Best Practices for Risk-Informed Decision Making Regarding Contaminated Sites: Summary of a Workshop Series

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BEST PRACTICES FOR RISK-INFORMED DECISION MAKING REGARDING CONTAMINATED SITES

SUMMARY OF A WORKSHOP SERIES

Dominic Brose, *Rapporteur*, Workshop 1
Jennifer A. Heimberg, *Rapporteur*, Workshop 2

Committee on Best Practices for Risk-Informed Remedy Selection,
Closure and Post-Closure of Contaminated Sites

Nuclear and Radiation Studies Board
Division on Earth and Life Studies

Science and Technology for Sustainability Program
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Preface

During the Second World War and the ensuing Cold War, the United States created a massive industrial complex to produce nuclear materials and weapons for national defense. This nuclear weapons complex encompassed 134 distinct sites in 31 states and 1 territory, with a total area of more than 2 million acres. Weapons production activities at these sites produced large quantities of radioactive and hazardous wastes that resulted in widespread groundwater and soil contamination. In 1989, Congress created the Office of Environmental Management (EM) within the Department of Energy (DOE) to clean up these sites. The cleanup program is planned to last until 2035 and cost upwards of $300 billion. Even after this program is completed, many sites will still require long-term stewardship and access restrictions to manage residual hazards. The cleanup program is proceeding under hundreds of legally enforceable agreements with federal and state regulatory agencies that specify cleanup remedies, endpoints, and schedules.

DOE anticipates that declining federal budgets for its cleanup program will push completion schedules out by as much as a decade. As a consequence, the agency is reviewing its cleanup baselines to identify more cost- and schedule-effective approaches. DOE is particularly interested in exploring approaches for incorporating sustainability principles into risk-informed decision making about these cleanups.

The National Research Council (NRC) was requested by DOE to organize two public workshops on best practices for risk-informed remedy selection, closure, and post-closure control of radioactive and chemically contaminated sites that present significant difficulty for remediation to site-specific restoration levels as defined by regulatory programs (e.g., unrestricted release). The workshop series aimed to explore best practices that promote effective, risk-informed decision making and future opportunities to improve remediation approaches and practices.

This report is the result of substantial effort and collaboration among several organizations and individuals. The workshop series was a collaborative effort between two organizations within the National Academy of Sciences of the NRC: the Science and Technology for Sustainability (STS) Program and the Nuclear and Radiation Studies Board (NRSB). Erin Wingo (NRSB) managed the logistics of both workshops and edited early versions of the report. Toni Greenleaf (NRSB) managed the financial reporting for the project. Finally, we wish to extend a sincere thanks to each member of the planning committee for his or her contributions in scoping, developing, and carrying out this project.

This report integrates the indivdual summaries of each workshop into a single volume. The planning committee's role was limited to planning and convening the workshop. The statements made are those of the rapporteurs and do not necessarily represent positions of the workshop participants as a whole, the planning committee, or the NRC.

Dominic A. Brose
Rapporteur, Workshop 1
Jennifer (Jenny) Heimberg
Rapporteur, Workshop 2

Acknowledgement of Reviewers

This report integrates the summaries of each workshop into a single volume. Each workshop summary, authored by separate rapporteurs, has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. Similarly, the integrated report was reviewed by a subset of the reviewers following the same process. The purpose of these independent reviews is to provide candid and critical comments that will assist the institution in making its published summary as sound as possible and to ensure that the summary meets institutional standards for clarity, objectivity, and responsiveness to the charge. The review comments and draft manuscript remain confidential to protect the integrity of the process.

We wish to thank the following individuals for their review of the workshop summaries:

Workshop 1:
  Rula Deeb, Geosyntec
  Mary Fox, Johns Hopkins University
  Alan Hecht, Environmental Protection Agency (EPA)
  Bruce Means, EPA (retired)
  Michael Truex, Pacific Northwest National Laboratory (PNNL)
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  David Maloney, CH2M HILL

Michael Truex, PNNL
John Tseng, Department of Energy (retired)
Integrated Final Report:
Michael Kavanaugh, Geosyntec
Bruce Means, EPA (retired)

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the content of the report, nor did not see the final draft of the workshop summary before its release. The review was overseen by Dr. Edwin Przybylowicz (NAE). Appointed by the NRC, he was responsible for making certain that an independent examinations of each summary and this final report were carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the authors and the institution.

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Introduction and Overview

The Department of Energy (DOE) Office of Environmental Management's (EM's) mission is the safe cleanup of sites associated with the government-led development of nuclear weapons and nuclear energy. Although many of these legacy sites have completed cleanup, the largest and most complex sites have not been fully remediated. The cleanup of EM's sites is proceeding under legally enforceable agreements with timelines for hundreds of milestones. EM is reviewing alternative approaches to increase effectiveness and improve cost-efficiencies of its cleanup activities, especially for sites that will have residual contamination when active cleanup is complete. To inform this review, EM asked the National Research Council (NRC) to convene two workshops to examine best practices for risk-informed remedy selection, closure, and post-closure control of radioactive and chemically contaminated sites that cannot be remediated for unrestricted release (see Appendix A for the statement of task).

The two workshops were organized by a four-member planning committee with extensive expertise in contaminated site cleanup and environmental decision-making practices. Biographical sketches of the committee members and staff are provided in Appendix B. The workshops brought together federal and state agency decision makers responsible for contaminated site cleanup and closure decisions, federal and state regulators, key stakeholders, and other technical experts to explore topics contained in the statement of task through presentations, case studies, and discussions.

The first workshop was held on October 30-31, 2013. It focused on examining holistic approaches for remediating sites with multiple contaminant sources and post-closure uses, and approaches for incorporating a sustainability framework into decision making regarding site remediation, closure, and post-closure control (bullets 1 and 4 of the statement of task; see Appendix A). The agenda for Workshop 1 can be found in Appendix C.[1] The workshop summary is Volume I of this report.

The second workshop was held on January 9-10, 2014. It focused on post-closure controls, assessment of long-term performance of site remedies (bullets 2 and 3 of the statement of task; see Appendix A), and best practices for risk-based remediation decisions. The agenda for Workshop 2 can be found in Appendix E.[2] The workshop summary is Volume II of this report. The workshop summaries were authored by different rapporteurs so there are stylistic differences between them.

The workshop summaries provide factual descriptions of the workshop presentations and discussions. They do not contain consensus findings and recommendations. Several major themes and debated topics emerged from the workshops and are described below.

DECISION-MAKING PROCESSES

Remediation decisions for DOE's contaminated sites can involve complex technical issues, cost millions or even billions of dollars, and be impactful to human health and the environment. Various tools and approaches have been developed to guide remediation decisions in an effective, efficient, and transparent manner.

Several tools and approaches were discussed at the workshops including risk assessments, decision analysis, and sustainability frameworks. Risk assessments traditionally account for technical components of risk (e.g., calculating risk of exposure of radioactive or chemical contaminants) (see Volume I, Chapter 2 [Vol. I, Ch. 2] and Volume II, Section 2.8 [Vol. II, Sec. 2.8]). Workshop 1 participants discussed other aspects of risk including scheduling and external risks (see Vol. I, Ch. 2 and Sec. 3.5). Decision analysis tools can be used to quantify the many components that contribute to risk management decisions for a complex problem such as cleanup technologies, contamination levels, remedy costs, and societal preferences for the use of the site. The components are individually characterized (e.g., in the case of multi-attribute utility analysis by utility functions) and then combined. The results provide insight into how multiple components combine to affect final outcomes (e.g., reduction in risk, access to the site in least amount of time, or determination of costs of remedies) which can be used to make decisions (see Vol. II, Sec. 2.8). Sustainability frameworks

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[1] Presentations from Workshop 1 can be found at: http://sites.nationalacademies.org/PGA/sustainability/PGA_085849.

[2] Presentations from Workshop 2 can be found at: http://dels.nas.edu/Past-Events/Best-Practices-Risk-Informed-Remedy/AUTO-8-12-72-G?bname=nrsb.

(see Vol. I, Sec. 1.6 and Vol. II, Sec 2.4) describe how to integrate sustainability principles[3] into a decision-making process. This process allows the environmental, societal, and economic issues to be communicated among the stakeholders and can result in decisions with broader consensus and longevity.

Workshop 1 introduced the concept of the use of sustainability frameworks to guide remediation decisions and provided several case studies (see Vol. I, Sec. 4.1). Workshop 2 discussed the importance of balancing and optimizing the environmental, societal, and economic pillars of complex, contaminated sites and also provided several case studies (see Vol. II, Sec. 2.4 and 3.5). It was recognized that within the sustainability framework approach a win-win-win solution is rarely available. Rather, a balancing between the environmental, societal, and economic issues is a more likely outcome—sometimes requiring lengthy discussions and negotiations among stakeholders (see Vol. II, Sec. 5.1 and Ch. 6).

REGULATIONS AND FLEXIBILITY

Workshop participants discussed the flexibility of laws and regulations that govern environmental cleanup decisions. The following laws were specifically discussed:

- National Environmental Policy Act (NEPA) was highlighted as containing language compatible with sustainability principles, "to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations" (NEPA [1969]; EO 13514 [2009]; see Vol. I, Sec. 1.6). Some workshop participants recognized that the NEPA process included sustainability principles from its inception (although at the time of NEPA's enactment the term "sustainability" was not widely adopted) (see Vol. II, Sec. 2.4).
- Resource Conservation and Recovery Act (RCRA) (see Vol. I, Sec. 1.2) was discussed at both workshops. Many participants noted that RCRA imposes prescriptive standards-based approaches for remedies and therefore is least favorable toward the incorpo-

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[3] Sustainability principles and sustainability frameworks are discussed in Vol. I, Sec. 1.6. Sustainability principles guides an agency's implementation of regulatory mandates and discretionary programs in ways that optimize benefits as they relate to the social, environmental, and economic pillars. Sustainability frameworks provide an analytical process for decision making related to linkages of sustainability principles across all federal agencies. A framework is divided into four distinct phases: (1) preparation and planning; (2) design and implementation; (3) evaluation and adaptation; and (4) long-term outcomes.

ration of sustainability principles as compared to the other laws discussed (see Vol. II, Sec. 4.5).

- Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (see Vol. I, Sec. 1.2) was discussed widely at both workshops. Workshop 1 focused on whether CERCLA allowed for the flexibility to include sustainability considerations into its remedies. Some participants proposed adding a “tenth criterion”[4] to CERCLA to define the incorporation of sustainability principles into the law (see Vol. I, Ch. 2). Discussions during Workshop 2 highlighted CERCLA’s inherent flexibility and its demonstrated ability to accommodate sustainability principles within the existing nine criteria for remedy selection (see Vol. II, Box 2.2 and Sec. 2.6 and 4.5).

Workshop 1 focused on the flexibility to make remediation decisions within existing regulations; Workshop 2 considered how existing regulations based on the laws identified above may need to be “reset” or updated to account for the complexities of the contaminated sites that have yet to be fully remediated. Discussions included how updating of regulations could account for the knowledge gained from three decades of site remediation work (see Vol. II, Sec. 2.8, 3.3, and 4.1).

MODELS AND TIMEFRAMES

The usefulness of conceptual site models to communicate with the public and guide decisions was raised at both workshops (see Vol. I, Sec. 3.1, and Vol. II, Sec. 2.8 and 5.1). The importance of models based on realistic physical processes, as opposed to conservative estimates of the physical processes, was highlighted in Workshop 2 (see Vol. II, Sec. 2.3 and 5.1).

Long-term assessments that use models which utilize realistic timeframes were discussed. For example, limiting model predictions to timeframes of hundreds—instead of millions—of years was discussed in Workshop 2 (see Vol. II, Sec. 2.3 and 5.1).

The sequencing of remediation activities within the decision-making process was introduced in Workshop 1 (see Vol. I, Ch. 2). Sustainability frameworks may offer a way to incorporate sequencing into the existing remedy selection process to guide decisions as discussed in Workshop 2 (see Vol. II, Sec. 5.1).

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[4] CERCLA has nine criteria; descriptions of these criteria can be found in Vol. II, Box 2.2.

COMMUNICATION AMONG STAKEHOLDERS

Communication among stakeholders throughout the decision-making process was discussed in both workshops. Workshop 1 participants explained how communication enables flexibility in regulations (e.g., the frequent and occasionally lengthy discussions among stakeholders mentioned previously; also see Vol. I, Ch. 2). Several participants in Workshop 2 stressed the importance of communication with local stakeholders (e.g., tribal nations) early and often in the decision-making process (see Vol. II, Sec. 3.1). Tools developed to support decision making can provide transparency and improve communications if used properly (e.g., decision analysis tools; see Vol. II, Sec. 2.8).

WEIGHING ENVIRONMENTAL RESOURCES IN DECISIONS

There was debate on how to appropriately weigh environmental concerns in a sustainability-based decision-making process. Specifically, participants discussed how to represent environmental concerns within a sustainability framework when the societal and economic pillars may have stronger interests and advocates (Vol. I, Ch. 4 and Vol. II, Sec. 3.6).

Volume I

Workshop 1 Summary

Dominic A. Brose, Rapporteur

1

Introduction

This workshop featured a range of expert briefings as well as extensive discussion sessions. The workshop was organized into three sessions, reflected in Chapters 2, 3, and 4 of this volume as follows:

1. Challenges to regulatory flexibility and risk-informed decision making;
2. Holistic approaches to remediation; and
3. Incorporating sustainability into decision making for site remediation.

Each session followed a similar format: the subject matter was introduced by an expert followed by a set of presentations highlighting case studies on that subject. After each presentation, a discussion session was held. All workshop presentations are available online: http://sites.nationalacademies.org/PGA/sustainability/PGA_085849.

This summary was written by a rapporteur to present the various ideas and suggestions that arose in the workshop. It does not include conclusions or recommendations, nor does it cover the full spectrum of issues around this topic.

The remainder of this chapter is based on a white paper (Brose and Heimberg 2013) distributed to the workshop participants and is intended to provide the reader with background information regarding regulatory history and status of environmental cleanup of nuclear legacy sites, relevant National Research Council (NRC) reports, and sustainability frameworks.

1.1 HISTORY

The nuclear weapons industrial complex, which grew out of the Manhattan Project and the Cold War, is massive by any number of measures. More than $450 billion was spent and hundreds of thousands of workers were employed to support nuclear material production, weapon assembly, and nuclear testing (DOE 1995).[1] More than 100 sites spanning 31 states, 1 territory, and 2.3 million acres were developed. One hundred and twenty million square feet of buildings were utilized (DOE 1995; NRC 2010). By the end of the Cold War, the United States had produced about 994 metric tons of highly enriched uranium and more than 100 metric tons of plutonium (DOE 1995). A large portion of this industrial complex was devoted to the production of the nuclear materials required for weapons. In 1939, physicists Niels Bohr and John Wheeler hypothesized that a specific, rarely occurring isotope of uranium (U-235) was more fissile than the more naturally abundant U-238 and was required to sustain the nuclear chain reaction (Bohr and Wheeler 1939). Because U-235 occurs in less than 1 percent of natural uranium, which itself occurs in concentrations of 2 to 5 parts per million in mined ore, Bohr expressed deep doubt that a nuclear bomb could be made “unless you turn the United States into one huge factory” (DOE 1995, p. 2).

Uranium has multiple uses in the production of nuclear weapons; it can be used for bomb material or as a fuel and target in plutonium production. Several processing steps are required to enrich uranium: It is first mined from rock and refined to natural uranium (also called yellow cake), converted to uranium hexafluoride (UF_6), enriched to increase the required U-235 content, and then converted to metal. The mining and milling of uranium ore for the Manhattan Project and Cold War took place at more than 400 locations within the United States. Approximately 60 million tons of ore were mined (DOE 1995). The conversion and enrichment primarily took place in Tennessee (Oak Ridge), Ohio (Portsmouth), and Kentucky (Paducah). About 700,000 metric tons of UF_6 were produced. Conversion to nuclear fuel for plutonium production and metal (for weapons) took place at Fernald, Ohio. Over its operational lifetime, the Fernald plant produced 250,000 tons of uranium metal products (WM 2011).

Plutonium-239 is also used in nuclear weapons and does not occur naturally in useful abundance; it is created by bombarding uranium fuel and targets with neutrons usually in a nuclear reactor. Pu-239 is later extracted from the irradiated uranium fuel. Plutonium production and separation of Pu-239 from the irradiated uranium targets (i.e., reprocessing) took place in Hanford, Washington, and Aiken, South Carolina, near the Savannah River. The Hanford and Savannah River Sites housed a total of 14 produc-

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[1] Adjusted for 2013 dollars.

tion reactors, encompassed nearly 1,000 square miles, and produced more than 100 tons of plutonium (Gephart 2003). When Bohr later joined the Manhattan Project and learned the extent of its operations, he confirmed his earlier prediction, "I told you that you would have to turn the United States into a factory. You have done just that," (DOE 1995 p. 2).

The end of the Cold War in 1991 and a nuclear weapons test moratorium in 1992 brought an end to large-scale production of nuclear materials for weapons within the United States. The diversity and extent of lands in which facilities were built are vast. The surface topography, climate, subsurface geology, and hydrology of these sites vary widely (Figure 1-1; NRC 2000). Population densities and cultural uses of the lands around these sites have changed with time. In some cases, population densities increased to support the operations at the facilities (e.g., Hanford, Oak Ridge, Los Alamos); in other cases, they increased because of expansion of

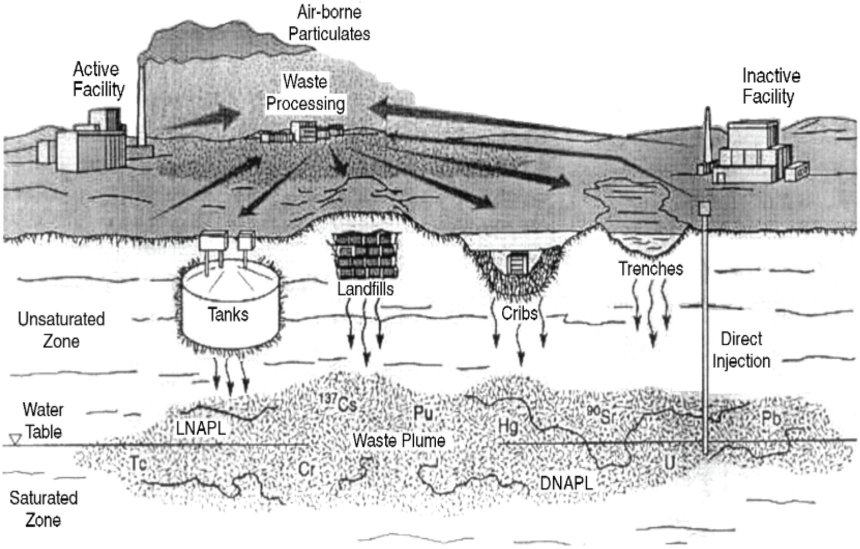

FIGURE 1-1 A schematic illustration of historical waste management practices in the DOE nuclear industrial complex and contaminant pathways to the environment. This schematic also shows the geologic features at the surface and subsurface and their relationship to the sources of waste. The contaminants in the soil and groundwater shown above are light and dense non-aqueous phase liquids (LNAPLs and DNAPLs, respectively), technetium (Tc), chromium (Cr), cesium (Cs-137), plutonium (Pu), mercury (Hg), strontium (Sr-90), uranium (U), and lead (Pb).
SOURCE: NRC 2000.

suburbs around cities previously considered far removed from the site (e.g., the Rocky Flats site near Denver; DOE 1995).

Since the creation of the Office of Environmental Management (EM) in 1989, the diversity and magnitude of the wastes and contamination have become well known, including approximately 88 million gallons of radioactive wastes stored in tanks, 1,000 tons of spent nuclear fuel, more than 10,000 containers of plutonium and uranium, more than 5,000 contaminated facilities, millions of cubic meters of contaminated soil, and 1 billion gallons of contaminated ground water (DOE 2013). Cleanup efforts have cost approximately $190 billion to date (NRC 2010); remediation of the remaining sites is expected to cost more than $300 billion and take an additional 40 years (DOE 2013). The cost of the cleanup efforts could ultimately exceed those for the development of the nuclear weapons.

1.2 REGULATORY HISTORY

Beginning with the Atomic Energy Act in 1954, laws have been enacted to control and regulate the cleanup of radioactive and hazardous waste to protect human health and the environment.[2] Two of the main laws are the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, also known as Superfund) and the Resource Conservation and Recovery Act (RCRA). CERCLA, which typically applies to releases from facilities that are no longer operating, allows for broad federal authority to respond to releases or threatened releases of hazardous substances (including radioactive substances) that endanger public health or the environment. The law has subsequently been amended, by the Superfund Amendments and Reauthorization Act of 1986 (SARA), and the Small Business Liability Relief and Brownfields Revitalization Act of 2002. RCRA, which applies to active or planned facilities, focuses on disposal of hazardous wastes, including some of the chemical by-products of nuclear weapons production. Both laws require that DOE and other federal and state regulators enter into interagency agreements to address site remediation (CERCLA section 120, and 3008(h) and RCRA section 6001).

Federal Facility Agreements and Consent Orders have been established between Department of Energy (DOE), the Environmental Protection Agency (EPA), and state regulators to satisfy CERCLA and RCRA requirements. Also called tri-party agreements, they define agreed-upon and legally enforceable milestones toward achieving compliance with laws and reaching site closure. The tri-party agreements for the states with the largest and most problematic waste issues are Washington (1989 and 2003), Idaho

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[2] The Environmental Protection Agency (EPA) has a summary of laws, directives, and presidential orders that are used to guide regulation decisions at http://www.epa.gov/rpdweb00/laws/.

(1991), and South Carolina (1993), and define what DOE cleanup efforts must accomplish, timelines for the accomplishments, and in many cases, the means by which the accomplishments are to be achieved (NRC 2005a).

1.3 CURRENT STATUS OF CLEANUP EFFORTS

Since cleanup activities began in 1989, DOE has conducted an accounting of the number of sites requiring cleanup, begun characterization of wastes and contamination, and initiated cleanup activities. Currently, 90 out of 107 sites have completed cleanup activities required by those sites' tri-party agreements (Figure 1-2). Completed cleanup does not necessarily mean that the site has been returned to pre-contamination conditions or has been approved for unrestricted public use. Many of the 90 completed sites have wastes remaining on site and restrictions on future use; these sites require long-term monitoring to ensure that the existing remedies continue to protect human health and the environment. When wastes remain on a site, CERCLA requires 5-year reviews to provide an opportunity to evaluate the implementation and performance of a remedy to determine whether it remains protective of human health and the environment. For example, the sites in Rocky Flats, Colorado, and Fernald, Ohio, have restrictions on future uses because wastes remain on site. For Fernald, the On-Site Disposal

FIGURE 1-2 Location of principal sites within the DOE nuclear industrial complex. The four major DOE sites are labeled.
SOURCE: Modified from NRC 2000.

Facility (OSDF) contains low-level radioactive wastes and contaminated groundwater. The Fernald Preserve, now managed by DOE's Office of Legacy Management, has a public visitors center and hiking trails with access restrictions (e.g., excluding access to the OSDF). At Rocky Flats, contaminated surface soils and groundwater remain, and the site has been transferred to the Department of Interior's Fish and Wildlife Service for use as a National Wildlife Refuge.

Long-term monitoring is required for both sites. Monitoring is usually performed using direct measurements of groundwater and soil collected at predetermined locations known as points of compliance. The points of compliance are usually at the perimeters of storage locations or groundwater plumes. Point-of-compliance testing requires sample collection, processing, analysis, and reporting. Other long-term monitoring activities include institutional controls, which are non-engineered instruments, such as administrative and legal controls, that help minimize the potential for human exposure to contamination and/or protect the integrity of the remedy. Although the majority of DOE sites have completed cleanup, the largest and most technically challenging sites remain. Each has unique terrain, subsurface geology, contaminants and wastes, regulations, and tri-party agreements. Wastes will remain on site, and future land use will likely be restricted. As such, all remaining sites are faced with long-term monitoring until either technologies can be developed to effectively address the contamination or the radioactive wastes decay through natural processes.

