioactive Wastes. http://books.nap.edu/catalog.php?record_id=11595.

NRC. 2004. Improving the Characterization Program for Contact-Handled Transuranic Waste Bound for the Waste Isolation Pilot Plant. http://books.nap.edu/catalog.php?record_id=10900.

NRC 2003d. Improving the Regulation and Management of Low Activity Radioactive Wastes: Current Regulations, Inventories, and Practices: Interim Report. http://books.nap.edu/catalog.php?record_id=10835.

NRC. 2003c. End Points for Spent Nuclear Fuel and High-Level Radioactive Waste in Russia and the United States. http://books.nap.edu/catalog.php?record_id=10667.

NRC. 2003b. Long-Term Stewardship of DOE Legacy Waste Sites: A Status Report. http://books.nap.edu/catalog.php?record_id=10703.

NRC. 2003a. Improving the Scientific Basis for Managing DOE's Excess Nuclear Materials and Spent Nuclear Fuel. http://books.nap.edu/catalog.php?record_id=10684.

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NRC. 2001h. Characterization of Remote-Handled Transuranic Waste for the Waste Isolation Pilot Plant. http://books.nap.edu/catalog.php?record_id=10244.

NRC. 2001g. A Strategic Vision for Department of Energy Environmental Quality Research and Development. http://books.nap.edu/catalog.php?record_id=10207.

NRC. 2001f. Science and Technology for Environmental Cleanup at Hanford. http://books.nap.edu/catalog.php?record_id=10220.

NRC. 2001e. Improving Operations and Long-Term Safety of the Waste Isolation Pilot Plant: Final Report. http://books.nap.edu/catalog.php?record_id=10143.

NRC. 2001d. Research Needs for High-Level Waste Stored in Tanks and Bins at U.S. Department of Energy Sites: Environmental Management Science Program. http://books.nap.edu/catalog.php?record_id=10191.

NRC. 2001c. Research Opportunities for Deactivating and Decommissioning Department of Energy Facilities. http://books.nap.edu/catalog.php?record_id=10184.

NRC. 2001b. Research and Development on a Salt Processing Alternative for High-Level Waste at the Savannah River Site. http://books.nap.edu/catalog.php?record_id=10170.

NRC. 2001a. Evaluation of Criteria for Selecting a Salt Processing Alternative for High-Level Waste at the Savannah River Site: Interim Report. http://books.nap.edu/catalog.php?record_id=10088.

NRC. 2000g. Long-Term Research Needs for Deactivation and Decommissioning at Department of Energy Sites: Interim Report. http://books.nap.edu/catalog.php?record_id=10004.

NRC. 2000f. Long-Term Research Needs for High-Level Waste at Department of Energy Sites: Interim Report. http://books.nap.edu/catalog.php?record_id=9992.

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NRC. 1999f. Interim Report of the Committee on Cesium Processing Alternatives for High-Level Waste at the Savannah River Site. http://books.nap.edu/catalog.php?record_id=9703.

NRC. 1999e. Decision Making in the U.S. Department of Energy's Environmental Management Office of Science and Technology. http://books.nap.edu/catalog.php?record_id=9448.

NRC. 1999d. The State of Development of Waste Forms for Mixed Wastes: U.S. Department of Energy's Office of Environmental Management. http://books.nap.edu/catalog.php?record_id=9459.

NRC. 1999c. Groundwater and Soil Cleanup: Improving Management of Persistent Contaminants. http://books.nap.edu/catalog.php?record_id=9615.

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Appendix B

Workshop Agenda

Development and Implementation of a Cleanup Technology Roadmap for DOE's Office of Environmental Management

March 13, 2007

Keck Center of the National Academies
500 Fifth Street, NW
Washington, DC

8:30 am	Welcome and introductions Meeting objectives and ground rules Ed Przybylowicz, Chair, Workshop Organizing Committee
8:45 am	Background on the DOE request for this workshop Mark Gilbertson, Deputy Assistant Secretary, Office of Engineering and Technology, DOE-EM
9:10 am	Congressional interest in a DOE-EM technology roadmap Terry Tyborowski, Staff Assistant, House Committee on Appropriations, Energy and Water Development Subcommittee

Panel Discussions on Science and Technology Gaps and Priorities for DOE Site Cleanup