1.4 CHARACTERIZATION OF WASTE AND CONTAMINATION

To determine an achievable end state and the actions needed to reach that end state, it is necessary to understand the extent of the cleanup task. A thorough characterization of the wastes and the contamination is needed at each site. Characterization of the wastes can be difficult because of poor accounting and documentation practices for wastes and waste discharges during the early days of the Manhattan Project (e.g., tank waste). Characterization of the contamination of groundwater and soil is difficult because of the challenges of measuring the subsurface hydrology and a full understanding of the contaminants' interaction with different media (i.e., soil or water) (NRC 1998, 1999).

The NRC has offered advice to DOE on many of these topics. Reports on the characterization of waste include advice on tank waste retrieval and processing, which concluded that sufficient characterization has taken place to extract wastes from the tanks but that more detailed characterization would be needed before final processing (NRC 2006). The importance of characterizing transuranic and high-level waste is captured in several reports (NRC 2001c, 2002a, 2004, 2005b). NRC reports on soil and groundwater contamination focus on improving models, technologies, and characterization methods. The main message from many of these reports is that better characterization is still needed for contaminated soil and groundwater—especially the subsurface geological structures (e.g., better characterization of wastes/chemicals transport in the subsurface). Also, many reports conclude that the majority of the problematic sites will not be remediated to the level of unrestricted use (NRC 1999, 2007, 2013a). One NRC report states, "Effective technologies do not exist for treating the contamination to soil and groundwater even for the most common contaminants" (NRC 1999, p. 1). Unfortunately, this remains true today (NRC 2013a). Other notable challenges are listed below:

- Measurements from monitoring may be near background levels and have large uncertainties—communicating measurements that exceed background levels to regulators and the public will be challenging (NRC 2007).
- Pumping groundwater for treatment is marginally effective for some common contaminants with no viable alternatives (NRC 1999, 2013a).
- Remediation through natural attenuation is appropriate for only a few contaminants and is an acceptable solution only when the process can be proven effective and sustainable (NRC 2000).

1.5 TECHNOLOGIES AND DECISION MAKING

DOE has requested the advice of the NRC on its research and development programs throughout the years (NRC 1997, 2000, 2001a, 2001b, 2001d, 2002b, 2009, 2010, 2011a). It is understood that new technologies are still needed to close capability gaps to address cleanup issues. The most difficult issues remaining are soil and groundwater contamination. The NRC report *Groundwater and Soil Cleanup: Improving Management of Persistent Contaminants* provides an overview of the existing technologies and their limitations in this area (1999, pp. 5-6, 8-9).

The NRC report *Risk and Decisions about Disposition of Transuranic and High-level Radioactive Waste* provides a summary of studies and programs starting in 1988 aimed at incorporating risk into decision making (2005a). A chronological overview of DOE's decision-making programs is also included. Risk-based decisions have a technical component that characterizes the scientific aspects of the problem by quantifying risk. However, many of the NRC committees (NRC 1997, 2000, 2001a, 2001b, 2001d, 2002b, 2009, 2010, 2011a) stress the following general characteristics of risk-based decision making that are not technical or scientific in nature:

- Risk *assessment* is not risk *management*; assessment of risk should guide but not make decisions;
- A formalized decision-making process provides consistency and transparency in agency decisions;
- Meaningful stakeholder involvement and communication between interested parties are needed early and throughout the risk analysis and decision-making processes; and
- Risk to human health is important but is one of many other considerations that should be incorporated into decisions.

In 2003, DOE approved Policy 455.1 to include risk-based end states in a re-evaluation of cleanup activities. The policy specifically stresses the importance of stakeholder involvement in determining a risk-based end state vision. Stakeholder involvement and environmental end states have been highlighted by DOE and outside committees providing advice to DOE as important components of risk-based decisions. However, implementing an effective risk-based decision process that sufficiently incorporates stakeholder concerns has proven difficult. Sustainability principles are being explored as a method to better incorporate those concerns into the decision-making process.

1.6 OPERATIONALIZING SUSTAINABILITY

Sustainability has permeated all sectors of society—the private sector, federal, state, and local agencies, nongovernmental organizations (NGOs), and academia are all working on incorporating sustainability into their practices and operations. Sustainability is now being incorporated into what has been conventionally risk-based decision making at contaminated cleanup sites (Holland et al. 2011; Döberl et al. 2013). Although cleanup strategies for complex multi-contaminant sites remain site specific, the incorporation of sustainability principles at ongoing DOE sites, such as Hanford or Savannah River, could help move cleanup strategies forward in a way that addresses ongoing social, economic, and environmental concerns.

The NRC report *Sustainability and the U.S. EPA* (2011b) used the definition for sustainability from Executive Order 13514, where it is defined as "to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations" (p. 8). The 1969 National Environmental Policy Act (NEPA) embodies sustainability, which requires an integration of social, environmental, and economic policies—the three pillars of sustainability. International acceptance of sustainability was spurred by the 1987 report of the World Commission on Environment and Development, *Our Common Future* (WCED 1987). In 1992, at the

United Nations Conference on Environment and Development in Rio de Janeiro, the United States and other countries endorsed a global plan of action for sustainable development and a set of principles to guide that effort (UNCED 1992). The 2011 NRC report for EPA further described sustainability as a process—because the United States and other countries are far from being sustainable—and a goal. Sustainability is achieved in particular places and contexts—it is a place-based approach—and it is necessary to maintain the conditions supporting it in the face of social, technological, environmental, and other changes.

As the private sector, federal, state, and local agencies, NGOs, and academia struggle to address cross-cutting, complex, and challenging issues, sustainability as an operational framework is being increasingly embraced and incorporated into decision-making processes. Several examples of sustainability frameworks have been developed, including those by the National Research Council (NRC) and the U.S. Sustainable Remediation Forum (SURF). In 2009, EPA requested that the NRC convene an expert committee to develop a framework for incorporating sustainability into the agency's principles and decision making (NRC 2011b). The framework was intended to help the agency better assess the social, environmental, and economic impacts of various options as it makes decisions. In its Strategic Plan, EPA has made "working toward a sustainability future" a major cross-program goal, and it continues to develop an implementation plan for adopting the committee's recommendations as it moves toward incorporating sustainability into its decision-making processes.

The resulting framework is organized into two levels (Figure 1-3). Level 1 consists of several components that define the agency-wide process: the social, environmental, and economic pillars of sustainability and the principles and legal mandates that feed into the process; EPA's sustainability vision, goals, and organization; the Sustainability Assessment and Management (SAM) approach; and periodic evaluation and public reporting activities. Level 2 articulates the elements of the SAM approach, which is intended to be equally applicable to human health, ecological risks, and other challenges. The SAM approach is designed to be comprehensive, systems-based, and intergenerational and to solicit stakeholder involvement and collaboration. It is driven by sustainability principles and goals and involves setting, meeting, and reporting on measurable performance objectives (NRC 2011b).

The report states that the framework incorporates and goes beyond an approach based on assessing and managing the risks posed by pollutants that has largely shaped environmental policy since the 1980s. Although risk-based methods have led to many successes and remain important tools, as the report states, they are not adequate to address many of the complex problems that put current and future generations at risk, such as depletion

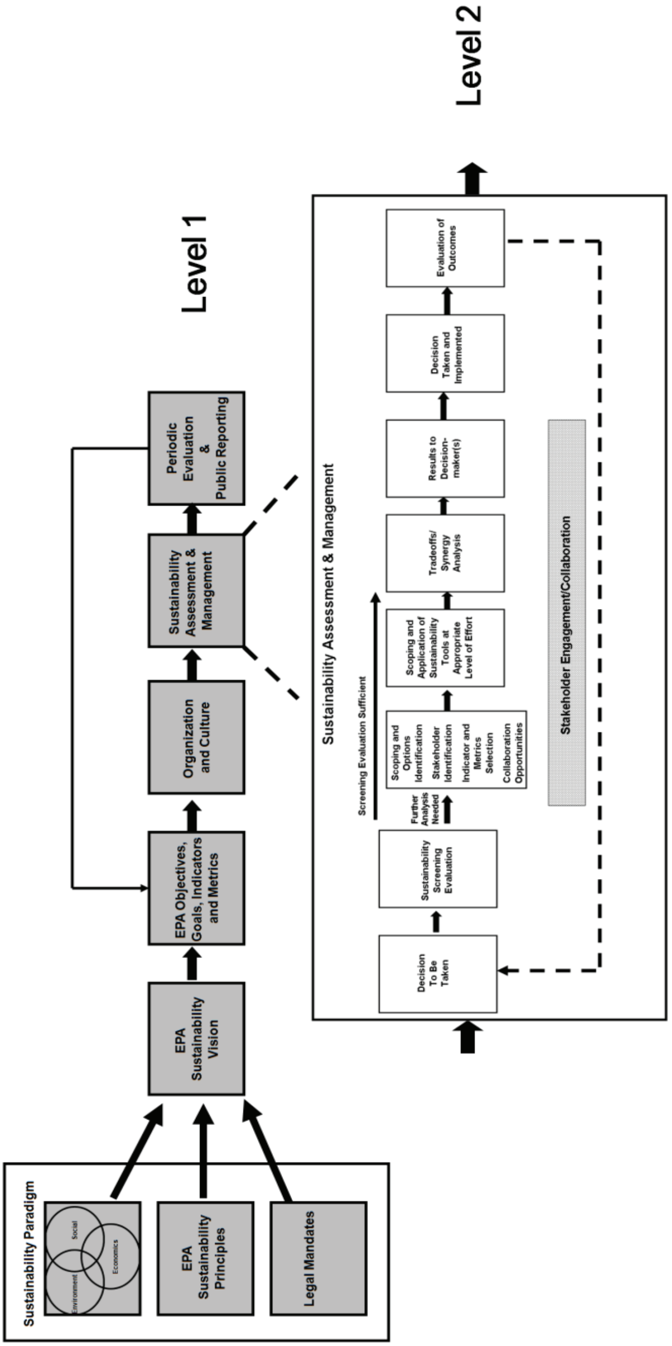


FIGURE 1-3 A framework for EPA sustainability decision making.
SOURCE: NRC 2011b.

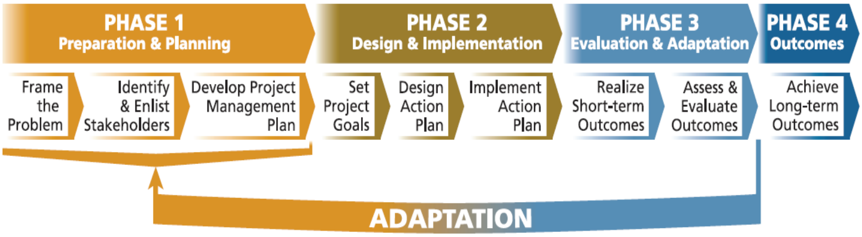


FIGURE 1-4 Conceptual Decision Framework. Four phases are shown, along with the relevant steps in each phase. The framework could be applied in creating either programs or projects related to sustainability.
SOURCE: NRC 2013b.

of natural resources, climate change, and loss of biodiversity. The report also stated that EPA could benefit from formally developing, adopting, and publishing a set of broad "Sustainability Principles" that underlie all agency policies and programs. These principles would guide the agency's implementation of regulatory mandates and discretionary programs in ways that optimize benefits as they relate to the social, environmental, and economic pillars. Examples of such principles could include those of public administration, such as openness and transparency, reliability, accountability, efficiency, and effectiveness. The most widely cited and used set of principles are the sustainable development principles from the Rio Declaration of 1992. The report recommended that some of the key dimensions of the principles that EPA should consider including are intergenerational and intragenerational equity, justice, and a holistic-systems approach to environmental problems and solutions.

The NRC report *Sustainability for the Nation* (2013b) provides an analytical framework for decision making related to linkages of sustainability across all federal agencies (Figure 1-4). The framework is divided into four distinct phases: (1) preparation and planning; (2) design and implementation; (3) evaluation and adaptation; and (4) long-term outcomes (NRC 2013b).

The report describes each phase as follows (NRC 2013b):

- **Phase 1: Preparation and planning.** This phase has three major steps that need to occur prior to the actual program or project design: (1) frame the problem (determine baseline conditions, key drivers, metrics, and goals based on these metrics); (2) identify and enlist partners; and (3) develop a project management plan.

- **Phase 2: Design and implementation.** This phase has three main steps, including (1) define goals; (2) design action plan; and (3) implement plan.
- **Phase 3: Evaluation and adaptation.** This phase focuses on realizing short-term outcomes, assessing outcomes, and adjusting actions. Outcomes are assessed and evaluated relative to the baseline conditions established in Phase 1.
- **Phase 4: Long-term outcomes.** Long-term outcomes are on the scale of several years or more and should closely track the goals identified in the first phase. Using outcome measures developed under Phase 2, at this stage evaluations are conducted to see if short- and long-term outcomes are meeting goals. Ideally, this evaluation should be able to be compared to the baseline evaluation finalized in Phase 2. Based on this evaluation, necessary changes to the team, goals, outcomes and measures, management plans, design, implementation, or maintenance are made.

SURF recently offered another sustainability framework. SURF was initiated in 2006 as a private-sector effort to incorporate sustainability into decisions on remedial actions at contaminated sites. In 2011, SURF developed a framework "to enable sustainability parameters to be integrated and balanced throughout the remediation project life cycle, while ensuring long-term protection of human health and the environment and achieving public and regulatory acceptance" (Holland et al. 2011). Because sustainability is a cross-cutting issue, this framework integrates sustainability throughout the entire remediation system. SURF describes sustainable remediation as "balancing the impacts and influences of the triple bottom line of sustainability (i.e., environmental, societal, and economic) while protecting human health and the environment." Over the past few years, remediation practitioners have incorporated sustainability parameters more frequently during remedy selection and implementation; however, methodologies have been inconsistent, partly because of a lack of a broad, widely applicable sustainable remediation framework.

To address this need, SURF developed a framework to mirror each phase of a traditional remediation project: investigation, remedy selection, remedial design and construction, operation and maintenance, and closure (Figure 1-5). The framework can be thought of as interconnected components of the wider remediation system, which interact with each other as the project progresses. Practitioners are encouraged to look both prospectively and retrospectively throughout the project to integrate sustainability improvements. Some benefits of using the framework, according to SURF,

Remediation Phase	Description (in Context of Framework)
Investigation	In this phase, remediation practitioners identify the impacted media, contaminants of concern, and potential risk to human health and the environment. The project objectives and scope are developed, and stakeholder concerns are identified. Stakeholder groups are often contacted during this phase to provide input during decision making. Field activities are performed to gather pertinent information regarding site-related impacts. Effective project planning can help optimize data collection and analysis. Sustainability considerations should be specified in work plans and implemented in the field. A preliminary, site-specific conceptual site model (CSM) should be developed based on the information obtained during this phase.
Remedy Selection	In this phase, remediation practitioners use the information obtained during the investigation phase to evaluate the feasibility of applicable remedial alternatives. Practitioners should focus the evaluation on the preferred end use(s) or future use(s), while always being protective of human health and the environment. The results obtained during this phase should be balanced with project considerations (including sustainability) to determine the appropriate remedy. The information gained during this phase serves to improve the CSM and define a preferred approach to site management.
Remedial Design and Construction	In this phase, remediation practitioners design the approaches and technologies that will be applied to the site, including the integration of sustainability parameters into the design. Throughout the design process, remediation practitioners should ensure that sustainability parameters are continually improved through optimization and management of the site. Practitioners should consider how sustainability will be implemented and recorded during the construction and operation and maintenance (O&M) phases and should establish triggers within the design for re-evaluation of the remedy when appropriate. In the construction phase, practitioners should have the necessary resources in place to conduct performance monitoring during the O&M phase. The sustainability objectives established during the design and tendering process should be implemented and monitored. If needed, practitioners can identify and implement additional sustainability opportunities during this phase.
Operation and Maintenance	During this phase, remediation practitioners should assess opportunities for continual sustainability improvement of the system as site conditioners change and remediation technologies advance.
Closure	During this phase, remediation practitioners should ensure that the preferred end use(s) or future use(s) is achieved and that the site can be reused. Practitioners should determine whether the sustainability objectives have been met and should use this information to improve the sustainability approach for future projects.

FIGURE 1-5 Project Phase Descriptions.
SOURCE: Holland et al. 2011.

include fewer impacts on the environment and enhanced relationships with and investments in the local community. The framework is intended to be accessible to all stakeholders involved in or affected by a remediation project, regardless of prior sustainable remediation experience. It is process-based and adaptable over time. The framework is designed to assist practitioners to (1) perform a tiered sustainability evaluation, (2) update the conceptual site model based on the results of the sustainability evaluation, (3) identify and implement sustainability impact measures, and (4) balance sustainability and other considerations during the remediation decision-making process. The framework can complement and build upon existing sustainable remediation programs developed by government agencies, industry associations, and the regulated communities. The framework allows for goal-oriented outcomes but also introduces additional opportunities for incorporating sustainability parameters throughout the remediation project.

2

Challenges to Regulatory Flexibility and Risk-Informed Decision Making

Alice Williams, associate principal deputy assistant secretary in the Office of Environmental Management (EM) at the Department of Energy (DOE), discussed risk and sustainability and set the stage for the workshop. Risk means many things to EM, including risks to human health, the environment, and programs and projects, as well as financial and operational risks. This view of risk has evolved over the past 25 years, since a time when it was simply about a leaking tank. Risk today is more subtle, and often disagreements are over the subtleties rather than the bigger issues that have been addressed in the past. EM has eight overarching priorities: activities to maintain a safe and secure posture in the EM complex; radioactive tank waste stabilization, treatment, and disposal; spent nuclear fuel storage, receipt, and disposition; special nuclear material consolidation, processing, and disposition; high-risk soil and groundwater remediation; transuranic and mixed/low-level waste disposition; soil and groundwater remediation; and excess facilities deactivation and decommissioning. Although much cleanup has been accomplished, there are still more than 90 million gallons of highly radioactive waste stored in more than 200 aging underground storage tanks. There are also more than 100 square miles of soil and groundwater contaminated with both chemicals and radionuclides.

Ms. Williams described the long-term stewardship at two sites—Rocky Flats, Colorado, and Fernald, Ohio—as successful projects. At Fernald, community leaders and regulators knew that the economic landscape of that part of Ohio would not support an industrial park and proposed a nature preserve as the end use for the site. The local community was a key factor in the dialogue and decision making. Similarly, Rocky Flats was turned over to the Department of Interior's Fish and Wildlife Service as a wildlife preserve, and both sites serve as a model that DOE hopes can be used at other sites. However, the life-cycle cost of the environmental management program is an ongoing challenge to continuing cleanup. The EM legacy cleanup program is forecasted to continue past 2060 with "to go" costs of up to $209 billion. Tank waste activities are the most costly of EM's cleanup activities, and facility decontamination and decommissioning and soil and groundwater activities are the second most costly cleanup activity. Other sites will likely be added into EM's mission as well. For example, a site in Paducah, Kentucky, was recently added and will be an opportunity for DOE to use the lessons learned from Rocky Flats and apply them to another large cleanup activity. With ongoing and future cleanup, said Ms. Williams, several key concepts will need to be addressed:

- **Points of compliance.** Cleanup is long-term, and the location and boundaries for cleanup are extremely important to consider.
- **Risk prioritization.** Sequencing and scheduling the work are key components of the federal facility agreements and consent orders, and the nine criteria under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) continue to underpin remedy selection.
- **Decision making.** Decisions regarding cleanup priorities must be risk informed.
- **Stakeholder engagement.** Dialogues with stakeholders about onsite disposal have been successful and have become a more accepted practice. This will be important in considering long-term sustainable solutions.
- **Sustainability.** Stakeholders, environmental protection, and costs will all need to be considered to inform a final decision on the end state of a given site.

In 2008, President Obama issued Executive Order (EO) 13514, which requires federal agencies to establish an integrated strategy toward sustainability and to prioritize the reduction of greenhouse gas emissions. Ms. Williams stated that, to meet EO13514 requirements, EM has accelerated facility decontamination and decommissioning of high-energy-consuming excess facilities, ensured sites have robust energy management programs, promoted in situ decommissioning and green remediation, where appropriate, and successfully implemented energy reduction efforts at several sites. The nine CERCLA criteria do not directly include sustainability, but a tenth criterion addressing sustainability could contribute to more holistic approaches at ongoing sites for more successful cleanup. Looking forward, Ms. Williams stated that EM will face ongoing challenges, including

- holistic approaches to remediation of sites with multiple contaminant sources and multiple post-closure uses, including technically based, in situ, point-of-compliance, and point-of-use monitoring locations;
- effective post-closure controls: monitoring post-closure controls and engineering natural controls;
- approaches for assessing long-term remedy performance to reduce uncertainty and need for controls; and
- upfront consideration of sustainability options and analyses that cover the three sustainability pillars (social, environmental, and economic).

Carolyn Huntoon, independent consultant and former assistant secretary for environmental management at DOE, discussed challenges to regulatory flexibility. Dr. Huntoon serves on DOE's Environmental Management Advisory Board (EMAB), which consists of up to 15 members appointed by the secretary of DOE to advise the assistant secretary of DOE's EM. Dr. Huntoon chaired a subcommittee on risk and sustainability for EMAB, which was convened, in part, to review how to better engage stakeholders in the context of sustainability. It is important for a remediation project to provide a clear, concise, understandable statement of purpose to the general public and stakeholders, said Dr. Huntoon. This communication is imperative for finding flexibility in existing regulatory frameworks and in particular in tri-party agreements.

Larry Camper, director of the Division on Waste Management and Environmental Protection at the Nuclear Regulatory Commission, also commented on regulatory flexibility. He shared his views from a personal perspective as a practitioner rather than from an official perspective as a

Challenges to Regulatory Flexibility

- Overlap of regulations
  - Competing standards: Nuclear Regulatory Commission, EPA, state regulators
  - Differing implementation processes
- Political and stakeholder influence
- Lack of understanding of risk
- Risk assessment vs. risk management
- Implementation of restricted release option
- Exposure scenario options

Larry Camper, Nuclear Regulatory Commission, October 30, 2013 representative of the Nuclear Regulatory Commission. The Atomic Energy Act of 1954 charges the Nuclear Regulatory Commission to focus on radiological criteria—to account for chemical and radiological contamination in environmental analysis but not to clean up such contamination. One ongoing challenge to regulatory flexibility is an overlap of regulations that often involve competing standards, he said. For example, the Nuclear Regulatory Commission and the Environmental Protection Agency (EPA) use differing criteria. Implementation processes for fulfilling regulatory obligations can also differ between agencies.

There is also a challenge in communicating risk, because the general public lacks an in-depth understanding of risk, particularly of the difference between risk assessment and risk management. The extent of remediation at a site and the pathway toward risk management depend on the exposure scenarios chosen for the end state; there is a large difference between evaluating a site for residential versus industrial use. Thus, the exposure scenario greatly influences the amount of flexibility that can be incorporated into the remediation. Social media are driving increased stakeholder involvement and public engagement. Because of the increased level of attention, however, public interest groups may expect the responsible parties to follow particular paths that do not align with regulatory criteria. At times, a remediation strategy has satisfied regulatory criteria, which were set at a level to protect public health, but not stakeholders, who wanted a lower value for the level of residual contaminant.

Dr. Camper shared a case study from Milan, New Mexico, on the challenges to regulatory flexibility resulting from overlapping regulations. The Milan site is a uranium tailing impoundment and a Uranium Mill Tailings Radiation Control Act (UMTRCA) Title II site undergoing decommissioning. The mill operated from 1958 to 1990, and groundwater contamination was identified in 1976. Remediation of that contamination commenced in 1977 and is scheduled for completion in 2022. In 1983, the site was added to EPA's National Priority List (NPL). At the time, the site was being regulated by New Mexico as an agreement state. The Nuclear Regulatory Commission initiated regulatory authority in 1986, at which time the site had been on the NPL for 3 years. This resulted in three different regulators being involved at a single site. In 1993, the Nuclear Regulatory Commission and EPA entered into a memorandum of understanding (MOU) for the site, which designated the former as the lead regulatory agency for reclamation and closure activities at the by-product material disposal area. It also assigned EPA responsibility for monitoring all reclamation activities to assure that those conducted under the Nuclear Regulatory Commission's authority would allow attainment of applicable or relevant and appropriate requirements under CERCLA.

As of 2012, the tailings impoundment was considered to be between

70 to 80 percent remediated through a flush and process treatment imposed upon the licensee by the Nuclear Regulatory Commission. Although an MOU was in place and a successful remediation plan was being implemented, EPA took additional actions—conducted a human health risk assessment, a remedial systems evaluation, a feasibility study to move the tailings pile, and a record of decision for groundwater and surface remediation—to meet CERCLA requirements. This is an example of overlapping regulations inhibiting effective decision making and preventing better protection for the community, said Dr. Camper.

In contrast, DOE's effort to clean up waste incidental to reprocessing is an example of regulatory flexibility. Section 3116 of the National Defense Authorization Act of 2005 gives the Nuclear Regulatory Commission responsibility for consulting with DOE for assessing compliance with high level waste and waste incidental to reprocessing determinations at DOE sites in Idaho and South Carolina. For example, the Nuclear Regulatory Commission has consulted with DOE in the classification and cleanup of waste incidental to reprocessing at the Savannah River Site. The Nuclear Regulatory Commission, however, does not regulate DOE, and both agencies have created a pathway forward that ensures that they comply with the 2005 law and that the sites are successfully remediated. Their efforts reflect an ongoing, iterative process, but one that displays how communication and cooperation between two federal agencies can result in successful outcomes and flexibility within the existing regulatory framework.

Dr. Camper stated that the Nuclear Regulatory Commission incorporates the three pillars of sustainability (social, environmental, and economic) into its regulatory program. Regarding the social pillar, the Nuclear Regulatory Commission ensures that a site is remediated to a level that is as low as reasonably achievable (ALARA) and uses a dose-based standard, which ensures that the public is protected. The dose standard and an analysis based on the National Environmental Protection Act (NEPA) ensure that the environment is adequately protected. Economically, a cost-benefit analysis is performed at sites undergoing decommissioning.

Stephen Cobb, chief of the Governmental Hazardous Waste Branch for the Alabama Department of Environmental Management, provided a state regulator's perspective on overcoming challenges to risk-informed decision making. Mr. Cobb is responsible for the management and oversight of Resource Conservation and Recovery Act (RCRA) and CERCLA cleanup sites. Although Alabama does not have any large DOE cleanup sites, it does have Department of Defense (DOD) sites. Challenges at any site include the expense, long timeframes, current and future exposure pathways, natural resource impacts and losses, complexity of the cleanup, and technological limitations, said Mr. Cobb. Given these challenges, however, persistence and continued movement toward cleanup are important.

Sustainable remediation has many aspects, including cost, performance, operability, maintainability, effectiveness, protectiveness, and timeframes. Mr. Cobb stated that his department views sustainable remediation as an ongoing process to achieve the successful attainment of standards that requires maintenance over time. When sites are complex, the possibility of a technical impracticability waiver is often raised; however, Mr. Cobb questions the soundness of a public policy that waives cleanup standards for sites that are complex or too expensive to clean up. Sustainable remediation should not be an excuse to weaken standards necessary to protect human health and the environment. There are several drivers to sustainable remediation, including sound public policy, short- and long-term protection of human health and the environment, source removal where possible to enable longer-term environmental restoration, and economic development, the last of which is key to keeping communities viable.

Mr. Cobb presented a case study from the Anniston Army Depot, which has been a major, active, military industrial facility in central Alabama since the 1940s. The geology underlying the site is complex—a karst setting along a major fault line. A karst landscape is formed from the dissolution of soluble rocks, such as limestone, and is characterized by sinkholes, caves, and underground drainage systems. Also at the site is a thick clayey residuum overlying weathered and unweathered karst bedrock. Currently, there are interim groundwater pump-and-treat and monitoring systems, and the only offsite detection of contaminants is about 1.6 miles south of the site. The site is characterized as having an estimated 3.6 million to 27.1 million pounds of trichloroethylene (TCE) in the groundwater, of which 87 percent is estimated to be in the clayey residuum.

The offsite detection occurs at a spring with 32 million gallons per day base flow rate, which is a primary drinking water supply for the local city and eight other water systems in the area. Approximately 10 million to 20 million gallons of drinking water per day are pumped from the spring to at least 100,000 people. The spring is considered an invaluable high-quality water source, which operates at one-tenth the cost of the other reservoirs in the area. It is a high-quality natural resource, and it is the only known habitat for the pygmy sculpin, a small fish listed on the endangered species list. Mr. Cobb offered several lessons learned from the cleanup activities at this site:

- Recognize that no single technology can clean up a complex site; success will result from a system of technologies.
- Recognize that achieving full cleanup is a matter of time and perseverance and not of relaxed standards.
- Recognize that every pound of contaminant removed, treated, or

destroyed is a success, and that small successes over time can yield big results.

- Manage for long-term effectiveness and not immediate gratification.
- Always aim for a final remediation goal of unrestricted use.
- Be transparent about the remedy, acknowledge the full time and cost needed to achieve cleanup goals, and acknowledge and commit to monitoring and responding in perpetuity if necessary.
- Utilize real cost accounting. Long-term remedies that initially cost less could, over a long timeframe, cost more than more aggressive shorter-term remedies that are initially more expensive. The full long-term costs of interim protective measures, permanent reliance on monitoring and containment systems, loss of use of the resource (e.g., what is the future cost of a local drinking water supply), and impediments to local economic growth and development must be fully considered.

Anna Willett, director of the Interstate Technology and Regulatory Council (ITRC), discussed ITRC's sustainability activities. ITRC is a state-led organization focused on advancing innovative environmental technologies and approaches by integrating new technologies into existing rules and regulations for better environmental decision making. Removing barriers to new technologies and approaches, such as performance-based contracting, is part of this integration. Ms. Willet identified several challenges to risk-based decision making:

- Different agencies conduct risk assessments differently, and there should be better alignment among agencies and states on risk assessment and risk reduction.
- Risk management and decision making based on risk assessment results must be improved. Many aspects to risk management make it variable, including professional judgment, values, tolerance for risk, and consideration of the future value of resources.
- Disagreements among professionals over the fate of chemicals in the subsurface and the technical feasibility of cleanup have led to many remediation failures. Observations over the past 10 years have shown that there is no consistent determination of "maximum extent practicable," "technical impracticability," or "site closure"; definitions become a policy determination made by a regulatory agency.

When discussing risk and risk-based decision making, state agencies and the general public are challenged by variability in policy and technical definitions at the federal level, Ms. Willet said. States are starting to develop

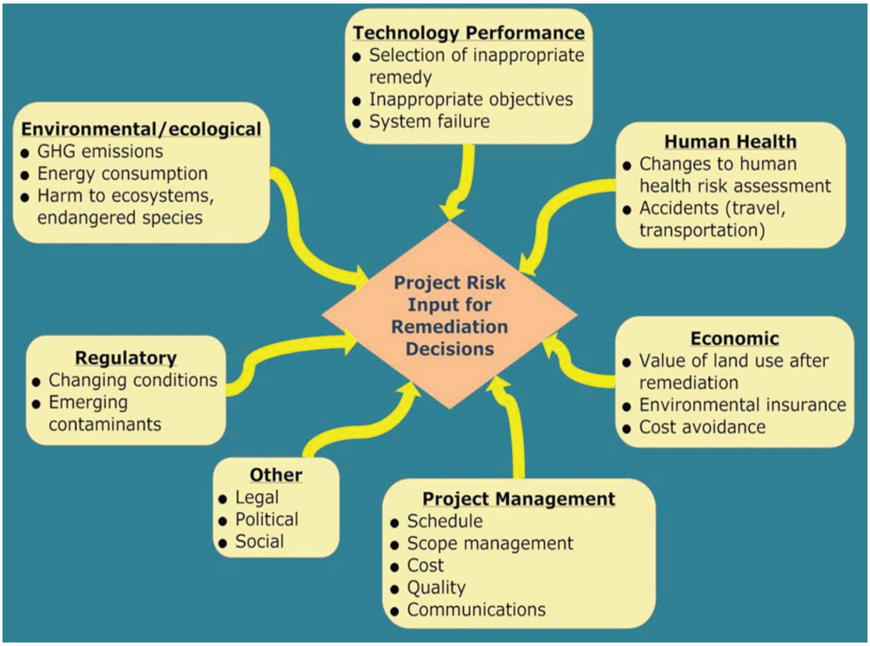


FIGURE 2-1 The different factors that comprise a remediation system.
SOURCE: Willett 2013.

their own approaches to risk-based site closures. The Indiana Department of Environmental Management is conducting risk-based closure for every regulatory program in the state, she noted. Currently, it is the only state taking such an approach across all regulatory programs. Although there is clearly a scaling difference between applying this approach at a state level and applying it at a national level, there are likely to be more valuable examples coming from states. Indiana is struggling with training staff in risk assessment and risk management procedures, and in particular in interpreting a risk assessment for a given site and deciding on necessary actions. When optimizing a remediation system, it is necessary to consider all of the different factors that comprise the system (Figure 2-1). Ideally, optimization would entail considering these factors prior to the implementation of the remedy.

3

Holistic Approaches to Remediation

3.1 OVERCOMING BARRIERS TO RISK-INFORMED REMEDIATION

Michael Truex, a senior program manager in the Environmental Systems Group at Pacific Northwest National Laboratory (PNNL), presented on approaches to overcoming remediation barriers at the Hanford, Washington, site. Many processes were used for weapons production at Hanford, including manufacturing of fuel elements, chemical separation, and plutonium finishing. Each of these processes generated different waste, and the entirety of the Hanford site covers 586 square miles. Thus, within the whole of the Hanford site are smaller sites where remediation efforts are more focused.

Recent work at Hanford resulted in a framework (Figure 3-1) that considers the unique aspects of multiple Hanford sites, which will require a longer timeframe to reach remediation endpoints. The framework

- uses conceptual models, which are a foundation for technical efforts and communication;
- uses the subsurface system and site context to inform remedy approach and timeframe;
- maintains protection while addressing future risk and cleanup;
- adapts as a plume evolves and responds to actions over time, enabling adaptation and transitions along a longer timeframe.

The conceptual models are dynamic; as information is collected during site characterization, it is incorporated back into the model. For example,

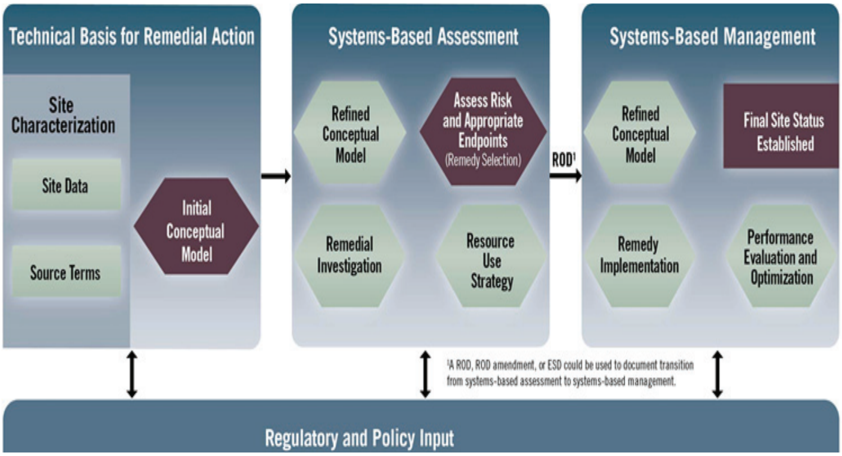


FIGURE 3-1 A framework for holistic remediation approaches.
SOURCE: Truex 2013.

data on subsurface systems relate to the fate and transport of contaminants, site context, exposure pathways, and size of the plume. All of these aspects are important in determining the remedy and timeframe. There often are not enough data for plume behavior at complex sites, so decisions may need to be adapted as more data are gathered.

Mr. Truex highlighted four examples at Hanford where application of these framework principles has been successful: soil vapor extraction, the 100-N Area, the 100-F Area, and the Central Plateau. The 100-N Area, which is located along the Columbia River north of the Central Plateau, includes a strontium groundwater plume adjacent to the river. Similarly, the 100-F Area is a reactor site that is also adjacent to the Columbia River and has multiple contaminants. The Central Plateau contained storage tanks where processing that created a large volume of waste took place (Figure 3-2).

3.2 SOIL VAPOR EXTRACTION

Significant amounts of carbon tetrachloride were disposed of at the Hanford site surface, which resulted in contamination of the vadose zone and groundwater. Because carbon tetrachloride is a volatile contaminant, soil vapor extraction was applied. This remedy is very effective at removing contaminant mass for most portions of the vadose zone, but in lower permeability zones, the residual contaminant diminishes more slowly. Over time, it became apparent to PNNL scientists and contractors that, although the contaminant mass was decreasing in the more permeable subsurface, the

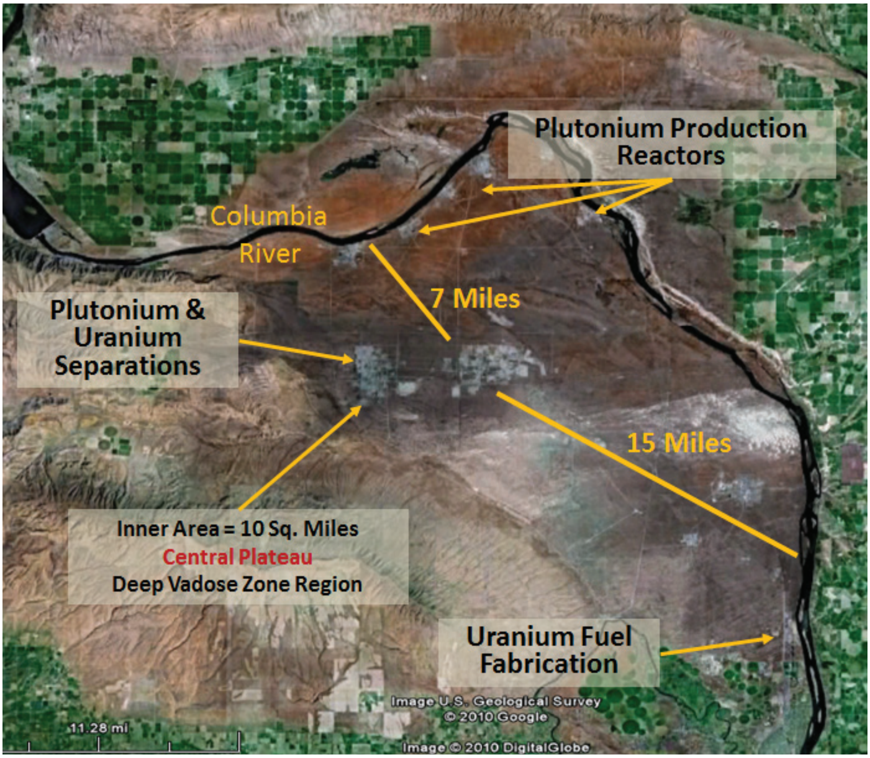


FIGURE 3-2 Schematic of the Hanford Site.
SOURCE: Truex 2013.

returns were diminishing with the soil vapor extraction approach. Questions were raised about the length of time the extraction should continue and about the levels to which the mass should be diminished to be considered protective of the groundwater. The conceptual model, which defines the characteristics of the system and the source mass discharge, was used in conjunction with transport calculations to determine the mass discharge that is protective of the groundwater.

3.3 100-N AND 100-F AREAS

The 100-N Area is a reactor site along the Columbia River where trenches were used to dispose of water laden with strontium-90, explained Mr. Truex. These disposal activities resulted in a plume of strontium-90 migrating away from the trenches and through the subsurface. During operation, water was continually added, and the hydraulic driving force pushed the plume farther away from the trenches. The site is currently inoperative, and questions remain about how much risk the plume poses to the Columbia River. A conceptual model helps to shed light on the transport of the strontium-90 plume and factors that may affect that transport. The half-life for radioactive decay of strontium-90 is approximately 30 years, and there is sorption to the aquifer solids that greatly reduces transport of the plume. It was determined that the strontium-90 nearest to the river posed the only risk, because the strontium-90 in the plume farther back would decay before reaching the river. An apatite barrier was applied to sorb and sequester the strontium closest to the river and to protect the river while the remaining strontium decays in situ. This is a protective remedy, because it mitigates risk to the receptor (Columbia River), and is an example of application of a passive remedy for the majority of the plume.

Similarly, the 100-F Area is also a reactor site along the Columbia River. This site was characterized as having trichloroethylene, strontium, nitrate, and chromium plumes. At this site, the decommissioning of facilities resulted in source reduction, and with an understanding of the dynamics of the underlying plumes and the relationship between the groundwater and interaction with the river, natural attenuation of contaminants appears feasible and is predicted to meet goals based on numerical modeling. Natural attenuation at this site will be long term, and monitoring will be necessary to verify that the plume behaves as predicted and that the river remains protected from contaminants.

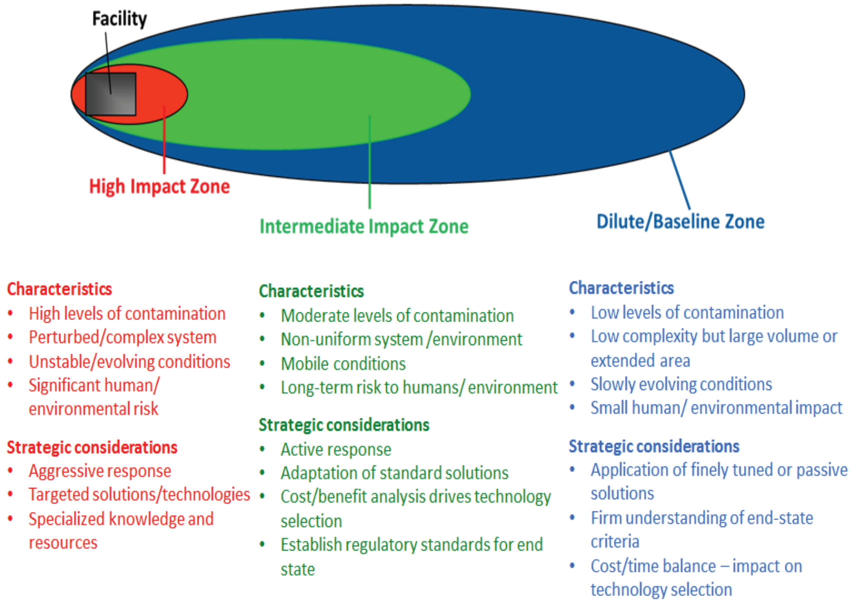
3.4 CENTRAL PLATEAU

Mr. Truex then explained remediation efforts in the Central Plateau region of the Hanford site, which held 149 single-shell tanks and 28 double-shell tanks. Approximately 67 single-shell tanks were known or suspected to have leaked waste into the surrounding soil. Interim actions have been taken to reduce migration of subsurface contamination, and final remedial actions will be coordinated with remediation activities elsewhere on the Central Plateau. As liquids were generated during production, they were disposed to the environment through planned and unintended releases via ponds and trenches. Within the Central Plateau region, there are multiple subsurface contaminants, such as uranium, technetium, and iodine in the vadose zone and groundwater. The vadose zone underlying the Central Plateau has properties that slow contaminants as they seep down. Because the source of the contamination is no longer present and the vadose zone retains much of the contamination, the groundwater has not yet been contaminated under this area. Many questions remain regarding how far contaminants will seep and to what extent the groundwater will be impacted. The long timeframe and minimal near-term risk because of a long path to potential exposure supports a more holistic approach to better assess the system. This approach includes predictive modeling estimates, target actions that will be protective and reduce future risk, monitoring to verify behavior and responses of contaminants, and a progressive and adaptive remedial strategy.

These brief examples highlight key decision factors that are appropriate for complex sites and present a more holistic view that informs development of a description of the system and an appropriate response to meet remediation objectives, said Mr. Truex. Source reduction has been key in transitioning many of the plumes to natural attenuation or other terminal phases. Also, combining much of the contamination into a single operable unit with common issues has been a useful approach to addressing complex systems. Ongoing efforts to make data from the Hanford site more accessible through a web-based geographic information system (GIS) database will enhance data usage by researchers and the public and will facilitate communication. It is important to recognize that communicating and identifying the scientific basis for predictive assessments are important and that addressing complex sites in terms of maintaining protectiveness has been successful.

Jeffrey Griffin, associate laboratory director of the Environmental Stewardship Directorate at Savannah River National Laboratory, presented examples of overcoming barriers to risk-based remediation at the Savannah River Site (SRS). Dr. Griffin stated that the strategy at SRS is to match a remediation solution to the problem and to align resource investments to reduce risk. Soil and groundwater remediation strategies take into account a source, such as a facility or tank, and a zone around the source that is the high-impact zone (Figure 3-3). Addressing the high-impact zone requires a more aggressive response, such as source removal and excavation of contaminated sediments.

The next area farther out from the source is the intermediate-impact zone, which is typically characterized as having moderate levels of contamination that is non-uniform in distribution and fairly mobile. Contaminants in this zone represent a long-term risk to humans and the environment. The remediation approach to this zone would still be active, such as pumping groundwater and treating it for disposal elsewhere or re-injecting it back into the aquifer. This approach is often determined by a cost-benefit analysis of the technologies and regulatory end states. The third zone farthest from the source is a dilute or baseline zone, which is characterized by low levels of contamination. Although this zone may be less complex, it may also be larger in volume and comprise a more extended area. Risk to humans and the environment in this zone is smaller, but not negligible. Remediation approaches may be passive, such as natural attenuation. This conceptual framework of the risk associated with each contamination zone and the different remediation approaches that may be used in each zone



Characteristics
- High levels of contamination
- Perturbed/complex system
- Unstable/evolving conditions
- Significant human/ environmental risk

Strategic considerations
- Aggressive response
- Targeted solutions/technologies
- Specialized knowledge and resources

Characteristics
- Moderate levels of contamination
- Non-uniform system /environment
- Mobile conditions
- Long-term risk to humans/ environment

Strategic considerations
- Active response
- Adaptation of standard solutions
- Cost/benefit analysis drives technology selection
- Establish regulatory standards for end state

Characteristics
- Low levels of contamination
- Low complexity but large volume or extended area
- Slowly evolving conditions
- Small human/ environmental impact

Strategic considerations
- Application of finely tuned or passive solutions
- Firm understanding of end-state criteria
- Cost/time balance – impact on technology selection

FIGURE 3-3 Soil and groundwater remediation strategy: matching solutions to the extent of contamination.
SOURCE: Griffin 2013.

illustrates how investment is aligned to the risk reduction that must be achieved. Ideally, a site would move from active remediation, which is a high-cost and high-energy effort, to more passive remediation, which would be a low-cost and low-energy effort.

SRS is approximately 300 square miles and has a radioactive waste burial ground, operational disposal pits around the site, and seepage basins and associated process sewer lines, similar to the Hanford site. Closure at the site is an integrated effort of Area Completion Projects to address project-specific needs through applied technology, said Dr. Griffin. This effort provides opportunities for innovative development of holistic strategies and results in cost-effective, schedule-efficient, and improved cleanup. Site cleanup is being accomplished by grouping 515 individual waste units into completion areas based on geography and priority. There are currently 14 consolidated completion areas, and 400 of the 515 waste sites have been completed.

A key component of the approach at SRS has been the Core Team Process, which is a formalized, consensus-based process in which individuals with decision-making authority, including representatives from the Department of Energy (DOE), Environmental Protection Agency (EPA), and the South Carolina Department of Health and Environmental Control reach agreement on key remediation decisions. Each organization sends empowered decision makers, and the Core Team reaches specific and actionable agreements. The Core Team engages with technical staff and stakeholders for input into the decision-making process. This process has proven successful at expediting decision making, improving project focus, streamlining documentation, and minimizing the comment and review process, said Dr. Griffin.