9:30 am	Savannah River Site <u>Panelists</u> Pat Suggs, Chemical Engineer, DOE Savannah River Operations Office, Salt Processing Project Division John Marra, Associate Laboratory Director, Savannah River National Laboratory Shelly Sherritt, Federal Facilities Liaison, South Carolina Department of Health and Environmental Control David Wilson, Bureau Chief, South Carolina Department of Health and Environmental Control
10:00 am	Discussion period
10:30 am	Break

10:45 am	Idaho Site
	Panelists Scott Van Camp, Assistant Manager, DOE Idaho Operations Office Nick Ceto, Program Manager, Office of Environmental Cleanup, Hanford/Idaho National Laboratory Project Office, EPA Kathleen Trever, Coordinator, State of Idaho INL Oversight Office
11:20 am	Discussion period
11:50 am	Lunch
12:50 pm	Reconvene for announcements and afternoon session
12:55 pm	Oak Ridge Reservation
	Panelists David Adler, Environmental Management Program Director, DOE Oak Ridge Office Phil McGinnis, Program Manager, Oak Ridge National Laboratory Dale Rector, Assistant Director, Emergency Services Coordinator, Tennessee Department of Environment and Conservation, DOE Oversight Division Susan Gawarecki, Executive Director, Oak Ridge Reservation Local Oversight Committee, Inc.
1:25 pm	Discussion period
1:55 pm	Hanford Site
	Panelists John Morse, Senior Technical Advisor for Soil and Ground Water Remediation, DOE Richland Operations Office Steve Wiegman, Senior Technical Advisor, DOE Office of River Protection Roy Gephart, Geohydrologist, Battelle Pacific Northwest National Laboratory Terri Stewart, Initiative Lead for Environmental Biomarkers, Battelle Pacific Northwest National Laboratory Nick Ceto, Program Manager, Office of Environmental Cleanup, Hanford/Idaho National Laboratory Project Office, EPA Nancy Uziemblo, Environmental Specialist, Nuclear Waste Program, Washington State Department of Ecology Dirk Dunning, Program Coordinator, Oregon Office of Energy, Nuclear Safety Division, Oregon Department of Energy Susan Leckband, Chair, Hanford Advisory Board
2:45 pm	Discussion period
3:25 pm	Break

Promoting the Effective Use of Science and Technology in DOE Site Cleanup

3:45 pm	Perspectives from a site cleanup contractor David Maloney, Director, Technology—Nuclear Group, CH2M Hill
4:10 pm	Perspectives from CRESP David Kosson, Chair, and Chuck Powers, Professor, Department of Civil and Environmental Engineering, Vanderbilt University
4:25 pm	Discussion period
5:10 pm	Wrap-up: Important workshop messages

Workshop Organizing Committee

Ed Przybylowicz, Chair
Allen Croff
Carolyn Huntoon

Mark Gilbertson, Deputy Assistant Secretary, Office of Engineering and Technology, DOE-EM

5:40 pm Adjourn

Appendix C

Workshop Participants

Adler, David	U.S. Department of Energy, Oak Ridge Reservation
Antizzo, James	U.S. Department of Energy, Office of Environmental Management
Ceto, Nick	Office of Environmental Cleanup, Hanford/Idaho National Laboratory Project Office, EPA
Chang, Ker-Chi	U.S. Department of Energy, Office of Environmental Management
Chee, Texas	U.S. Department of Energy, Office of Environmental Management
Clark, Sue B.	Washington State University
Croff, Allen G.	Oak Ridge National Laboratory (retired)
Crowley, Kevin	Nuclear Radiation Studies Board, National Research Council
Culligan, Patricia J.	Columbia University
D'Arrigo, Diane	Nuclear Information and Resource Services
Detwiler, Rachel J.	Braun Intertec Corporation
Dunning, Dirk	Oregon Office of Energy, Nuclear Safety Division
Gawarecki, Susan	Oak Ridge Reservation Local Oversight Committee, Inc.
Gephart, Roy	Battelle Pacific Northwest National Laboratory
Gesell, Thomas F.	Idaho State University
Gilbertson, Mark	U.S. Department of Energy, Office of Environmental Management
Gombert, Dirk	Idaho National Laboratory
Halada, Gary P.	State University of New York at Stony Brook
Hamilton, Dennis	CH2M Hill
Hirsch, Roland F.	U.S. Department of Energy, Office of Science
Huntoon, Carolyn L.	CLH Associates, Inc.
Jantzen, Carol M.	Savannah River National Laboratory
Jobson, George	BGI, Inc.
Jostes, Rick	Nuclear Radiation Studies Board, National Research Council
Kosson, David	Vanderbilt University
Lahoda, Edward	Westinghouse Science and Technology Center
Leckband, Susan	Hanford Advisory Board
Lowenthal, Micah	Nuclear Radiation Studies Board, National Research Council
Maloney, David	CH2M Hill
Marra, John	Savannah River National Laboratory
McCallister, Russell	U.S. Department of Energy, Rocky Flats Field Office
McGinnis, Phil	Oak Ridge National Laboratory
McNamara, Mike	Washington Group International