Dr. Griffin presented two key Core Team case studies focusing on the F-Area Seepage Basin and the T-Area. Billions of liters of radioactive waste were dumped from separations processing at the F-Area Seepage Basin, which resulted in contamination of the groundwater. The original remediation plan at this location was to pump out and treat groundwater for strontium-90, iodine-129, and uranium. The plan was implemented several years ago, was projected to run for 30 years at a cost of up to $10 million to $12 million per year. Using the Core Team approach, more innovative practices and alternative remedies were considered for this location. The innovative thinking was to work with natural flow patterns rather than fight against them, and sequester and treat groundwater contaminants *in situ*. This system required developing technologies to employ enhanced natural attenuation of contaminants in groundwater using hydrologic flow models, engineered structures, and injection of chemical amendments. This system placed barriers underground to direct groundwater to a treatment zone where alkaline and silver chloride injections resulted in contaminant precipitation out of the water column. The system was successful: the pump-and-treat system was turned off, and spending was reduced from $12 million to approximately $1 million per year.

Although the T-Area did not have radionuclides, it is close to the river and had substantial amounts of solvents and degreasers. The buildings were a source of contamination and were removed, and pump-and-treat and soil vapor extraction systems were installed in 1992 to extract trichloroethylene (TCE). These systems were expected to run for 30 years and cost approximately $1 million per year. TCE concentrations decreased from about 5,000 micrograms per liter to about 600 micrograms per liter over 15 years of operation. Because the concentration levels were lower, replacement of the pump-and-treat and soil vapor extraction systems with an enhanced attenuation approach was considered. The Core Team Process was used to gain regulatory acceptance, and transition to the attenuation approach began. Edible oil, such as vegetable oil, was injected into the ground in emulsified form to create zones for the treatment of TCE by bacterial degradation. The objective was to encourage the TCE plume to flow through a series of anaerobic and aerobic treatment zones to take advantage of natural deg-

Core Team Process at the Savanna River Site

The Core Team Process at the Savannah River Site (SRS) has been highlighted as an exemplary process for moving decision making forward at complex contaminated sites. It is a formalized, consensus-based process in which individuals with decision-making authority, including the Department of Energy, Environmental Protection Agency, and the South Carolina Department of Health and Environmental Control reach agreement on key remediation decisions. The SRS Core Team focuses on making sound, consensus-based decisions for all aspects of the SRS remediation program, from initial characterization efforts through remedial selection and implementation to post-closure monitoring and maintenance.

The Core Team Process operates using four principles of environmental restoration:

- Building of an effective Core Team is essential.
- Clear, concise, and accurate problem definition is critical.
- Early identification of likely response actions is possible, prudent, and necessary.
- Uncertainties are inherent and will always need to be managed.

This process leads to many benefits including

- Traceable history of in-process decision-making increases confidence
- Increased understanding of links between decisions and technical activities
- Clear understanding of the known and unknown results in increased confidence that issues will be identified and managed in time

radation processes. It is projected that, with the attenuation approach, the standards will be met in approximately 10 years. Dr. Griffin commented that they continually work to move away from active to more passive remediation strategies, particularly as budgets become more constrained, because these strategies allow for standards to be met more cost-effectively and often in less time.

3.5 ALTERNATE END STATES

John Applegate, Walter W. Foskett professor of law and executive vice president for academic affairs at Indiana University, described sustainability and alternate end states for site remediation. Dr. Applegate described the evolution of risk relating to cleaning up contaminated sites. Originally, the Comprehensive Environmental Response, Compensation, and Liability Act

(CERCLA), and environmental law more generally, held the basic premise that a site would simply be cleaned up. It was either clean or not. With the growth of risk assessment, however, the realization emerged that there was a spectrum rather than absolutes, and the question of how clean is clean was continually raised. Also emerging from the discussion of risk was the discussion of future use. Understanding exposure is a component of establishing risk; risk is affected by changing exposure to a given contaminant as well as through the cleanup levels achieved at a given site. It became more evident that when end uses of facilities were taken into consideration, calculations of risk and the levels needed to be achieved would change.

In the early 2000s, DOE issued a risk-based end states directive, which made the consideration of future use more central to decision making. This shift meant that long-term stewardship would need to be considered concurrently. Sustainability is literally about time, and it is a useful concept under which risk and long-term stewardship fit well, Dr. Applegate said. Sustainable development in an international context is not about preservation but is about development while providing for the future—what is known as intergenerational equity. Sustainability is about accepting current usage while conserving the quality of the environment and avoiding taking too much from the future, he said. It is about conserving and investing in resources, which is also easily applicable to the remediation context. Sustainability is also often thought to be a process of inclusion, particularly of stakeholders. In that sense, it is similar to the risk-informed decision making that the National Research Council has recommended in the past, he said.

Dr. Applegate presented Rocky Flats as an example of the use of an alternate end state. Rocky Flats is located 15 miles northwest of Denver, where primarily plutonium triggers for nuclear weapons were fabricated. Each step in that process resulted in waste that had environmental consequences. Although a fairly standard industrial process, the process involved exotic materials, such as plutonium. There was extensive contamination of surface soils and underlying aquifers, as well as of numerous buildings that needed to be decontaminated and demolished. Early in the remediation process at Rocky Flats, future end uses were considered. The Rocky Flats National Wildlife Refuge Act of 2001 established and allocated permanent federal ownership of the entire site between DOE and the Fish and Wildlife Service of the Department of the Interior. This meant that examination of risk-based end states at Rocky Flats was enhanced by a given end state, for which the risk was able to be appropriately set. Currently, people are not allowed access to the wildlife refuge, and a retained area for cleanup remains.

Rateb (Boby) Abu-Eid of the Nuclear Regulatory Commission commented that Rocky Flats is a success story because of the focus on risk at the site's end state, which allowed for agreement among stakeholders and regulators. Similarly, the Nuclear Regulatory Commission has NUREG-1757, which provides guidance for decommissioning activities and future land use scenarios. Dr. Abu-Eid stated that conducting an assessment, analyzing costs, and exploring options in discussion with stakeholders and the public is the appropriate approach. He noted, however, that obstacles such as demand for a residential scenario instead of an alternate end state, such as a wildlife refuge, exist.

David Maloney, director of technology for CH2M HILL, discussed the application of risk-based management in site remediation. There are three enablers of the process: the contract, technologies used during cleanup and innovations implemented during the project, and regulatory flexibility. For Rocky Flats, CH2M HILL estimated in 2000 that it would take $37 billion and until 2060 for completion. The first 5 years of the project involved an ongoing dialogue with stakeholders and regulators to better understand the site and project completion. At the end of those 5 years, it was estimated that the project could be completed by 2010 for $7 billion. DOE requested that it be completed 4 years sooner and for $1 billion less, and, in return, CH2M HILL would share the savings from the project. The company completed the project at $350 million under target and in 2005 instead of 2006, which Dr. Maloney attributed largely to technology.

Needed are many technologies, as well as a complete flow sheet with detailed activity levels that includes the risk of the technologies being successful, to help chart the path forward. Dr. Maloney stated that the flow sheet for Rocky Flats, for example, built into the 40,000 activities the technology costs, schedule risks, and externality risks. CH2M HILL's contract with DOE allowed for flexibility to use whatever methodology was needed to reach the end state, which was key to moving forward and completing the project. The end state never changed in the last 5 years of the contract once the wildlife refuge was agreed upon. Flexibility allowed for the incorporation of new technologies as they emerged from one year to the next. This type of contract was more of a partnership with DOE and state regulators, one that required those involved to have the right attitude to make such a partnership work.

4

Incorporating Sustainability into Decision Making for Site Remediation

Geoffrey Fettus, senior project attorney for the nuclear program at the Natural Resources Defense Council, discussed sustainability considerations for ongoing remediation at Department of Energy (DOE) sites. Mr. Fettus expressed the concern that sustainable remediation may be used as a justification for not cleaning up a site to the fullest extent. He provided brief historical context leading to his concerns. Congress enacted the Atomic Energy Act (1946) to protect the public and to encourage the development of the atomic energy industry. The act also established a program to encourage widespread participation in the development and utilization of atomic energy for peaceful purposes to the maximum extent consistent with the common defense and security and with the health and safety of the public. Waste and environmental impacts were neither components of nor considered under this early regulation.

The Energy Reorganization Act of 1974 split off the Nuclear Regulatory Commission from the Atomic Energy Commission, which became the Energy Research and Development Administration and eventually DOE. The Energy Reorganization Act also assigned the Environmental Protection Agency (EPA) as the authority for radiation standards. Mr. Fettus stated that the 1970s saw the development of the Independent Review Group (IRG), which was an effort to develop a coherent national nuclear waste disposal policy. The IRG consisted of 14 federal agencies and other key stakeholders. It evaluated possible disposal options and locations for U.S. nuclear waste repositories. The Nuclear Waste Policy Act of 1982 directed DOE to develop a repository, the Nuclear Regulatory Commission to license the repository, and EPA to set the environmental protection standards for which the Nuclear Regulatory Commission would license the repository. Cleanup efforts through the 1990s and 2000s, he noted, experienced cost estimates rising to the hundreds of billions of dollars and contentious disagreements with states over cleanup goals, end states, and long-term stewardship.

Mr. Fettus commented that the challenge of cleaning up sites such as Hanford or the Savannah River Site is enormous and understandably will cost millions of dollars; however, positive lessons can inform future actions. The Rocky Flats (see Chapters 1 and 3) and Fernald, Ohio, sites (see Chapter 1) are useful examples of compromise over endpoints between stakeholders and the public. Unique to the Rocky Flats site, stated Mr. Fettus, was the State of Colorado's desire for DOE to finish the site and cease its presence in the state, which has not been true of other states in which DOE sites have been located. The budget for cleanup will remain a key element for successful programs moving forward. Having a stable cleanup budget will allow DOE to complete ongoing cleanup and to maintain current infrastructure.

Mr. Fettus stated that DOE is largely self-regulating and that the Atomic Energy Act should be amended to end environmental exemptions for DOE so that EPA and state regulatory agencies have the authority to impose compliance with standards. Needed are baseline statutory and regulatory requirements for cleanup projects so that all agencies and stakeholders involved know the endpoint. Many of the disagreements among the stakeholders and agencies, he stated, are due to the lack of ability to set clear and binding statutory and regulatory requirements. Once clear, enforceable cleanup standards are in place for the dozens of remaining DOE contaminated sites, more holistic approaches to sustainable remediation decision making can be implemented without risk of the process being abused to justify cost savings and less cleanup.

4.1 SUSTAINABILITY FRAMEWORKS AND CASE STUDIES

Buddy Bealer with the Sustainable Remediation Initiative (SRI) presented frameworks for sustainable remediation. SRI is a collaboration of organizations—such as the Sustainable Remediation Forum (SURF), Interstate Technology and Regulatory Council (ITRC), and American Petroleum Institute (API)—that seeks to promote the understanding and implementation of sustainable remediation. He stated that when considering sustainable remediation, it is important to remember that sustainable practices are dependent on many circumstances, such as site conditions. Mr. Bealer gave an example of how water use in Pennsylvania would be considered sustainable under a given context, but the same situation in California under a water shortage would quickly be considered non-sustainable. The same situation results in a different impact, based on conditions at different locations, so evaluation of sustainable remediation practices depends on place-based consideration.

Similarly, when ITRC was developing the framework for green and sustainable remediation, it realized that the sustainability of a given remediation technology depends on specific site conditions. Often in subsurface remediation, such as when groundwater is pumped up and treated, an initial mass of contaminant is removed, but with time the concentration that is pumped up diminishes, resulting in concentrations levels approaching an asymptote with time. Ongoing treatment results in higher costs but lower treatment efficacy (Figure 4-1).

Such a scenario often raises the question of when it is appropriate to stop treatment, especially if regulatory levels have not yet been attained. If there is no receptor or risk to human health or the environment from the contaminant, for example, then should indefinite costs and efforts be required to further treat a contaminant, especially if that contaminant would naturally decompose in place? When addressing this type of issue, many

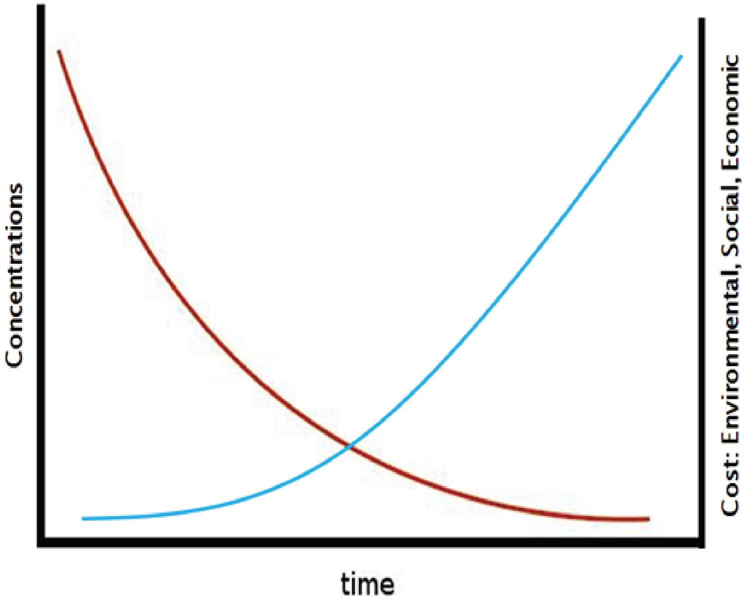


FIGURE 4-1 In a remediation scheme, contaminant levels in the subsurface do not decrease over time as much as during previous pumping, resulting in concentration levels approaching an asymptote. Continual pumping results in increasing costs for a project.
SOURCE: Bealer 2013.

environmental, social, and economic considerations must be considered, as well as the many trade-offs among these. Needed is a framework that can be applied to many projects to help sift through these important issues. Three current frameworks try to accomplish this sifting: SURF's Framework for Integrating Sustainability into Remediation Projects; ITRC's Technical and Regulatory Guidance Document, Green and Sustainable Remediation: A Practical Framework (GSR-2); and ASTM's Green Remediation Guide (WK35161) and Standard Guide for Integrating Sustainable Objectives into Cleanup (E2876-13).

Mr. Bealer explained the common elements to all these frameworks are complementary to each other:

- Stakeholders and decision makers are important, and it is necessary to engage and communicate with them throughout the process.
- Processes should be in place to filter options that the responsible party, decision makers, and other stakeholders can agree on.
- The project status should be clearly defined, possibly by using a conceptual model that includes all the elements of sustainability. This allows all parties to clearly understand and agree on the scope and extent of a project.
- An evaluation process to assess the available remedial options is needed. There should be clear project goals, metrics, and tools to assess the project's progress toward completion.

Mr. Bealer stated that sustainable remediation is not new and is a formalized and systematic process of remediation strategies. Frameworks assist project managers to be more systematic when incorporating sustainability principles into a project.

Nicholas Garson, president of SURF also discussed the incorporation of sustainability into remediation approaches. SURF is a nonprofit collaboration with a mission to maximize the overall environmental, societal, and economic benefits from the site cleanup process by advancing the science and application of sustainable remediation, developing best practices, exchanging professional knowledge, and providing education and outreach. Mr. Garson stated that sustainable remediation focuses on the triple bottom line—environmental, economic, and social benefits.

Environmental footprint reduction includes efforts such as reducing the amount of resources used on a project, reducing air pollution generated by treatment systems, reducing energy usage, considering alternative energy sources for a treatment system, using the waste from another industry in a treatment system, and finding an alternative use for the waste generated from a remediation project. Economic benefits include realizing savings when employing a remedy, such as finding a beneficial reuse for waste

> "The overall value proposition is that using sustainability as a framework for remediation projects helps reduce long-term liabilities and costs. For projects under this framework, it is often found that investing more money upfront for a cleanup project is a better option than extending expenditures over a long period of time."
>
> *Nicholas Garson, October 31, 2013*

products. Often a reduction in an environmental footprint reduces overall costs, said Mr. Garson. Societal considerations include transparent communication with the public and stakeholders. Safety is also a consideration when maximizing societal benefits, especially with staff involved on large excavation projects or the general public located near a project with heavy truck traffic. The overall value proposition is that using sustainability as a framework for remediation projects helps to reduce long-term liabilities and costs. For projects under this framework, it is often found that investing more money up front for a cleanup project is a better option than extending expenditures over a long period of time.

Mr. Garson discussed some of the challenges to implementing sustainable remediation. Currently the practice of sustainable remediation is more qualitative than quantitative; however, metrics and tools are continually being developed to better quantify and assess the benefits of sustainable remediation. There have also been challenges to employing sustainable remediation because organizations lack the regulatory infrastructure to support it. There is a need for more case studies to illustrate successful sustainable remediation projects, Mr. Garson said. It is important to convey to the public, stakeholders, and regulators that sustainable remediation is not about doing less comprehensive cleanup.

Mr. Garson presented case studies of successful sustainable remediation projects. The first case study involved a site at a former manufacturing facility at the King County Airport in Seattle. The challenge was to clean up trichloroethylene (TCE) and other chlorinated solvents in groundwater in a way that would have the lowest footprint in terms of material use, energy use, and disruption to an active facility. Part of the sustainable remedy came from an unlikely source. A beverage distribution facility in Seattle disposed of whole pallets of damaged soda bottles and cans in landfills. The remediation team realized that the sugar in the soda would serve as an excellent substrate for bacteria that would break down the chlorinated solvents. In this bioremediation strategy, soda from the rejected pallets was injected into the groundwater, and bacteria broke down the sugar into byproducts that served as substrates for other bacteria that were able to degrade the chlorinated solvents. This example demonstrates the environmental, social, and economic benefits of using a waste product acquired for free from one industry, keeping it out of landfills, and using it instead to clean up contamination to meet remediation objectives.

The second case study involved a chemical recycling facility in Kansas City that was contaminated with chlorinated solvents and metals. The project management team engaged the public and stakeholders to develop a plan for a green space restored with native grasses as the end state for the site. Several practices were put in place to complete the remediation strategy in a sustainable manner: idling was not allowed for heavy equipment, contaminated groundwater was treated on site and reused, environmentally preferred materials were used for part of the on-site construction, and the grass mix planted required minimal mowing to limit future impacts from maintenance.

The third case study involved a site in Seattle that had polychlorinated biphenyls (PCBs) in storm water from legacy contamination in the on-site storm drains. EPA's Region 10 office provided the project management team with sustainable remediation guidelines. The guidelines, all of which were met, included the following:

- Energy conservation efficiency through 100 percent use of green power, met by purchasing 100 percent renewable energy.
- Cleaner fuels, diesel emissions controls and retrofits, and emission reduction strategies, met by adding to contractor specifications.
- Water conservation and efficiency approaches, met by filtering storm water used for backflushing; no supplemental water was needed.
- Sustainable site design, met by allowing for future reductions of electrical power requirements.
- Industrial material reuse or recycling within regulatory requirements, met by reusing steel enclosures, piping, and equipment designed for 20 years.
- Recycling of materials generated at or removed from the site, met by recycling asphalt, excavating soil reused for backfill, and using offsite soil disposal via rail.
- Environmentally preferable purchasing, met by using post-consumer recycled paper and iron materials made from recycled metal.
- Greenhouse gas emission reduction technologies, met by adding to contractor specifications for heavy equipment.

This case study demonstrated the ability to incorporate sustainability principles into EPA cleanup processes, which allowed for the site to be remediated in a timely and cost-effective way.

4.2 OTHER AGENCIES' PERSPECTIVES ON INCORPORATING SUSTAINABILITY INTO SITE REMEDIATION

Walter Mugdan, director of the Emergency and Remedial Response Division in EPA Region 2, discussed cleanup efforts in New York State. A sustainable remedy in the context of EPA Superfund cleanup efforts generally refers to green remediation within a selection of remedies based upon the nine CERCLA criteria, Mr. Mugdan explained. Also considered are the long-term viability, reliability, and protectiveness of a remedy, which relate to the social, economic, and environmental pillars of sustainability.

Mr. Mugdan provided two examples of how sustainability considerations are incorporated into Superfund cleanup sites. The first example was the Gowanus Canal, a 1.8-mile-long waterway in Brooklyn, New York, that has had three manufactured gas plant sites along its banks since the 1860s. The highest levels of contamination along the canal outside of the manufactured gas plant site locations are found to be in the percent range of polycyclic aromatic hydrocarbons (PAHs). The canal is also contaminated to a lesser extent with PCBs and heavy metals. In addition, the canal receives sewage solids from combined sewer overflows (CSOs) from the city. Older cities have combined storm water and sewer pipes that overflow into local waterways when runoff exceeds the capacity of storm water channels during heavy rain.

Although historically industrial, the area surrounding the canal is now high-end residential neighborhoods. With years of sediment loading, the canal is only 100 feet wide and about 10 feet deep at high tide. The canal is poorly flushed, with little tidal difference across its length, resulting in heavy flows of raw sewage during heavy rain fall. The site was added to the Superfund list in 2010, and a plan was issued in December 2012. After a 4-month public comment period, EPA had the largest administrative record in Region 2's history (all the comments and responses take up 310 three-ring binders). The Record of Decision (ROD) was issued in September 2013 to dredge 600,000 cubic yards of soft sediment and to stabilize and cap the underlying native sediments, which are contaminated to a depth of about 100 feet. The ROD also requires that retention tanks be installed to prevent CSOs from spilling raw sewage into the canal. The total budget was approximately $500 million, and the project has an expected timeframe of 8 to 10 years.

Mr. Mugdan listed the sustainability considerations for the Gowanus Canal cleanup as they relate to the social, economic, and environmental pillars. Social considerations include a high degree of local interest and support, a very informed and engaged public, the largest Community Advisory Group (CAG) in the nation with approximately 60 members, and overwhelming public support for cleanup, particularly for CSOs. Economic considerations include high expenses for potential responsible parties (PRPs), estimated at $506 million, including $78 million for CSOs; the National Grid's (public utility) responsibility for remediation of three sites adjacent to the canal with a possible cost of approximately $500 million; a real estate boom with a 52 percent property value increase from 2008-2012; and local job creation. Environmental considerations include capping soft sediments in the canal after dredging, despite concerns about the long-term reliability of such a cap. Additionally, New York City asserts that the CSOs have background levels of contaminants that need not be addressed by the Superfund program. These discharges, however, carry contaminants that can be two to three times higher than background levels.

Mr. Mugdan also discussed the Hudson River site, which runs 40 miles up the river from Albany to the location of two General Electric facilities that dumped polychlorinated biphenyls into the river. This site is one of the largest Superfund remedial projects under way. Approximately 500 acres of the upper Hudson will be dredged, removing 2.5 million cubic yards of sediment at an estimated total cost of $2 billion. The sediments will be dewatered after removal and disposed of in permitted landfills. The water will be treated to lower than maximum contaminant levels (MCLs), and a habitat layer will be backfilled and tens of thousands of plants re-established. After fighting it for 20 years, General Electric has finally accepted the plan and has been moving forward with the cleanup very well, said Mr. Mugdan.

As of September 2013, more than 1.9 million cubic yards have been dredged (>71 percent of expected total), and there is lower than expected re-suspension of sediments with virtually no exceedance of standards. Mr. Mugdan explained the social, economic, and environmental sustainability considerations for the Hudson River cleanup. The social considerations include initial opposition from local governments and residents, which have all but disappeared since cleanup started. From an economic standpoint, the cleanup is very expensive for General Electric (approximately $2 billion over 10 years), but it has added 500 jobs to the local economy. Finally, there are environmental concerns about the long-term maintenance of sediment caps; however, the caps remained unaffected after a 100-year flood event in 2011.

Maureen Sullivan, director of environmental management in the Department of Defense's (DOD's) Office of the Deputy Under Secretary of Defense discussed DOD's efforts to incorporate sustainability into cleanup activities. DOD modified the definition of sustainability in Executive Order 13514 to better align with its mission, Ms. Sullivan said. DOD's vision of sustainability is to maintain the ability to operate into the future without decline either in mission or in the natural or manmade systems that support operation. This definition aligns more directly with DOD's mission. Sustainability is often defined as a three-legged stool—one leg for social, one for environmental, and one for economic considerations. The DOD, however, substitutes its mission for the social leg of the sustainability stool.

DOD has approximately 38,000 sites and invests up to $2 billion a year in cleanup activities. Currently, 76 percent of those sites are considered response complete because there is an ROD and the cleanup goals of that ROD have been met. Those sites will continue to be monitored before being considered closed. The remaining sites comprise a liability for the DOD of $28 billion, second only to military benefits. Cleanup sites are segmented into three major categories. First are sites on active installations that have a mission to perform. Second are bases that were closed under the Base Realignment and Closure Act (BRAC), so there is currently no mission. The third category consists of former defense sites, that is, bases that were closed prior to 1986 and no longer belong to DOD. They might be owned by private landholders, state governments, local governments, or other federal agencies. Those sites that DOD is cleaning up that are listed as Superfund sites on the National Priority List are subject to an interagency agreement with EPA, which is the co-lead on the sites. DOD works directly with the states on the remaining sites.

DOD has stated a goal that 90 percent of the sites will be response complete by 2018 and 95 percent of the sites will be response complete by 2021. The Strategic Environmental Research and Development Program is reviewing the remaining sites to develop an approach to addressing the contamination at those locations. DOD does not apply sustainability to the cleanup program as a formal process, but it does implement green remediation strategies when possible. The Massachusetts Military Reservation on Cape Cod, for example, has a wind turbine that provides the energy to run the cleanup activities at that site. The closest example of DOD efforts to address a site's sustainability, Ms. Sullivan stated, can be found in the BRAC sites, where DOD is collaborating with local economic development groups to redevelop those communities.

One challenge to incorporating sustainability into site cleanup is that the DOD process and its interaction with regulators are very regimented and have been established for decades, said Ms. Sullivan. The DOD is very averse to changing the process. Other challenges arise from a multitude of definitions and misconceptions around sustainability and its application to a cleanup process. Regulators have been willing to work with DOD program managers as they try new and different technologies, but the program managers need to have certainty that innovative decisions and actions will be supported by the regulators. That support will help with the risk-averse nature of the agency. Funding will also be an important consideration moving forward, said Ms. Sullivan. The ultimate acceptance of a paradigm shift will occur when sustainable solutions are funded, which will send a strong signal of culture change.

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Volume II

Workshop 2 Summary

Jennifer A. Heimberg, Rapporteur

1

Introduction and Background

The second workshop, held on January 9-10, 2014, focused on post-closure controls and assessment of long-term performance of site remedies. Additionally, best practices for risk-based remediation decisions for contaminated sites were discussed and highlighted. The agenda for this workshop can be found in Appendix E.

This workshop featured a range of expert briefings as well as extensive discussion sessions. The workshop was organized into four sessions, discussed in Chapters 2 through 5 of this report:

1. Effective and efficient risk-informed decision making;
2. Approaches for assessing long-term performance of site remedies;
3. Effective post-closure controls, monitoring, and long-term stewardship; and
4. Identification of best practices for improving remediation/closure/post-closure of challenging sites.

All but the fourth session followed a similar format: an expert introduced the subject matter and then presenters highlighted case studies on that subject. A discussion was held after each presentation. The fourth session involved a round-robin discussion, which allowed the invited speakers representing tribal, federal, state, regulatory, academic, and practitioners to express viewpoints on best practices for effective site remediation. The final chapter of this report, Chapter 6, summarizes the goals of the workshops and the participants' perspectives on each.

All workshop presentations are available online: http://dels.nas.edu/Past-Events/Best-Practices-Risk-Informed-Remedy/AUTO-8-12-72-G?bname=nrsb. This summary was written by a rapporteur to present the various ideas and suggestions that arose in the workshop discussion and to synthesize the main discussion items. It does not include conclusions or recommendations, nor does it cover the full spectrum of issues around this topic.

The remainder of this chapter is based on a white paper (Heimberg 2014) distributed to the workshop participants and is intended to provide the reader with background information regarding selected nuclear legacy

Box 1.1
Definitions of Waste Types

Definitions of the types of radioactive wastes are listed below.

Waste Types Definitions

High-level Waste (HLW)

HLW is defined in U.S. Code, Title 42, Section 10101 as

(A) the highly radioactive waste material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and

(B) other highly radioactive material that the Commission, consistent with existing law, determines by rule to require permanent isolation.

It is current U.S. policy to dispose of HLW in a deep geologic storage facility.

Transuranic (TRU) Waste

TRU waste is defined in the Waste Isolation Pilot Plant Land Withdrawal Act, Public Law 102-579 as

waste containing more than 100 nanocuries of alpha emitting transuranic isotopes [atomic number greater than 92] per gram of waste, with half-lives greater than 20 years, except for:

- *High-level radioactive waste;*
- *Waste that the Secretary [of Energy] has determined, with the concurrence of the Administrator [of the Environmental Protection Agency], does not need the degree of isolation required by the disposal regulations; or*
- *Waste that the Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with part 61 of title 10, Code of Federal Regulations.*

waste sites that are likely to require post-closure controls and long-term management.

1.1 REMEDIATION OF LEGACY WASTE SITES

Legacy wastes can be roughly grouped into four categories: contained and/or stored waste, buried waste, contaminated soil and groundwater, and contaminated building materials and structures. Examples of contained or stored waste are wastes in tanks, canisters, and stainless steel bins. For example, large quantities of high-level radioactive wastes are stored at Department of Energy (DOE) legacy sites in tanks. Buried wastes include radioactive and chemically contaminated wastes disposed of in near-surface pits and trenches (see Box 1.1). These wastes may or may not be stored in

It is current U.S. policy to dispose of TRU waste in a deep geologic storage facility. However, waste buried prior to issuance of the directive above (established in 1970) nonetheless meets the definition of TRU waste. This requires excavation of burial pits and trenches in order to retrieve the TRU waste.

Spent Nuclear Fuel (SNF)
SNF is defined in the Nuclear Waste Policy Act of 1987 (as amended, 2002) as
The term "spent nuclear fuel" means fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

Low-level Radioactive Waste (LLRW)
LLRW (also referred to as low-level waste or LLW) is defined in the Low-Level Radioactive Waste Policy Act of 1985 (P.L. 99–240) and the Nuclear Waste Policy Act of 1987 (as amended, 2002) as
The term "low-level radioactive waste" means radioactive material that—
(A) is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or by-product material as defined in section 11e(2) of the Atomic Energy Act of 1954 [42 U.S.C. 2014(e)(2)]; and
(B) the [Nuclear Regulatory] Commission, consistent with existing law, classifies as low-level radioactive waste.

Mixed Low-level Waste
Mixed LLW is defined as LLW determined to contain both source, special nuclear, or byproduct material and a hazardous component.

containers prior to burial (NRC 2005).[1] Contamination of soil and groundwater occurred through intentional (following past environmental practices) and accidental (e.g., leaching of buried wastes or leaking of tanks) releases. Building materials that are considered waste were contaminated by nuclear material (e.g., pipes, filters, and pumps). The structures themselves may also be contaminated.

Remediation decisions for closure and post-closure controls are site specific because of the complexities of each site. Several factors contribute to a site's remediation complexity, including its size, location, geology, and climate; activities associated with its original and current missions; relationships with local regulators and stakeholders; and the type and scope of the principal legacy wastes.[2] Several DOE nuclear legacy sites provide background on the complexities and diversity of sites, wastes, and challenges related to long-term remediation issues (DOE 2001a, 2001b). The Hanford site, Savannah River Site (SRS), Idaho National Laboratory (INL), and the Oak Ridge Reservation (ORR) are discussed below.

Hanford

The Hanford site is located in southeastern Washington and covers an area of about 580 square miles. The Colombia River passes through the north portion and borders the south-eastern quadrant of the site (see Figure 1-1). It is located within the Columbia Plateau between the Cascade Mountains (to the west) and the Rocky Mountains (to the east) (Horton 2000). The subsurface geology contains horizontal sedimentary layers and layered basalt lava flows, and vertical clay dikes cut across these horizontal layers in some areas of the site (NRC 2010). Hanford has a cold, desert climate with light and occasional moderate rain and snow.

Hanford was established in 1943 by the U.S. government with a mission to produce plutonium and perform research on plutonium production. Plutonium was produced at the site through three main steps: reactor fuel fabrication, irradiation of the fuel in reactors to produce plutonium, and chemical processing of the irradiated fuel to separate and recover the plutonium. Fuel fabrication took place in the southeastern portion of the site, near the Columbia River, in a location designated as the 300 Area (see Figure 1-1). The fuel was irradiated in nine production reactors located in

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[1] In 1970 the U.S. Atomic Energy Commission identified transuranic (TRU) waste as a separate category of radioactive wastes (see definitions in Box 1.1). Prior to this determination, wastes meeting the definition of TRU waste were often buried with low-level wastes (LLW). After 1970, TRU wastes were placed in retrievable storage (DOE 2000).

[2] Legacy wastes are wastes generated during the development, production, and testing of nuclear weapons for the Manhattan Project and the Cold War. They can contain a wide range of radioactive materials and/or hazardous chemicals.

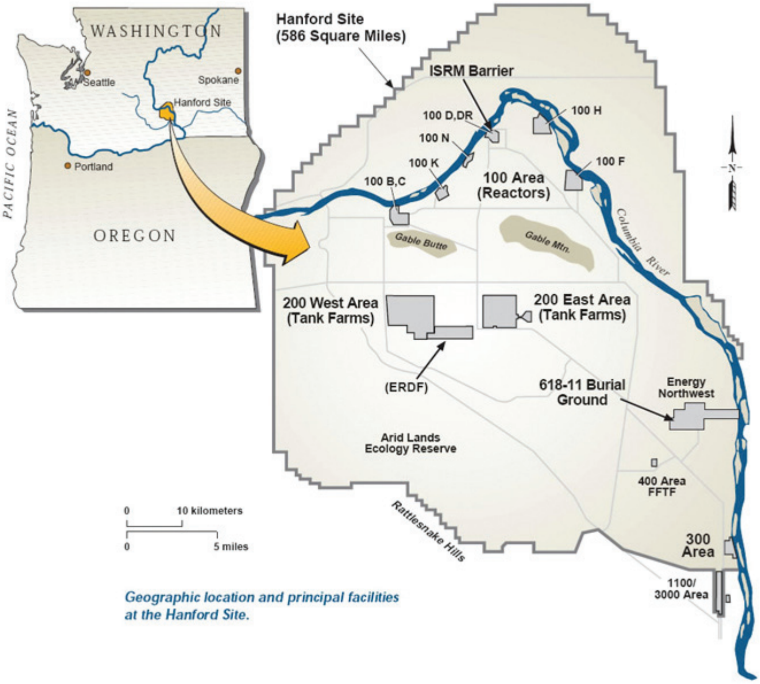

FIGURE 1-1 A map of the Hanford site showing the locations of the major legacy production facilities described in the text. The 100 Area housed the production reactors. The 200 Area (also called the Central Plateau) housed the chemical processing plants. The 100 Area housed the fuel fabrication facilities.
SOURCE: http://www.hanford.gov/page.cfm/ProjectsFacilities.

the north portion of the site along the Columbia River (100 Area). Chemical processing of the irradiated fuel took place in the 200 Area, also referred to as the Central Plateau. The plutonium production mission at Hanford ended in 1989 (DOE 2001b). The site is currently undergoing environmental remediation by DOE's Office of Environmental Management (EM).

Legacy Wastes

The chemical separation processes in the 200 Area generated the largest volume of stored legacy waste at Hanford (DOE 2001b). Several hundred thousand metric tons of chemical and radioactive waste were produced, most of which is contained in large underground storage tanks (DOE 2001b). The tanks currently store approximately 56 million gallons of high-level waste (HLW) and await final remediation (DOE 2013a). This waste is stored in 149 single-shell and 28 double-shell tanks. The acidic HLW was neutralized with sodium hydroxide and has segregated into two main components: a thick hydroxide sludge (the HLW fraction) and a liquid salt solution. The salt solution is rich in sodium nitrite-nitrate and sodium hydroxide but also contains radioactive elements (cesium and strontium). Additional tank wastes and wastes from chemical processing operations were intentionally or accidentally discharged into the subsurface (DOE estimates that up to 67 of the single-shell tanks have leaked waste into the subsurface). Starting in the 1980s, the drainable salt solution was pumped from the single-shell tanks into the double-shell tanks to reduce the risk of further leaks.

The tank waste is a significant remediation challenge. Under current plans it will be retrieved and stabilized into high activity waste (HAW) and low activity waste (LAW) (once the cesium and strontium are removed from the salt solution). The former will be disposed of off site and the latter on site; both will be stabilized in glass (i.e., vitrified). Once the waste has been removed, the tanks will be stabilized and entombed in place. Processing facilities to separate the wastes between high and low activity and convert each to a stable form have yet to be built and made operational. The Waste Treatment and Immobilization Plant (WTP) is the intended solution for this challenge but its construction has experienced numerous delays.

Hanford's waste burial grounds include both lined and unlined trenches. Burial of solid wastes—low-level waste (LLW), mixed LLW (MLLW) and, prior to 1970, transuranic (TRU) waste—occurred primarily in open pits and near-surface trenches. An estimated 25 million cubic feet of solid waste was buried in 175 trenches (Brockman 2010).

Radioactive and chemical contaminants are present in surface and subsurface soils and groundwater throughout the site. At the start of cleanup in the late 1980s, DOE estimated that 25 to 35 percent of groundwater under the Hanford site was contaminated (DOE 2001b). More than 350 billion gallons of liquid were discharged to the ground in the 200 Area, resulting in an estimated 32,000 cubic meters of TRU-contaminated soil (DOE 2000). Groundwater contamination is being actively remediated in some cases and monitored in others. It is anticipated that residual soil and groundwater contamination will remain at Hanford after cleanup activities have been completed and will require long-term stewardship.

A large number of buildings containing radioactive or chemical materials were located throughout the Hanford site at the start of cleanup activities (DOE [2001b] estimated up to 800 buildings). The 100, 200, 300, and 400 Areas house shut-down reactors, chemical separation plants, waste-handling facilities, and various support facilities no longer in use. Since 1989, many of these facilities have gone through deactivation and decommissioning (D&D). Six of the nine production reactors have been placed in interim safe storage (through a process called "cocooning"[3]); two of the three remaining reactors are also planned for cocooning. The cocooned reactors will remain on site until the radioactivity decays to safer levels and decisions can be made on final disposition. The remaining reactor, B Reactor, has been partially decommissioned and preserved as a national landmark.

Issues Related to Long-Term Remediation

Most of the wastes generated by the EM cleanup program will be disposed of on site. Two large Resource Conservation and Recovery Act (RCRA)-compliant waste storage facilities have been built to dispose of these wastes. The Environmental Restoration Disposal Facility (ERDF) is located in the Central Plateau (see Figure 1-1). It became operational in 1996 and currently stores 14 million tons of contaminated waste, LLW and MLLW.[4] The ERDF's current capacity is 18 million tons of waste; it is designed to be expanded as needed.

The Integrated Disposal Facility (IDF) will be used to dispose of the LLW and MLLW from tank treatment operations (e.g., vitrified LAW) and other on-site remediation activities (such as D&D) (DOE 2013b). The IDF's capacity is 165,000 cubic meters. A 7-foot-thick liner at its base has been designed to collect leachate to reduce the risk of soil contamination beneath the containment facility. The IDF is not yet operational.

The wastes stored at the ERDF and IDF will remain on site with long-term post-closure controls and monitoring. Planning the size of these facilities based on current predictions of waste volumes can be difficult. Many of the DOE sites share the same key challenges including unpredicted compaction of the stored waste and accurate forecasting of waste volumes (Benson 2008).

Final retrieval and remediation decisions have not yet been made for much of Hanford's tank waste. For example, EM is in the process of proposing remediation decisions for the Waste Management Area C (WMA C) in the 200 Area. This decision requires consideration of different tank waste retrieval technologies in contaminated soil.[5] The WMA C decisions may impact future single-shell tank farm remediation decisions.

After active remediation activities of the full site are completed, wastes

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[3] The cocooning process leaves the reactor core intact after it is encased with concrete. The surrounding reactor building is decontaminated and demolished and a safe storage enclosure roof is installed.

[4] Information on the ERDF can be found at: http://www.hanford.gov/page.cfm/erdf.

[5] For more information, see http://www.hanford.gov/files.cfm/WMA-C%20INFO%20SHEET.pdf.

will remain on site in LLW and MLLW disposal facilities (e.g., the ERDF and IDF), in the residual contamination of soil and groundwater, and as entombed buildings and structures. Post-closure control and monitoring to ensure effectiveness of the remedies will be part of the final remediation of this site.

Savannah River

At 310 square miles, the Savannah River Site is slightly smaller than the area within the Washington, DC, beltway. It is located in rural south central South Carolina, 20 miles south of Aiken and 25 miles northeast of Augusta (see Figure 1-2). The Savannah River defines its southwest border. The site, located on the Atlantic coastal plain (Denham 1995), is dissected by tributaries to the Savannah River. The subsurface contains heterogeneous coastal-plain sediments. SRS has a warm, humid temperate climate with hot summers and no dry season.

SRS produced tritium and plutonium for the U.S. government beginning in the early 1950s. Five production reactors, two chemical separation plants, and fuel fabrication facilities were designed and built to produce plutonium for the nation's nuclear arsenal. Additionally, a heavy water extraction plant was built to supply heavy water for SRS reactor operations. From 1953 to 1988, SRS produced approximately 36 metric tons of plutonium (DOE 2001b). SRS no longer produces plutonium but continues to process, store, and recycle nuclear material. None of the original five production reactors is active; two are used for nuclear material storage. One chemical processing plant (H Canyon) is still in operation. The Tritium Extraction Facility (TEF), operational in 2007, is a critical source of tritium for the U.S. nuclear weapons stockpile. SRS remains an active DOE research site with research and development activities conducted at the Savannah River National Laboratory (SRNL) and other laboratories on site.[6]

Legacy Wastes

At the start of cleanup activities in the late 1980s, SRS reported approximately 35 million gallons of liquid high-level waste stored in 51 underground tanks (DOE 2001b). These wastes were created as a result of SRS's past chemical (plutonium and irradiated fuel) separation activities. Wastes within the tanks were neutralized with sodium hydroxide and have since separated into HLW sludge and a salt solution (similar to the tanks at the Hanford site). Current mission activities also produce additional HLW

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[6] Other laboratories and research organizations include a timber and forestry center run by the U.S. Forest Service and the Savannah River Ecology Laboratory run by the University of Georgia.

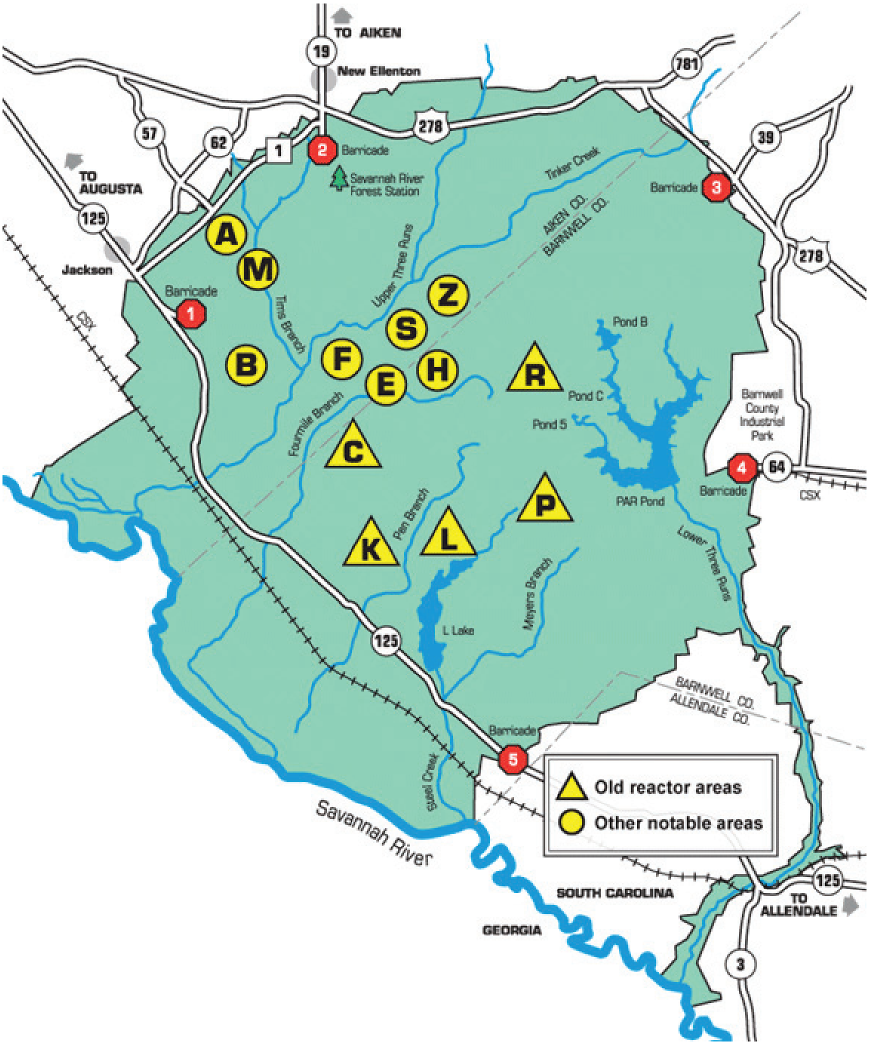

FIGURE 1-2 A map of the Savannah River Site. The triangles indicate locations of SRS's five production reactors (the C-, K-, L-, P-, and R-reactors). Circles indicate location of other major facilities including A: the Savannah River National Laboratory and the Savannah River Ecology Laboratory, M: fuel fabrication facilities, E: onsite disposal of low-level waste, H: H-canyon and the Tritium Extraction Facility (TEF), F: chemical processing (F-Canyon and FB Line) and tank farms, S: the Defense Waste Processing Facility (DWPF), and Z: the Saltstone facilities.
SOURCE: http://www.srs.gov/general/tour/online.htm.

waste. More than half of the tanks are double shelled (27 are double-shell tanks, 24 are single-shell tanks; notably, all of the tanks at SRS have a secondary containment sump). Six of the single-shell tanks have been grouted and closed;[7] 12 are suspected of leaking.

SRS has built and operated several large-scale facilities to process stored tank wastes: the Defense Waste Processing Facility (DWPF, see Area S in Figure 1-2) and two Saltstone facilities (see Area Z in Figure 1-2). The DWPF has been used to stabilize the HLW fraction of the tank waste (i.e., the HLW sludge) by vitrifying it in a glass matrix form (completed in April 1996); the vitrified waste is stored at SRS awaiting a federal repository. The saltwaste solution is currently being processed by the Actinides Removal Process (ARP) and Modular Caustic-side Solvent Exchange Unit (MCU). The removed actinides and cesium are fed to the DWPF for vitrification; the decontaminated salt solution is treated in the Saltstone Production Facility (SPF) through grouting and disposed of as LAW in the Saltstone Disposal Facility (SDF). The ARP/MCU is a pilot for the Salt Waste Processing Facility (SWPF), which has been designed to address the remaining radioactive salt waste within the tanks but it is not yet operational. This remediation decision is notably different from the vitrification of LAW at the Hanford site (which requires LAW to be stabilized in a glass matrix).

Radioactive and chemically contaminated wastes were disposed of in basins and burial grounds. One of the largest burial grounds, the Old Radioactive Waste Burial Grounds (ORWBG), covers roughly 76 acres (the ORWBG is located in area E in Figure 1-2). Currently an interim remediation measure is in place for the ORWBG—a 4-foot-thick soil cover to reduce ground-level radiation exposure, contact with rain water, and leaching waste into groundwater. DOE estimates that there are 4,500 cubic meters of buried TRU-waste at SRS (DOE 2000, Table 1).