Meyer, Alfred	Alliance for Nuclear Accountability
Morse, John	U.S. Department of Energy, Richland Field Office
Nicholson, Thomas	U.S. Nuclear Regulatory Commission
Oliver, Tom	STUDSVIK
Powers, Chuck	Vanderbilt University
Przybylowicz, Edwin	Eastman Kodak Company (retired)
Rampertaap, Artur	U.S. Department of Energy, Office of Environmental Management
Rector, Dale	Tennessee Department of Environment and Conservation
Ridge, A. Christianne	U.S. Nuclear Regulatory Commission
Sessler, Andrew M.	Lawrence Berkeley National Laboratory (retired)
Shafer, David S.	Desert Research Institute
Sherritt, Shelly	South Carolina Department of Health and Environmental Control
Smith, J. Leslie	University of British Columbia
Stewart, Terri	Battelle Pacific Northwest National Laboratory
Suggs, Patricia C.	U.S. Department of Energy, Savannah River Operations Office
Szilagyi, Andrew	U.S. Department of Energy, Office of D&D and Facility Engineering
Trever, Kathleen	Idaho Department of Environmental Quality
Tyborowski, Terry	House Committee on Appropriations, Energy and Water Development Subcommittee Staff
Uziemblo, Nancy	Washington State Department of Ecology
Van Camp, Scott	U.S. Department of Energy, Idaho Operations Office
Walton, Terry	Battelle Pacific Northwest National Laboratory
Wiegman, Steve	U.S. Department of Energy, Office of River Protection
Wiley, John	Nuclear Radiation Studies Board, National Research Council
Wilson, David	South Carolina Department of Health and Environmental Control
Wilson, Mike	Washington State Department of Ecology

Appendix D

Committee on Development and Implementation of a Cleanup Technology Roadmap

EDWIN P. PRZYBYLOWICZ, Chair, Eastman Kodak Company (retired), Webster, New York
ALLEN G. CROFF, Vice-Chair, Oak Ridge National Lab (retired), St. Augustine, Florida
LINDA M. ABRIOLA, Tufts University, Medford, Massachusetts (Resigned May 3, 2007)
RICHELLE M. ALLEN-KING, University at Buffalo, SUNY (After August 20, 2007)
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PATRICIA J. CULLIGAN, Columbia University, New York City, New York
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EDWARD LAHODA, Westinghouse Science and Technology Center, Pittsburgh, Pennsylvania
ROBIN ROGERS, University of Alabama, Tuscaloosa
GARY S. SAYLER, University of Tennessee, Knoxville, Tennessee
ANDREW M. SESSLER, Lawrence Berkeley National Laboratory (retired), Berkeley, California
J. LESLIE SMITH, University of British Columbia, Vancouver, Canada

Staff

KEVIN D. CROWLEY, Study Director (through April 25, 2007)
JOHN R. WILEY, Study Director (after April 25, 2007)
TONI GREENLEAF, Administrative Associate
MANDI M. BOYKIN, Senior Program Assistant

Appendix E

Acronyms

AEC	Atomic Energy Commission
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CRESP	Consortium for Risk Evaluation with Stakeholder Participation
D&D	Deactivation and Decommissioning
DOE	U.S. Department of Energy
DWPF	Defense Waste Processing Facility
EM	Office of Environmental Management (U.S. Department of Energy)
EMSP	Environmental Management Science Program
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
ETTP	East Tennessee Technology Park
HLW	high-level waste
LLW	low-level waste
NRC	National Research Council
ORNL	Oak Ridge National Laboratory
PRA	programmatic risk assessment
R&D	research and development
SWPF	Salt Waste Processing Facility
TRU	Transuranic
WIPP	Waste Isolation Pilot Plant
WTP	Waste Treatment Plant