Radioactive and chemically[8] contaminated waste has been identified in soil, surface water, and groundwater. Approximately 300 million cubic meters of groundwater and nearly 9 million cubic meters of soil and sediment have been contaminated (NRC 1999). Contamination is treated in a number of ways at SRS including pump and treat and monitoring. Residual contamination will remain on site after active remediation is complete.

SRS also has waste from contaminated building materials and structures. Contaminated legacy waste facilities have been identified for deactivation and decommissioning (D&D). Some have already completed D&D activities creating contaminated waste. They include a portion of the tank farms, the heavy water and fuel fabrication facilities, one of the chemical

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[7] The following tanks in the F area have been closed: 5, 6, 17, 18, 19, and 20.

[8] Most of the chemical contamination was trichloroethylene (TCE).

processing plants, and three of the five production reactors (C, P, and R reactors).

Issues Related to Long-Term Remediation

Some legacy wastes will remain on site at SRS as mentioned previously. Most of the LLW generated during remediation activities will remain on site at the SDF and a facility in Area E (see Figure 1-2).[9] This LLW, residual contamination of soil and groundwater, and entombed buildings and structures (e.g., the underground storage tanks) will remain on site with long-term post-closure controls.

Remedies at SRS include waste stabilization (e.g., vitrification, saltstone), capping, waste removal, grading, monitoring, and assessments. Monitoring programs are in place or planned throughout the site. Some of the remaining remediation challenges for SRS are the processing of salt waste, SNF, and plutonium[10] remaining on site.

Idaho National Laboratory

The Idaho National Laboratory (INL) occupies approximately 890 square miles in a remote desert area along the western edge of the upper Snake River Plain. The closest population center, Idaho Falls, is approximately 25 miles to the east (see Figure 1-3). The site is flat, high-desert terrain with buttes and an average elevation of 5,000 feet; the subsurface geology is comprised of fractured basalt lava flows and sediment (Anderson 1999) that hosts the Snake River Plain Aquifer.[11] The site has a cold and semi-arid (steppe) climate with light rain and snow and summertime thunderstorms.

U.S. government activities at the site have a long history. The government established the Naval Proving Ground in the 1940s to test fire World War II Pacific Fleet guns.[12] In 1949, the site was expanded and converted to the Nuclear Reactor Testing Station, where approximately 100 reactor concepts were built, tested, and operated including reactors for naval nuclear propulsion. From 1953 to 1992, the Idaho Chemical Processing Plant reprocessed and extracted uranium and plutonium from U.S. government

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[9] See http://www.srs.gov/general/outreach/srs-cab/library/meetings/2011/fb/201107_solid waste.pdf.

[10] A Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF) will process plutonium into fuel for nuclear power facilities. The MFFF is delayed and not yet operational.

[11] The Snake River Plain Aquifer is a sole source aquifer supplying water to most of Idaho's 300,000 southeastern residents (see http://www.deq.idaho.gov/media/552772-newsletter_0505.pdf).

[12] See http://energy.gov/em/idaho-national-laboratory.

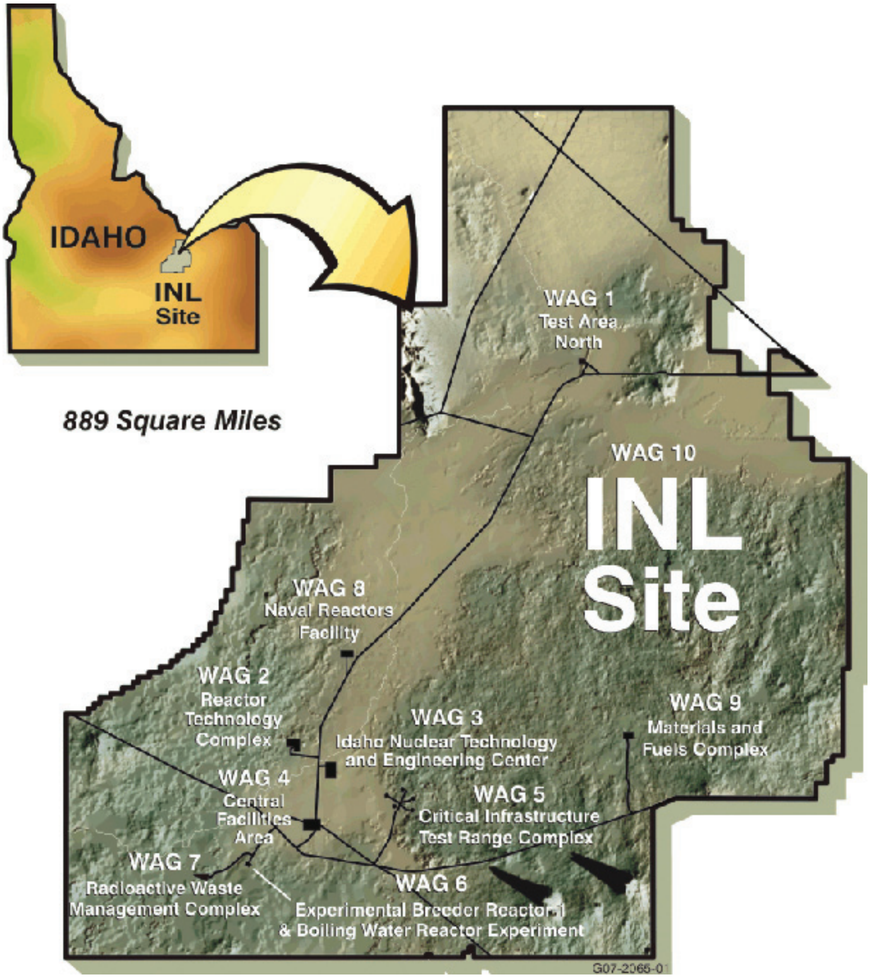

FIGURE 1-3 A map of Idaho National Laboratory. Waste Area Groups (WAGs) correspond to the site's major facilities. Notable WAGs related to legacy waste activities are WAG 2 (test reactors), WAG 3 (the Idaho Chemical Processing Plant and the Idaho CERCLA [Comprehensive Environmental Response, Compensation, and Liability Act] Disposal Facility), and WAG 7 (the Radioactive Waste Management Complex [RWMC]).
SOURCE: https://cleanup.icp.doe.gov/ics/.

spent fuel. The spent fuel currently stored at INL has come from multiple sources: naval reactors, onsite test reactors, commercial, Three Mile Island core debris, West Valley Demonstration Project, and foreign research reactors (Provencher 2010). In addition to these activities, the Radioactive Waste Management Complex (RWMC) was established in 1952 to dispose of wastes from other sites (e.g., Rocky Flats). INL no longer reprocesses spent fuel or accepts wastes from other sites. Its current mission is to conduct research and testing of new nuclear fuel concepts and to conduct a safe environmental remediation of the legacy wastes within the site.

Legacy Wastes

INL has actively addressed its tank wastes on site. A tank farm stored the waste generated from the chemical separation process. The waste calcining facility was built to treat and stabilize the HLW from this tank farm.[13] The resulting calcine is stored in a total of 43 stainless steel bins within 6 concrete bin sets, rated to be safe for several hundred years. The bin sets are stored on site awaiting a federal repository.[14] Eleven of the 15 HLW tanks have been emptied and grouted, but sodium bearing waste (SBW) tanks remain. A new facility, the Integrated Waste Treatment Unit (IWTU), has been built to process sodium bearing waste; it is a Fluidized Bed Steam Reformer (FBSR). During initial system testing in 2012, the IWTU experienced a pressure control shutdown event. In March 2014 the ITWU facility underwent an Operational Readiness Review and a Technology Readiness Assessment. Spent nuclear fuel from a variety of sites is stored in ponds and dry casks within INL.

Waste disposal ponds and ditches and subsurface disposal were used at all nine WAGs (DOE 2001b). In one of the largest current remediation activities on site, sections of the RWMC are being exhumed to retrieve buried TRU waste (primarily from Rocky Flats, see Box 1.1) to be packaged and transported to the Waste Isolation Pilot Plant (WIPP) in New Mexico. DOE estimates nearly 37,000 cubic meters of TRU waste has been buried at INL (DOE 2000).

Due to past practices, groundwater and soil contamination has occurred throughout the site. Amounts of radioactive and chemical contami-

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[13] The calcining process converts liquid HLW to a granular solid by a combined high-temperature drying, denitrating (nitrogen removal), and evaporation process. Calcining reduces the volume of HLW by a factor of approximately seven. This waste was calcined as a nitrate; unlike the waste tanks at the Hanford site, NaOH was not added to neutralize the HLW. The calcining facility operated from 1963 to 1987. The aboveground structures have been decontaminated and demolished; the underground structures have been grouted and entombed.

[14] It is not clear whether a future repository will accept calcined waste so INL has been investigating the stabilization of the calcine into glass ceramic via hot isostatic pressing (HIPing).

nation have been estimated at 7.6×10^5 cubic meters of groundwater and 6.5×10^5 cubic meters of soil and sediment (NRC 1999). Contaminated groundwater from WAGs 1, 3, and 7 (see Figure 1-3) placed INL on the National Priorities List.

Many of the reprocessing and waste storage facilities are no longer needed and have been decommissioned. These include some of the fuel storage pools, hot cells and hot shops, a fuel reprocessing plant, warehouses, and waste storage buildings.[15] Three nuclear reactor vessels have been disposed of in the Idaho CERCLA Disposal Facility (ICDF), located in WAG 3. The ICDF stores INL-generated LLW and MLLW.

Issues Related to Long-Term Remediation

Remediation of the TRU waste within the RWMC is one of the challenges at INL. After active remediation of the site is completed, wastes will remain through controlled LLW facilities (the ICDF and the RWMC), residual contamination of soil and groundwater, and entombed buildings and structures. Groundwater remediation and ecological monitoring currently take place throughout the site.[16] Challenges to post-closure monitoring include adequate stabilization of residual contamination on site (in the soil and groundwater), and evaluation on long-term performance of current passive remedies (e.g., caps and grout).

Oak Ridge Reservation

The Oak Ridge Reservation (ORR) is located about 25 miles west of Knoxville, Tennessee, and is approximately 60 square miles in area. Three major watersheds within the site form parallel northeast to southwest trending valleys: Melton Valley, Bear Creek, and Bethel Valley. The Clinch River defines the eastern and southern borders of the site (see Figure 1-4), and the Tennessee River is downstream. The site contains low-permeability soils and fractured rock above bedrock. The climate at the site is temperate with hot summers and no dry season. Rain is the most likely form of precipitation, ranging from light to heavy.

ORR was established by the U.S. government in the early 1940s. The reservation had three major facilities: the X-10 research facility, the Y-12 Plant, and the K-25 Plant (see Figure 1-4). X-10 was originally constructed as a research and development facility to support plutonium production technology. The Y-12 and K-25 plants were built to produce highly enriched uranium (HEU). The Y-12 Plant enriched uranium by electromagnetic

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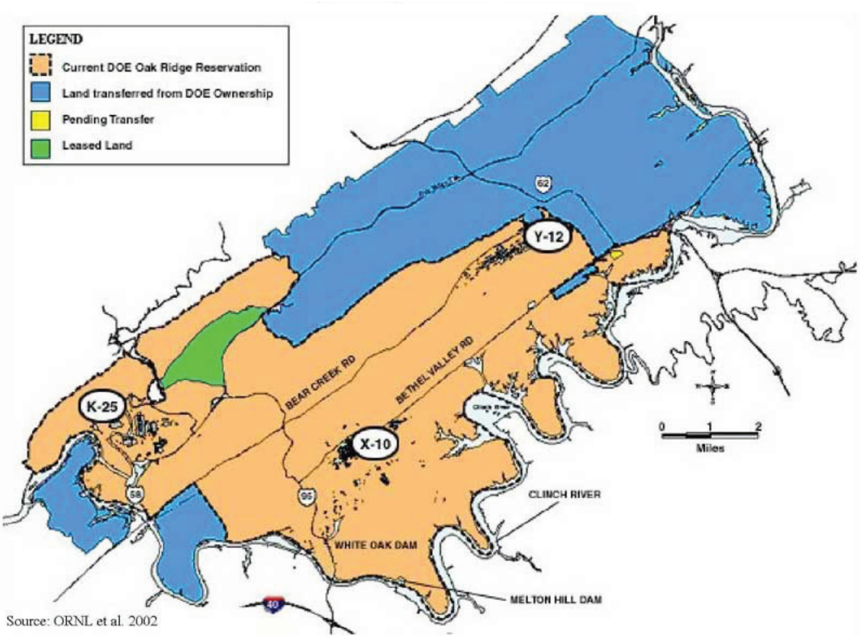
[15] See http://energy.gov/em/idaho-national-laboratory.

[16] The following website lists the institutional controls for each of the WAGs: https://cleanup.icp.doe.gov/ics/#10.



Source: ORNL et al. 2002

FIGURE 1-4 ORR site map indicating original facilities. X-10 was originally used to research plutonium production; it is now the Oak Ridge National Laboratory (ORNL). Y-12 was originally used to enrich uranium using electromagnetic separation; it is now the Y-12 National Security Complex. K-25 was also known as the Oak Ridge Gaseous Diffusion Plant; it is now the East Tennessee Valley Technology Park (ETTP).
SOURCE: http://www.atsdr.cdc.gov/HAC/PHA/OakRidge0806-TN/whiteoakcreek/images/woc_f2.jpg.

separation; the K-25 Plant used gaseous diffusion. Of the three mission goals, the enrichment of uranium encompassed the most area, energy, and resources.

ORR is currently a multi-mission site. It is used for nuclear material storage but no longer carries out nuclear material production.[17] The Oak Ridge National Laboratory (ORNL) has replaced X-10; it is a national laboratory conducting research in materials, alternative fuels, and supercomputing. The Y-12 Plant is now the Y-12 National Security Complex

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[17] "It [ORR] is the only field site that performs every mission under the DOE's portfolio—energy research, environmental restoration, national security, nuclear fuel supply, reindustrialization, science education, science and technology, and technology transfer" (see http://www.oakridge.doe.gov/external/Home/AboutUs/tabid/24/Default.aspx).

with a current mission of reducing worldwide nuclear stockpiles, storing nuclear material, and improving defense systems. The K-25 Plant area, now known as the East Tennessee Technology Park (ETTP), is being demolished. The site will eventually become a private industrial park.

Legacy Wastes

Legacy wastes at ORR are stored in both above- and below-ground storage. Depleted uranium hexafluoride, or DUF6, is a by-product of uranium enrichment through gaseous diffusion. DUF6 had been stored as a solid in steel, above-ground cylinders (approximately 5,000 cylinders were stored at the ETTP). All of these cylinders have been transported to Portsmouth for further processing. Underground tanks containing legacy waste remain on site including 12 gunite tanks[18] (containing wastes from plutonium separation research and pilot experiments) and 5 storage tanks (constructed as feed tanks for the Hydrofracture Facility, see below).[19]

Wastes have been buried throughout the ORR site (Webster and Bradley 1987). At the start of cleanup, it was estimated that there were up to 1,100 acres of unlined buried waste, facilities, inactive tanks, and unlined ponds (DOE 2001b). Pits and trenches were used for disposal of intermediate-level wastes.[20] Intermediate-level wastes were also combined with grout and pumped into the subsurface at the Hydrofracture Facility (this practice was later discontinued). Solid LLW was disposed of in shallow trenches and auger holes near the X-10 and Y-12 facilities. DOE estimates that approximately 570 cubic meters of waste has been buried near the surface and 8,800 cubic meters of waste is buried at intermediate depths (via hydrofracture) (DOE 2000, Table 1).

Contamination of soil and groundwater has been detected throughout the site and in the surrounding areas. As a result of past operations, nearly 4,000 acres either were or had the potential to be contaminated (DOE 2001b).[21] The main contaminants are mercury and PCBs (from metal work and electricity generation for enrichment), and cesium and strontium (Cs-137 and Sr-90 are fission products of U-235, DOE 2001b). These

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[18] Gunite is a mixture of cement and sand sprayed over a frame of steel-reinforced wire mesh. The gunite tanks on the ORNL campus have been closed. They were constructed to support X-10 R&D activities to support plutonium production at Hanford. Tanks in Melton Valley are used to recover wastes from R&D and chemical separations operations.

[19] See http://web.ornl.gov/info/reports/1996/3445604249739.pdf.

[20] There is no formal regulatory definition for intermediate-level waste in the United States. The International Atomic Energy Agency (IAEA) describes intermediate-level waste as radioactive waste that requires remote handling (see http://www.iaea.org/OurWork/ST/NE/NEFW/_nefw-documents/LILWaste2011.pdf).

[21] For a relative comparison, the total area of ORR is 35,000 acres.

contaminants—especially mercury—can be found in soils, sediment, and groundwater at the site and in onsite and offsite waterways.

Contaminated buildings and building materials existed throughout the three major areas within ORR. The largest buildings were in the K-25 and Y-12 areas. The gaseous diffusion facility (K-25) was the largest building under one roof (44 acres in area) at the time it was constructed. Recently, DOE announced its final demolition of K-25.[22]

Issues Related to Long-Term Remediation

ORR's waste disposition for LLW and MLLW generated through remediation activities on site is the Environmental Management Waste Management Facility (EMWMF). TRU waste is to be addressed in the TRU Waste Processing Facility (not yet operational) and transported to WIPP or other sites (Gelles 2013). Some TRU wastes from ORR have already been shipped to WIPP. It is expected that other wastes will remain on site through residual contamination, buried wastes (e.g., hydrofractured wastes), and entombed facilities.

Long-term monitoring of the site will be required after active remediation is complete incurring costs for years to come. The State of Tennessee has a potential best practice for ensuring a constant source of funds for long-term stewardship (Benson 2008): long-term monitoring and remediation activities will be paid for in part by Tennessee's perpetual care trust fund—a trust established by the U.S. government over several years ($1 million/year for 14 years). Once remediation has been completed, the $14 million will be returned.[23]

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[22] See http://energy.gov/em/articles/energy-department-completes-k-25-gaseous-diffusion-building-demolition.

[23] See http://ndep.nv.gov/lts/nga_funding_1002.pdf.

2

Using Risk to Inform Decisions

To start the workshop, an introductory presentation by William (Bill) Levitan, Associate Deputy Assistant Secretary for Site Restoration for Department of Energy's (DOE's) Office of Environmental Management (EM), provided insights on the motivations for and expectations of the workshop series. The first session of the workshop focused on promoting effective and efficient risk-informed decision making. To address this topic, federal and academic practitioners provided background and examples of effective use of risk in complex decisions related to environmental remediation decisions. The session was moderated by Michael Kavanaugh, Principal, Geosyntec Consultants and planning committee member, who provided a short introduction to the session by highlighting findings and recommendations from past National Research Council (NRC) reports. Next, Bernard (Bernie) Goldstein, Professor Emeritus, Department of Environmental and Occupational Health, University of Pittsburgh, presented the keynote address on the historical use of risk and sustainability within U.S. government decisions.

This set of briefings was followed by speakers who provided case studies and examples of decision making for complex remediation sites:

- Reggie Cheatham, Director of the Federal Facility Restoration and Reuse Office, Environmental Protection Agency, and
- Paul Black, Ph.D., Principal, Neptune and Company, Inc.

This chapter provides summaries of the key points made by each of these individuals and by participants in the subsequent discussion sessions.

These statements reflect the viewpoints of the individual speakers, not the consensus views of the workshop participants or of the National Academy of Sciences.

2.1 INTRODUCTORY PRESENTATION: DOE EM'S PERSPECTIVES ON THE WORKSHOPS

William (Bill) Levitan

EM has multiple considerations when making remediation decisions: agreements with the sites and site stewards, the environment, and the taxpayers. DOE is not alone in reconsidering how remediation decisions should be made. Several reports and recent policy documents support this statement. For example, *Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites* (NRC 2013), the recent release of the Environmental Protection Agency's (EPA's) groundwater strategy,[1] and the U.S. Nuclear Regulatory Commission's (USNRC's) white paper on policy strategies for risk management provide evidence of the need for a national conversation on decision making for contaminated site cleanup.

There are several challenges to establishing a decision-making process for site remediation. The process must balance many concerns and impacts including

- Short-term and long-term impacts
- Worker and community impacts
- Local and global impacts
- Cost and risk mitigation
- End states and future use

It is becoming increasingly apparent that some wastes will remain on site after active cleanup activities are completed (recognized by a potential shift from the basic question of "How clean is clean?" to "How much waste might be left behind?"). It is not yet clear how to incorporate risk and the sustainability process into decisions addressing residual contamination.

DOE is seeking advice on how to complete remediation and make decisions related to long-term stewardship of its sites. These topics are highlighted in the statement of task (Appendix A) and are shown in Figure 2-1.

Projected cost profiles of existing DOE remediation programs indicate peak spending at about $8 billion per year (see Figure 2-2). Current budgets are not at this level nor are they expected to increase significantly.[2] To ad-

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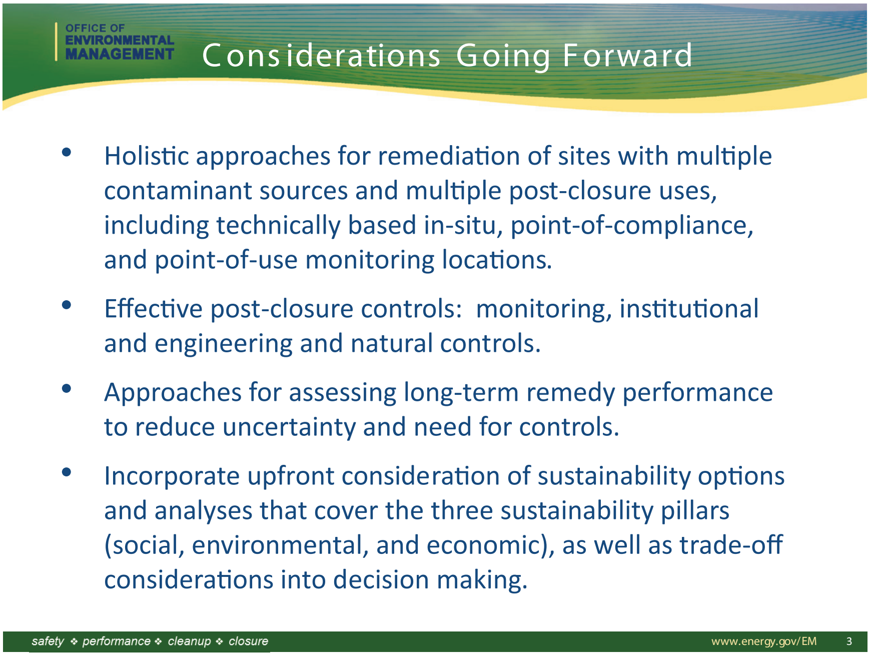
[1] See http://epa.gov/superfund/gwcompletionstrategy/.

[2] The funding level for EM in fiscal year 2014 was $5.6 billion (see http://energy.gov/sites/prod/files/2013/04/f0/FY2014_EM_Congressional_Budget_Request.pdf).



OFFICE OF ENVIRONMENTAL MANAGEMENT

Considerations Going Forward

- Holistic approaches for remediation of sites with multiple contaminant sources and multiple post-closure uses, including technically based in-situ, point-of-compliance, and point-of-use monitoring locations.
- Effective post-closure controls: monitoring, institutional and engineering and natural controls.
- Approaches for assessing long-term remedy performance to reduce uncertainty and need for controls.
- Incorporate upfront consideration of sustainability options and analyses that cover the three sustainability pillars (social, environmental, and economic), as well as trade-off considerations into decision making.

safety ❖ performance ❖ cleanup ❖ closure

www.energy.gov/EM 3

FIGURE 2-1 Intended main topics of the National Academy of Sciences' Workshop series.
SOURCE: Levitan 2014.

dress this shortfall, remediation end states for the sites may be reconsidered or further defined; remediation activities may be sequenced; and selection of remedies consistent with site end states may be considered.

Finally, Mr. Levitan provided the following eight topics as DOE's main reflections from the first workshop:

- The determination of end states is critical to the decision-making process.
- EM and the U.S. government are "not going away" and are committed to addressing the legacy wastes.
- Flexibility allows remediation goals to be accomplished over time (both a blessing and a curse).
- The intrinsic value of groundwater or environmental resources is ill defined.
- Adaptive management approaches are needed to incorporate new technologies and practices.

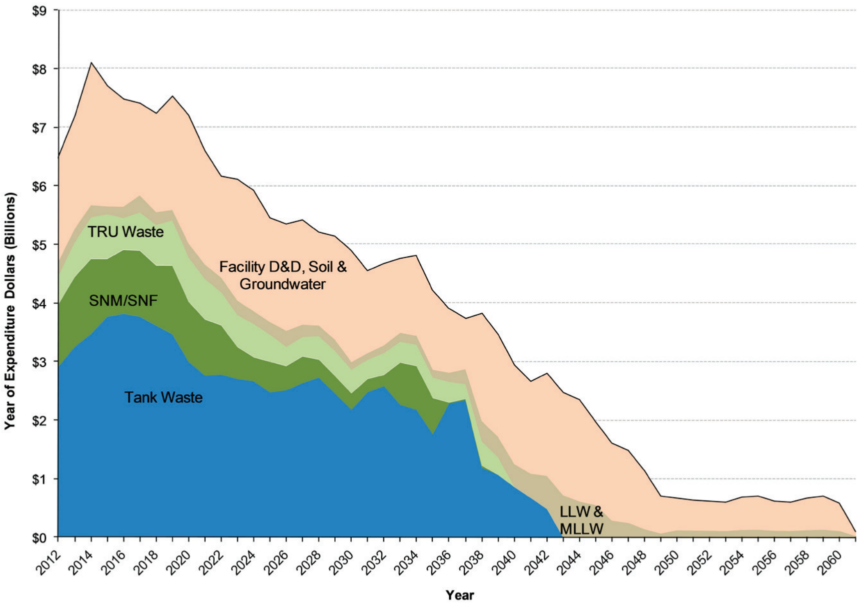


FIGURE 2-2 Projected spending for DOE's Office of Environmental Management (EM) site cleanup. The spending peaks at $8 billion in the coming years. Current funding levels for EM are ~$5 billion to $6 billion per year and are not expected to increase.
SOURCE: Levitan 2014.

- Sustainability should be considered as part of the remediation process because it can better accommodate multiple concerns including societal and economic values.
- The sequencing of remediation work should be considered.
- Communication is critical—both for risk assessments and throughout decision making.

2.2 SUMMARY OF DISCUSSION SESSION

Workshop 1 Highlights. The planning committee chair Paul Gilman (Covanta Energy) commented that EM's reflections and overview of the first workshop were fair. He suggested adding two additional topics to Mr. Levitan's list (see Vol. I, Ch. 3):

- the Savannah River Site's decision-making process as a model for risk-informed decision making with stakeholder support,[3] and
- David (Dave) Maloney's example of flexibility in contracting to allow for innovative solutions for cleanup as another highlight.

Other participants added to comments from Workshop 1. A workshop participant highlighted Michael Truex's presentation on the use of monitoring and modeling for remedy assessment. Dave Maloney noted that Workshop 1 included discussions about a movement away from prescriptive standards, which define how to reach a target value to performance-based standards, which in turn allow for a variety of methods to reach target values without relaxing the environmental standards themselves.

Workshop participants offered several other comments.

Challenges to Decision Making. Planning committee member Patricia Culligan (Columbia University) mentioned that an additional challenge to EM's decision making is that the stakeholders will change over the life cycle of the remediation. Mr. Levitan agreed that the stakeholders change over time, but added that at any given moment stakeholders are diverse because there are so many of them. Rateb (Boby) Abu-Eid (USNRC) emphasized two critical aspects of the decision-making process: future land use or end use is very important to determine and uncertainties can be large when considering long timeframes.

Waste Types of Future Reactors. Willie Preacher (Shoshone-Bannock Tribes) expressed concern about the types of waste the next generation of nuclear reactors (i.e., Gen IV)[4] will produce and the implications for future waste management. Mr. Levitan responded that poor waste practices existed in the past but are no longer followed. Current laws and regulations such as the National Environmental Policy Act (NEPA) forbid dumping or burial (previously accepted practices). Further, Gen IV development—taking place at the Idaho National Laboratory (INL)—and the associated waste practices are currently monitored to confirm that compliance is maintained.

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[3] For more details on the Core Team Process, see the summary of Mary Flora's presentation titled, "The Core Team Process: Making Risk-Informed Decisions for On-Site Monitoring," in Chapter 4 of this report.

[4] Nuclear reactors have been grouped into four generations. Generation I (or Gen I) were developed in 1950-60s. Most reactors in operation today are Gen II reactors. Gen III (or 3+) reactors are considered advanced reactors; they are operational in Japan or under construction elsewhere. Gen IV designs are still being developed.

2.3 HIGHLIGHTS FROM NATIONAL RESEARCH COUNCIL REPORTS

Michael (Mike) Kavanaugh

Planning committee member and the moderator for the first technical session of the workshop, Dr. Kavanaugh (Geosyntec), introduced the session with a short overview of relevant NRC reports and their findings:

Wastes will remain at many sites. Dr. Kavanaugh chaired the committee that wrote the recent groundwater contamination report, *Alternatives for Managing the Nations Complex Contaminated Groundwater Sites* (NRC 2013). The committee estimated that the United States has at least 126,000 contaminated groundwater sites with residual contamination levels that exceed cleanup goals. This number includes 3,650 DOE sites. DOE has stated that the majority of its sites will require long-term stewardship of residual and stored wastes (DOE 1999).

Long-term stewardship is difficult. *Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites* (NRC 2000) concludes that effective long-term stewardship will be difficult to achieve.

Analysis results need to be technically credible. Finding 8 of *Risks & Decisions about Disposition of TRU and High-Level Radioactive Waste* (NRC 2005) enumerated a list of characteristics of a credible decision-making process, highlighting the importance of credible and believable results (emphasis added): "An effective and credible risk-informed, decision-making process has several characteristics. It is (1) participatory; (2) logical; (3) consistent with current scientific knowledge and practice; (4) transparent and traceable; (5) structured with reasonable independence of the decision authority from the petitioner; (6) subjected to thorough, independent peer review; ***(7) technically credible, with believable results;*** and (8) framed to address the needs of the decision process" (NRC 2005, p. 7).

Containment systems will eventually fail. *Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites* (NRC 2000) states that DOE planners should safely assume that any containment system for long-lived radioactive wastes will ultimately fail over the wastes' lifetimes.

With this as the backdrop to the first session, Dr. Kavanaugh introduced the speakers.

2.4 HISTORY OF RISK AND SUSTAINABILITY IN DECISION MAKING FOR COMPLEX SITES

Bernard (Bernie) Goldstein

Over the past several years, the U.S. government's thinking about risk and sustainability has evolved to the point that, currently, we are at a tipping point between the two approaches to decision making. Twenty years from now, people will recognize the present moment as the cusp of adoption of sustainability practices into remediation decisions.

To provide credibility and historical context to this statement, one must consider the progression of decision making within environmental management:

1. Early years of site remediation assumed a command-and-control approach—"It's dirty, go clean it up."
2. The current approach to site remediation includes risk assessment and management, which recognizes that not all risks are obvious and visible. Exposure is used to calculate risk—"If you understand exposure, then you can understand the risk."
3. The near-term future of site remediation is moving toward inclusion of sustainability frameworks, which account for value judgments and other considerations during the decision-making process.

The U.S. government's adoption of risk assessment to inform decisions took many years. Released in 1983, the NRC's Red Book[5] (NRC 1983) outlined a risk assessment framework to guide government decisions. However, EPA took a full decade to develop the tools and processes necessary to measure and assess risk (i.e., risk was defined in terms of exposure). Integration of sustainability principles into decision making is likely to follow a similar timeframe and pattern. Factors contributing to the current movement toward the use of sustainability principles to inform decisions are as follows:

- Current and emerging problems are more complex and challenging (the easy sites have been cleaned up, the challenging sites remain),
- Sophisticated tools to address these complex problems are becoming available,
- Sustainability is becoming a common approach to address broader economic, social, and environmental issues, and
- A sustainability approach that allows consideration of economic

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[5] The full title of the report commonly referred to as the "Red Book" is *Risk Assessment in the Federal Government: Managing the Process.*

> and social issues in environmental protection is of potential value to the competitiveness of the United States.

Three NRC reports track the progression from risk to sustainability approaches: the Red Book (NRC 1983) defined a risk assessment framework for EPA; *Science and Decisions* (NRC 2009) defined a risk-based decision framework; and the "Green Book"[6] defined a framework for a sustainability process for EPA (NRC 2010). The NRC committee that authored the Red Book discovered that many of the regional EPA workers were incorporating risk into their decisions before headquarters directed them to do so. A similar finding was made by the committee that authored the Green Book; it saw that sustainability principles were already being employed by practitioners to guide decisions at local levels.

The Green Book purposefully did not define "sustainability." Rather, concepts compatible with a sustainability approach were referenced in other existing government documents including the National Environmental Policy Act (42 U.S.C. § 4331(a)):

> "[T]o create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans," and "[T]he continuing responsibility of the Federal Government" is to, among other things, "fulfill the responsibilities of each generation as trustee of the environment for succeeding generations."

Although not defining sustainability, the Green Book described how it could be used to guide decisions. A sustainability framework has two levels (see Vol. I, Sec.1.6):

- Sustainability Framework Level 1: Components that define the agency-wide process (an agencies' high-level framework); and
- Sustainability Framework Level 2: Elements of Sustainability Assessment and Management (practitioner-level framework).

The Green Book contains several recommendations to support the incorporation of sustainability principles into EPA's culture (NRC 2011, p. 5). In particular

> Recommendation 3.1: The committee recommends EPA adopt the proposed Sustainability Framework. The proposed Sustainability Framework requires a comprehensive approach including specific processes for incorporating sustainability into decisions and actions. As part of the framework, EPA should incorporate into its decision making upfront

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[6] Dr. Goldstein chaired the committee that issued *Sustainability and the U.S. EPA*.

> consideration of sustainability options and analyses that cover the three sustainability domains (social, environmental, and economic), as well as trade-off considerations. The framework was developed with the intent that EPA could apply it to any decision to which a need arose.

In the last sentence of this recommendation, the 2011 NRC committee recognized that there may be no need to add processes to some U.S. government decisions. However, for other decisions that require simultaneous consideration of social, environmental, and economic issues, a sustainability framework should be used. To implement the framework, more tools are needed.[7]

How does an organization move from consideration of risk to sustainability to guide its decisions? Some risk assessment practitioners are concerned that risk assessments are not needed in sustainability frameworks. Risk is part of the consideration of sustainability, but the sustainability framework goes beyond risk assessment. Recommendation 5.1 from the Green Book makes this clear: "The committee recommends EPA include risk assessment as a tool, when appropriate, as a key input in its sustainability decision making" (NRC 2011, p. 6). Practically speaking, a sustainability framework adds the factor of time into decision making—a factor missing in the risk assessment approach—making it valuable for DOE decision makers, who must consider long timeframes in site remediation decisions. A sustainability framework considers not only how to minimize risk but also how to maximize benefit.

The Science and Decisions (NRC 2009) report, with some modifications to the nomenclature, outlines how to incorporate sustainability into decisions. The decision-making framework is presented as three phases (see Figure 2-3). Phases 1, 2, and 3 in the framework show how risk assessment is part of a larger decision-making process.

This approach can be mapped to Sustainability Framework Level 2 of the recently proposed sustainability framework (NRC 2011). This shows that risk assessment has naturally been moving toward sustainability for a number of years.

However, sustainability and risk assessment are not the same thing. A public health analogy can highlight an important difference between sustainability and risk. In public health there are three levels of care: primary, secondary, and tertiary. Primary care is aimed at preventing the contraction of a disease or condition. Secondary care is focused on treating a contracted disease before adverse symptoms have occurred. Tertiary care treats the symptoms of the disease, attempting to prevent pain or further damage. In the analogy, primary care corresponds to a sustainability approach. It strives to avoid conditions that would be more costly and impactful in the

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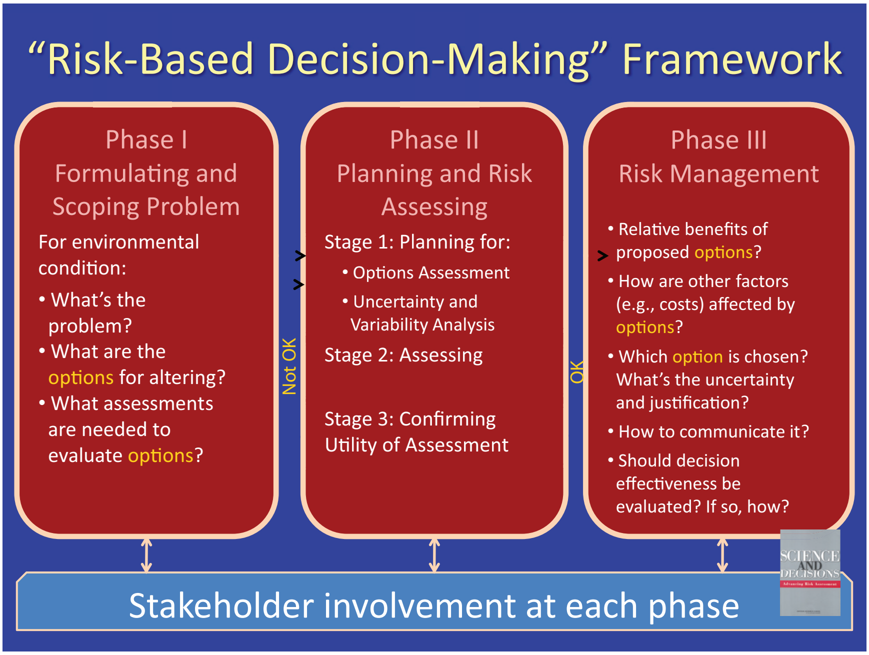
[7] See, for example, http://www.epa.gov/research/mmtd/.



"Risk-Based Decision-Making" Framework

Phase I
Formulating and Scoping Problem

For environmental condition:

- What's the problem?
- What are the options for altering?
- What assessments are needed to evaluate options?

Phase II
Planning and Risk Assessing

Stage 1: Planning for:

- Options Assessment
- Uncertainty and Variability Analysis

Stage 2: Assessing

Stage 3: Confirming Utility of Assessment

Phase III
Risk Management

- Relative benefits of proposed options?
- How are other factors (e.g., costs) affected by options?
- Which option is chosen? What's the uncertainty and justification?
- How to communicate it?
- Should decision effectiveness be evaluated? If so, how?

Stakeholder involvement at each phase

FIGURE 2-3 The risk-based, decision-making framework proposed by the Science and Decisions report (NRC 2009). Although not specifically mentioned, many components of a sustainability framework are represented.
SOURCE: Goldstein 2014.

future. Tertiary treatment is analogous to risk assessment. Its goal is to treat an existing problem that was created by failure of other preventative measures.

The current practice of risk assessment has several problems, which could carry over to future sustainability frameworks if not addressed. Box 2.1 provides an example of over-reliance on risk assessment without using common sense to balance the results.

The short analysis of this scenario shows that one can expect a single excess cancer death over the time period of 1.75 million years, roughly the time that humans have existed on the planet. Although sustainability frameworks require consideration of future generations, one should be careful about how the results of risk assessments—such as this example—are used to guide decisions. Risk to future generations currently depends on radiation exposures over periods of millennia, which implies that risks of cancer to humans remain unchanged over time. But this is not likely to be the case, as suggested by the progression of our understanding of other diseases and conditions. For example, in the early 20th century, Yellow

BOX 2.1
Stealth Farmer Scenario for Risk Assessment

Risk assessment for exposure risk is calculated for a remote DOE legacy site that is contaminated but secured through institutional controls. This includes a "stealth farmer" scenario.

Assumptions:
Unbeknownst to anyone, a family of four climbs the fence and lives off the land. The family secretly develops subsistence life style on DOE land contaminated to a level of 1/100,000 risk. The family is replaced every 70 years with another family of four.

The calculated risk of one cancer death from residual radiation is 1/100,000 lifetime. Using these numbers, one adverse event (excess cancer death) will occur every 1.75 million years.

Humans have been on the planet for approximately 1.75 million years.

SOURCE: Modified from Goldstein 2009, 2014.

Fever was potentially deadly and feared by many, but now the disease is understood and treatable (we can vaccinate against it). Isn't it possible that our understanding of and ability to treat cancer will significantly change over the next several thousand if not millions of years?

In 1994, DOE established a Comprehensive Environmental Response, Compensation, and Liability Act Disposal Facility (CERCLA)/NEPA Policy that states if DOE relies on and follows the CERCLA process (see CERCLA's nine criteria in Box 2.2), then no separate NEPA document or process would be ordinarily required.[8] Under this policy, DOE ensures that it will take steps to involve the public as early as possible in the decision-making process. NEPA requires an environmental impact statement (EIS) and a clear definition of the project goal with options considered (including the "do nothing" option). Although CERCLA does not require an EIS, for some of DOE's biggest sites, such as Hanford, an EIS for the full site might have been a beneficial exercise.

In summary, sustainable decisions for environmental management involve maximizing benefits while minimizing risks. It may be better to show maximum benefit now than to focus on reducing risks to individuals millions of years from now.

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[8] See http://energy.gov/sites/prod/files/G-DOE-Secy_NEPA_policy.pdf.

BOX 2.2
CERCLA's Nine Criteria

The analysis of alternatives under review reflects the scope and complexity of the site problems and the alternatives being evaluated and considers the relative significance of the factors within each criterion. The nine criteria are part of the National Contingency Plan (40CFR300.430(e)(9)).

The nine evaluation criteria are as follows:

Threshold Criteria
1. Overall protection of human health and the environment
2. Compliance with ARARs (applicable or relevant and appropriate standards)

Primary Balancing Criteria
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility or volume
5. Short-term effectiveness
6. Implementability
7. Cost

Modifying Criteria
8. State acceptance
9. Community acceptance

2.5 SUMMARY OF DISCUSSION SESSION

Maximizing Benefit, Minimizing Risk. Participants raised several questions about maximizing benefit. Mr. Levitan (EM) asked if the term "optimization" instead of "maximization" might be an alternative way of thinking about sustainability. Optimization allows for more factors to be maximized (instead of the implied single variable for maximization). Richard Mach (U.S. Navy) suggested that optimization is concerned with maximizing benefit, minimizing risk, and finding the right balance between options. Dr. Goldstein agreed with both comments.

Craig Benson (University of Wisconsin) pointed out that the boundaries of the optimization need to be carefully considered. There are consequences of restricting optimization objectives due to system boundaries, such as lines of funding. As the United States becomes more resource constrained, we should consider expanding those boundaries. Dr. Goldstein responded that the separation of federal and state systems may present fundamental challenges to the proposed modification to barriers such as lines of funding.

Planning committee member, Patricia Culligan (Columbia University) asked for further examples of maximizing benefits. Dr. Goldstein provided the following example from the Green Book (see NRC 2011, p. 117): The lighting systems in New York (NY) City Public Schools were leaking polychlorinated biphenyls (PCBs) into the school buildings, and EPA required their replacement. Under the initially proposed lighting-fixture replacement schedule, replacement costs coupled with a tough budget situation would have necessitated teacher layoffs. By balancing the cost savings from the new, more energy-efficient lighting systems and staggering replacement of the lights, the NY public school system and EPA worked out a solution that reduced the risks of PCB exposure while retaining all of the teachers. This example also highlights how time is introduced into a sustainability-based decision. Mr. Levitan provided another real-life example from a large site in which a small quantity of asbestos fibers was released during DOE cleanup. Because the release violated the Clean Air Act, EPA fined DOE. To offset the cost of the fine, DOE laid off cleanup workers.

CERCLA, NEPA, and Sustainability. Charles (Chuck) Powers (Consortium for Risk Evaluation with Stakeholder Participation [CRESP]) provided historical background on the policy decision to equate CERCLA's nine steps to NEPA. Lois Schiffer, then assistant attorney general at the Department of Justice (DOJ), voiced at least two concerns about this decision: (1) provisions within NEPA that would have allowed the stopping of cleanup actions and (2) increased participation in the decision-making process.[9] These concerns were to be alleviated by full adherence to all of CERCLA's nine criteria. Dr. Powers also noted that sustainability enters into the CERCLA process through the Remedial Investigation and Feasibility Study (RI/FS).

Planning committee chair Paul Gilman (Covanta Energy) responded to Dr. Power's comment on sustainability and CERCLA. The statement was made during the first workshop that CERCLA prevented EPA from incorporating sustainability. Yet the point has been made throughout both workshops that creative work with the stipulated agreements allows for sustainability principles to be part of the decisions (and while economic issues cannot be part of a rule, they can be included in the discussions with stakeholders that lead to decisions). Robin Anderson (EPA, Superfund program) responded by saying that if "sustainability" could be better defined, then it may be more easily incorporated into CERCLA. Questions remain about the number of options to consider for optimization and how to prioritize those options. She recognized that there currently are ways to incorporate sustainability principles into CERCLA's nine criteria.

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[9] See memorandum dated January 23, 1995, from Lois J. Schiffer, assistant attorney general, Department of Justice (http://energy.gov/sites/prod/files/G-DOJ_nepa_cercla_cleanups.pdf).

2.6 FEDERAL FACILITY CLEANUP DIALOGUE SERIES AND BROWNFIELDS DISCUSSIONS

Reggie Cheatham

As a regulator, EPA is in a unique position to offer perspectives on the decision-making process for contaminated sites. A few myths about CERCLA and Federal Facility Cleanup (see Figure 2-4) have arisen and must be dispelled, based on EPA's experience from many site closures.

"CERCLA is not flexible," is a common myth.

> CERCLA allows for a variety of remediation decisions at different sites that offer cost and time savings while protecting human health and the environment. It is very flexible.

Second, the idea that cleanup goals cannot be achieved is a myth.

> In early 2000, Rocky Flats and Mound were extremely challenging sites and were unlikely to be cleaned up for decades. Both of these ventures have been successful and have completed cleanup.

Third, "Federal Facility Agreement (FFA) milestones are not negotiable" is also myth.

> In reality, these agreements are renegotiated frequently because of changing funding levels and changing conditions on the sites (e.g., new contamination identified).

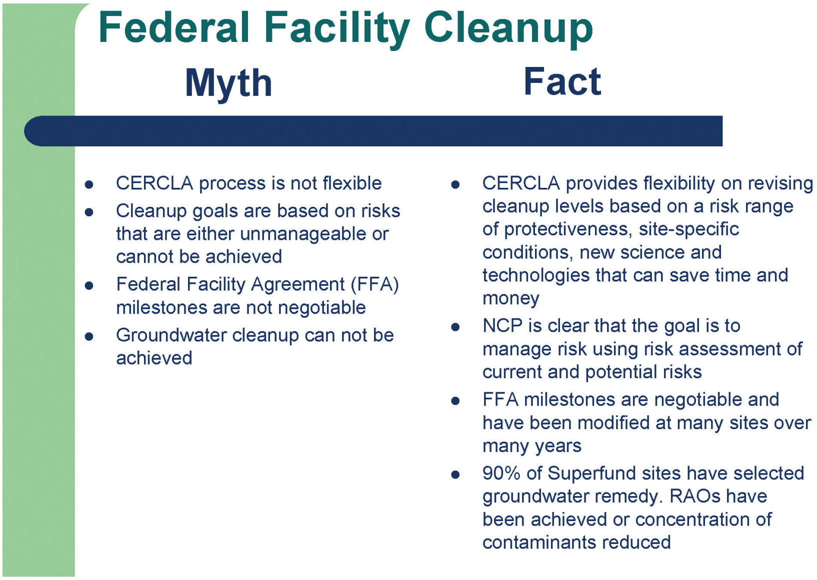
Finally, it is a myth that groundwater cleanup cannot be achieved.

> Groundwater is a valuable resource, and EPA has worked to ensure its protection. The vast majority (90 percent) of CERCLA/Superfund sites have a selected groundwater remedy.

Risk is a part of CERCLA. It is used to guide a variety of decisions including, policy directives from other agencies. CERCLA's intention, purpose, and design drive decisions at the sites to be risk-based. Risk is considered throughout the CERCLA process to develop defensible decisions by Remediation Project Managers (RPMs) and others.

In the mid-1990s, federal agencies and stakeholders involved with federal facility environmental cleanup met to discuss how to "do more with less." The Federal Facilities Environmental Restoration Dialogue Committee (FFERDC) produced a report (FFERDC 1996), outlining principles that are still relevant and important today. Specifically, EPA and EM regularly use Chapter 5, *Funding and Priority Setting,* as a resource. The report suggests that discussions leading to decisions should focus on accomplishments and review next steps based on available funding. This is especially relevant during times of tight budgets. The prioritization process should be transparent and should include factors beyond risk exposure.

A sustainability framework offers a way to incorporate these additional



Federal Facility Cleanup

Myth	Fact
CERCLA process is not flexible	CERCLA provides flexibility on revising cleanup levels based on a risk range of protectiveness, site-specific conditions, new science and technologies that can save time and money
Cleanup goals are based on risks that are either unmanageable or cannot be achieved	NCP is clear that the goal is to manage risk using risk assessment of current and potential risks
Federal Facility Agreement (FFA) milestones are not negotiable	FFA milestones are negotiable and have been modified at many sites over many years
Groundwater cleanup can not be achieved	90% of Superfund sites have selected groundwater remedy. RAOs have been achieved or concentration of contaminants reduced

FIGURE 2-4 Federal Facility Cleanup Myths and Facts, from the perspective of the Environmental Protection Agency, Federal Facility Restoration and Reuse Office. NCP=National Contingency Plan, RAO=remedial action objectives.
SOURCE: Cheatham 2014.

factors. EPA's Brownfields program is modeled after the Department of Defense's Base Realignment and Closure (BRAC) program. The focus of Brownfields is on economic development. Sustainability approaches allow the integration of societal and environmental values into Brownfields' decisions. Brownfield programs—and environmental cleanup activities, in general—need to focus on accomplishments and take more credit for the jobs created by cleanup activities. More than $7 billion/year is put into the economy by cleanup (more if private industry is considered). Cleanup, jobs, and economy are all parts of the pillars of a sustainability framework.

Protecting the nation's water is one of EPA Secretary McCarthy's top priorities.[10] EPA strongly supports inclusion of the use, value, and vulnerability of groundwater in decision making. But determining the value of groundwater is challenging. Because the primary responsibility of groundwater rests with the states, the public works within the states are best equipped to assess its value. At the same time, cost and technical limitations can prevent some sites with contaminated groundwater from being

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[10] See http://www2.epa.gov/aboutepa/epas-themes-meeting-challenge-ahead#protectingwater.

remediated to pre-contamination or maximum contaminant level (MCL) standards. The recent NRC report (NRC 2013) on groundwater remediation provides good examples and background.

"Technical impracticability" or TI waivers have been created to accommodate challenging cases. Although TI waivers are difficult to obtain, they have been granted. Whether or not a TI is in place, each site needs to consider a realistic approach to restoration based on actual and reasonable planned end uses and other sustainability factors.

There are no quick fixes for complex contaminated sites. Often remediation activities uncover additional contamination and waste problems. EPA supports incorporation of new technologies to reduce cost and time. Federal facility sites are a great test bed for these innovations because the U.S. government "holds all the marbles"—if the technology does not perform as expected, then the government can recover. Finally there are two points of caution regarding cost savings:

- cheaper cleanups based only on cost savings for today will ultimately cost more for future generations, and
- EPA will not allow the "writing off" of groundwater to shorten cleanups.

2.7 SUMMARY OF DISCUSSION SESSION

CERCLA Reviews and Timeframes for Analysis. Planning committee member Michael Kavanaugh (Geosyntec) noted that the focus of the recent NRC study (NRC 2013) was complex sites in which cleanup cannot be expected in a reasonable timeframe.[11] The study did not conclude that groundwater should be "written-off." He asked how "timeframe" enters into EPA's decisions on groundwater. Mr. Cheatham responded that when CERCLA sites have undergone four or five 5-year reviews and have reached steady-state conditions, discussion between EPA and the Primary Responsible Party (PRP) have often spurred on changes to the site remedies. He noted that the NRC report is helping EPA with these discussions, but EPA is realizing that the discussions need to occur with the right people (e.g., public water works and utilities).

FFERDC Background. Marolyn Parson (Savannah River Site's Citizens Advisory Board) asked for more details on the FFERDC. Mr. Cheatham succinctly described it as "an effort that came and went but left valuable insight." The FFERDC was reconvened in 2010 to continue the federal

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[11] Dr. Kavanaugh was the chair of *Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites* (NRC 2013).

dialogue. The main difference between the 1996 and 2010 groups is that the discussions have shifted to long-term stewardship, which is encouraging. Current efforts of a group that sprung from the 2010 meetings focus on improving the 5-year review process. The group is holding monthly meetings. Bill Levitan (EM) added that the original FFERDC membership included the Site-Specific Advisory Boards (SSABs).

TI Waivers and Sustainability. A workshop attendee asked about technical impracticability and the need to move forward with sustainability approaches, which might be in conflict. Mr. Cheatham responded that the TI waiver exists, and a few have been granted. How this relates to a sustainability framework is difficult and something he will consider in the future. Bill Levitan (EM) noted that this question targets the essence of the workshops—how do we make risk-informed decisions that recognize the large number of issues simultaneously? Richard Mach (U.S. Navy) noted that for complex sites—especially one that would be the subject of his presentation day (see Mach 2014)—the Department of Defense's (DOD's) approach is to consider multiple options for each site. A TI is not necessarily applied for even though the problem is technically impracticable, because it is still possible to come up with a sustainable, long-term solution (see Chapter 3, Bethpage case study example).

2.8 RISK-BASED APPROACHES FOR REMEDIATION DECISIONS

Paul Black

Optimizing the decision-making process requires the balancing of risk against benefit. One challenge to this approach is that risks of exposure can be measured and quantified whereas the "costs" of benefits based on value judgments are not easily quantified. Decision analysis is needed to make defensible, reproducible, and logical decisions that incorporate risk and value judgments for complex sites.

Models are an important tool in decision analysis. Most practitioners of decision analysis understand that—at some level—all models are wrong. Yet, if appropriately applied, then models can be useful. "Useful models" are as simple as they need to be—but no simpler—and they are based on reality. Conservatism in models results in outcomes that are unreliable because their assumptions are not based on reality. Conservative decisions can be made using realistic models, but good decisions cannot be made using conservative models.

Waste and cleanup regulations have impact beyond the environmental remediation of contaminated sites; the regulations can also impact the nuclear energy industry. Overly conservative cleanup standards result in "the waste management tail wagging the nuclear energy industry's dog." Thirty years ago, regulations and guidance—including Data Quality Objectives (DQOs)—were developed as part of nuclear cleanup standards. At the time, simplification made sense. The models, processes, and guidance should be revisited to take advantage of the technologies and experience that have been developed over the decades. The regulations and guidance are currently being updated, but the proposed changes do not go far enough. Meaningful and significant change is understandably difficult but in this case needed.

Environmental remediation is site specific, but aspects of the risk assessment for a given site are often not site specific. For example, the population and threat models (e.g., resident and intruder models) developed for more highly populated sites are also commonly used for remote sites. Probabilities of the likelihood of encounter should be assigned for each of the sites. Another example is the importance of value judgments of the stakeholders for each site. WIPP had strong state and local support, whereas Yucca Mountain did not. Risk assessments normally do not include stakeholder values, but it is possible to account for them using decision analysis tools.

What is decision analysis exactly? Decision analysis combines risk analysis and statistics with an aim to use optimization to guide decisions. One can think of this as "formalized common sense." Humans are not good at considering more than a few aspects or components of a problem at a given time. A decision analysis framework that incorporates value judgments allows for simultaneous consideration of all aspects of a complex problem (e.g., a Bayesian DQO). When faced with technical complexity, uncertainty, cost and value judgments, and multiple competing objectives, decision analysis provides an approach for making logical, reproducible, and defendable decisions. The analysis is easier to understand even if it is more complicated and time consuming to explain. Ultimately, it is easier to communicate and explain the results because the results are based on realistic models. This approach also avoids "re-dos" because it is more difficult to disagree with the results.

EPA has recently incorporated decision analysis into its decisions. Examples include the following:

- SMARTe (Sustainable Management Approaches and Revitalization Tools)—Brownfields project, the focus was on economy, the decision framework brought in environmental and societal issues to allow for balancing
- Re-Imaging Cleveland—original focus was on revitalization of economy, needed to bring in and balance other values
- DASEES (Decision Analysis for a Sustainable Environment, Economy, and Society)—an EPA model driven by stakeholder involvement, accounts for value judgments

Nuclear legacy sites have an inherently long timescale associated with cleanup. One approach that utilizes decision analysis for sites with long-lived radioactive wastes is to make a decision now but plan to revisit the analysis at least once per generation (e.g., every 25 years). The decision context will change as the remedy's effect on contaminants evolves and changes to populations occur. Now is the time to adopt decision analysis that can support sustainability frameworks into the decision-making process.

2.9 SUMMARY OF DISCUSSION SESSION

Models. Tom Nicholson (USNRC) asked how abstraction and realism should be balanced in models. Dr. Black responded that it depends on the stage of the problem at which the abstraction is happening. There are examples of models for very complex sites that are exceedingly detailed (i.e., the site has been segmented into one cubic meter sections). These models are parameter rich but data poor. It is better to focus on the broader problem—including uncertainties and sensitivities—and to set up an experimental design across the model space.

Bayesian Statistics. Planning committee member, Mike Kavanaugh (Geosyntec), asked for an example of a Bayesian DQO. Dr. Black explained the differences between traditional and Bayesian DQOs. Traditional guidance suggests the use of classical statistical methods to support implementation of the quantitative steps of the DQO process. However, classical statistical methods have several limitations that make them ill-suited for environmental remediation decision making, as follows:

- They begin with two hypotheses (null and alternative), which limits the number of options to two,
- The statistical evaluation of null and alternative hypotheses is asymmetric, and
- Classical statistics cannot be used to evaluate the probability or uncertainties that contamination may exist at a site, or to estimate the quantities of contamination that may exist in the future.

However, Bayesian statistics can easily accommodate multiple decision options (more than a null and an alternative hypothesis), are mathematically symmetric in addressing each decision option, and can estimate probabilities and uncertainties associated with each option. Bayesian DQOs can balance risks associated with the environmental system against costs and value judgments to arrive at an optimal decision given the information available.

High Consequence/Low Probability Events. Dr. Kavanaugh asked about low-probability, high-consequence events. Dr. Black acknowledged that this problem is difficult but addressable. Models can provide insights for these events but they must include the event's building blocks. This approach does not model the low-probability event itself but provides insight into how it might occur.

Qualitative versus Quantitative Information. Rateb (Boby) Abu-Eid (USNRC) commented that this discussion is partly about quantitative and qualitative probabilities and uncertainties. Quantitative uncertainties can be related to many unquantifiable value judgments. One needs to account for these contributions. Dr. Black admitted that addressing qualitative uncertainties is challenging. However, it is better to quantify value judgments in the models than to leave them out altogether. Needed are tools of the type suggested by Dr. Goldstein. For example, models provide insight, and sensitivity analysis provides information to guide decisions.

3

Approaches to Assessment

The second session of the workshop focused on approaches for assessing long-term performance of site remedies. Presentations on this subject were provided by a stakeholder and a government regulator:

- Willie Preacher, from the Tribal Department of Energy (DOE) Program and a member of the Shoshone-Bannock Tribes, and
- William Reckley, branch chief in the Japan Lessons Learned Project Directorate, Office of New Reactors, U.S. Nuclear Regulatory Commission respectively.

Federal and state case studies were provided by:

- Richard G. Mach, Jr., director of environmental compliance and restoration policy in the Office of the Deputy Assistant Secretary of the Navy, and
- Roger Petrie, Federal Facility Agreement (FFA) projects manager for the DOE Oversight Division of the Tennessee Department of Environment and Conservation.

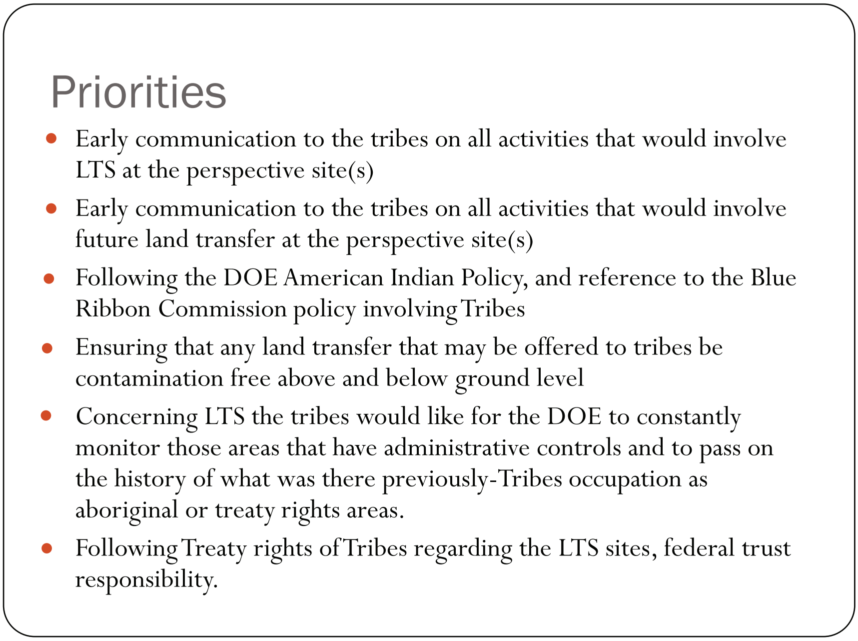
The session was moderated by Patricia Culligan, professor, civil engineering and engineering mechanics, Columbia University and planning committee member.

This chapter provides summaries of the key points made by each of these individuals and by participants in the subsequent discussion sessions. These statements reflect the viewpoints of the individual speakers, not the consensus views of the workshop participants or of the National Academy of Sciences.

3.1 LONG-TERM LAND USE AND OPPORTUNITIES TO AFFECT DECISIONS

Willie Preacher

Mr. Preacher worked at what is now the Idaho National Laboratory starting in 1973. He has been the interface between the tribes and DOE for many years. In 2002, he became director and spokesman for seven tribes. In government-to-government discussions (tribes have sovereign nation status), Mr. Preacher cannot speak for the tribes but he can provide a communication link between the federal government and the tribes. He is involved with state groups, DOE's Environmental Management Advisory Board (EMAB), National Transportation Stakeholders Forum, and the Citizen Advisory Board (CAB) at Idaho. The main priorities for the tribes on environmental management issues can be seen in Figure 3-1.



Priorities

- Early communication to the tribes on all activities that would involve LTS at the perspective site(s)
- Early communication to the tribes on all activities that would involve future land transfer at the perspective site(s)
- Following the DOE American Indian Policy, and reference to the Blue Ribbon Commission policy involving Tribes
- Ensuring that any land transfer that may be offered to tribes be contamination free above and below ground level
- Concerning LTS the tribes would like for the DOE to constantly monitor those areas that have administrative controls and to pass on the history of what was there previously-Tribes occupation as aboriginal or treaty rights areas.
- Following Treaty rights of Tribes regarding the LTS sites, federal trust responsibility.

FIGURE 3-1 Priorities of the tribes on environmental remediation and long-term stewardship (LTS) of contaminated sites.
SOURCE: Preacher 2014.

BOX 3.1
Order 144.1, Principle IV: Policy Principle for Cultural and Natural Resource Protection

Department-wide compliance with applicable cultural resource protection and other laws and Executive Orders will assist in the preservation and protection of historic and cultural sites including traditional religious practices, and traditional cultural properties and places (DOE 2009).

The American Indian Tribal Policy, Order 144.1 (DOE 2009), defines how DOE headquarters and field offices should interact with the tribes. Early and frequent communication is important—particularly when funding issues arise. All tribes understand the funding issue, but early communication of the issues will help with future decision making.

The protection of cultural and natural resources is a priority for the tribes (Principle IV within Order 144.1, see Box 3.1). There can be misunderstandings between the tribes and DOE about what is considered a cultural resource. For example, Idaho National Laboratory (INL) was initially a Naval Proving Ground (see Chapter 1 in this volume). Tribes had used the lands as a cultural resource for hunting and gathering but have been denied access since the proving grounds were established. Mr. Preacher represents a set of tribes that has a good working relationship with the DOE INL field office. The field office keeps the tribes informed of DOE Headquarters' upcoming changes.

Long-term performance of cleanup remedies is an important issue for the tribes. Independent monitoring and surveillance programs have been useful in establishing trust between the tribes and DOE. Almost every tribe has some form of monitoring and surveillance program of the sites. These programs collect samples in parallel to DOE monitoring programs. Analysis is performed at independent laboratories, and the tribes share the results with DOE. This verification of environmental sampling is also important to establishing trust between the tribes and DOE. Unfortunately, federal budget sequestration eliminated funding of the INL tribe monitoring program, even though DOE had agreed to continued-funding of this effort.

Another issue relates to the "trust responsibility" of the sites. Trust responsibility requires the U.S. government to uphold treaty rights, lands, assets, and resources of tribal nations.[1] The tribes would like resolution of the issues of trust responsibility and land use for cultural purposes.

The tribes would also like verification that different types of contamination from new reactor designs under development (e.g., advanced reactor designs) are being considered and studied. Questions exist about the types of contaminants that these new reactors will produce after they are built, operated, and eventually decommissioned. For example, areas across INL contain buried, entombed, and decommissioned reactors.[2] Reactors have been encased in concrete and buried at the Idaho CERCLA Disposal Facility (ICDF). The tribes question the soundness of this practice, especially for future generations.

Groundwater contamination is a difficult issue for the tribes to understand. In the past DOE has focused on cleaning up the groundwater, but now it appears as though cleanup may never be complete. The tribes recognize that cleanup costs a great deal. High costs and hazards to populations are the usual reasons given for incomplete cleanup of groundwater. Groundwater plumes migrate and may encroach onto tribal lands. Wells have been drilled to monitor plume migration and, as was described earlier, tribal monitoring programs have been set up to independently measure contamination.

The tribes would like early communication and involvement in land transfer of the legacy sites. They would like first consideration for any lands to be transferred from the U.S. government, as supported by treaty rights. The tribes would like all above- and belowground contamination to be addressed prior to land transfer. This could mean, for example, cleanup to background levels for remediation of radioactive contamination. Radioactive contamination and radioactivity are also difficult concepts for the tribes to understand. However, the continuation of monitoring programs could help to educate the tribes about these concepts and could potentially help with communication.

Concerns exist about sensitive, archeological sites that were never recorded by the tribes and have not yet been discovered. The tribes expect DOE to respect the American Indian Tribal Policy (DOE Order 144.1, DOE 2009) when these sites are discovered. For example, before DOE Order 144.1 was enacted (circa 1973), INL employees would collect arrow heads

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[1] Federal Indian trust responsibility is explained on the Bureau of Indian Affairs site: “The federal Indian trust responsibility is a legally enforceable fiduciary obligation on the part of the United States to protect tribal treaty rights, lands, assets, and resources, as well as a duty to carry out the mandates of federal law with respect to American Indian and Alaska Native tribes and villages. In several cases discussing the trust responsibility, the Supreme Court has used language suggesting that it entails legal duties, moral obligations, and the fulfillment of understandings and expectations that have arisen over the entire course of the relationship between the United States and the federally recognized tribes” (http://www.bia.gov/FAQs/).

[2] For example, the Boiling Water Reactor Experiment (BORAX)-1 is buried.

and other artifacts found on the site. Through Order-mandated training, DOE employees and contractors were directed to not pick up artifacts. The training has resulted in a noticeable shift in practices and an impact on employee actions.

Figure 3-1 summarizes the main priorities of the tribes. Early communication and involvement on decisions and land transfers are key to a good relationship between DOE and the tribes, which was reaffirmed by the recent Blue Ribbon Commission report on America's Nuclear Future.[3] The tribes are concerned about long-term stewardship and the need to transfer information and history about sites to future generations (e.g., information about buried waste and reactors). Trust responsibility and the recognition of treaty rights are also important. Finally, with every Administration change, the tribes have found that re-education of the new set of DOE federal employees is needed (e.g., an "Indian 101" overview). The tribes meet yearly to discuss these and other issues.

3.2 SUMMARY OF DISCUSSION SESSION

Monitoring Program. Session moderator and planning committee member Patricia Culligan (Columbia University) asked whether the tribes have monitoring and surveillance programs outside of the ones that are conducted with DOE. Mr. Preacher responded that the Shoshone-Bannock tribe collects and measures water samples, soil, plants, and animals (live and road kill) at the borders of the site and throughout the reservation. Recently, the tribe found trace amounts of radiation from the Fukushima accident on stagnant pond samples. The sampling program has temporarily stopped but is expected to restart soon. Idaho's Department of Environmental Quality also has a sampling program. The tribes and state monitoring programs share their independent reports with DOE.

Kevin Crowley (National Academy of Sciences staff) noted the importance that the tribes place on sites being contamination-free above and below ground. He wondered whether there have been any discussions with EM about the tribes acting as long-term stewards of sites for DOE, which could be a valuable arrangement. Tribes are multi-generational and have a strong interest in protecting the lands. Mr. Preacher responded that, when former DOE Secretary Bill Richardson visited INL, the tribes asked if an area north of the site, the Sagebrush Steppe Reserve, could be given back to the tribes. Secretary Richardson's response that the land would be trans-

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[3] See http://www.energy.gov/sites/prod/files/2013/04/f0/brc_finalreport_jan2012.pdf.

ferred to the Bureau of Land Management (BLM),[4] left the tribes with a "sour note" for future DOE land transfers. Tribes live close to the borders of many sites and could potentially benefit from land transfers. For the Shoshone, INL is approximately 35 miles away. The tribe's main objective is to gain access to the site to hunt and fish, but there are concerns about contamination, which leads back to the sampling programs. Animals near and on the site have been tested. Rock chicks sampled near and on the onsite disposal facilities contain radioactivity, but road kill has not been contaminated.

Dr. Crowley posed the same question to Bill Levitan (EM). Mr. Levitan responded that DOE has considered this approach. He could best speak about the Hanford site. Currently DOE and the tribes are discussing access rights for traditional uses by the tribes that recognize the challenges of remaining contamination. One of the challenges to granting rights is that nearly half of the Hanford site has been designated as a national monument and is under management by the U.S. Fish and Wildlife Service (FWS). Therefore, permits are required through the FWS, which highlights another detail that should be considered during the land-transfer and land-access discussions.

Diversity of Tribal Perspectives. Mr. Preacher noted that each tribe will have different values and perspectives, so one should resist grouping tribes together. For example, although 50 tribes are located along the subject transportation routes, only three tribal representatives speak at meetings of the National Transportation Stakeholder Forum. They cannot speak for all of the tribes.

3.3 A RISK-MANAGEMENT FRAMEWORK FOR DECISION MAKING

William Reckley

In early 2012, prior to the Fukushima accident, an activity headed by Commissioner Apostolakis[5] of the USNRC resulted in a report on a regulatory framework that incorporated risk. Although the framework does not focus exclusively on long-term stewardship decisions, it could be used for such decisions. The framework recognizes that federal agencies are trying to

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[4] In 1999, the Sagebrush Steppe Reserve was established to preserve Idaho's high-desert sagebrush. See http://www.bnl.gov/bnlweb/pubaf/pr/2000/bnldoepr110900.html for more details. Part 1 of 2: http://ar.inel.gov/images/pdf/200409/2004090700578GSJ.pdf. Part 2 of 2: http://ar.inel.gov/images/pdf/200409/2004090700582TLR.pdf.

[5] NUREG-2150 defines the new framework (see http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr2150/, accessed March 12, 2014).

establish processes that can be followed when making many different types of decisions and that produce common-sense answers, a theme throughout this workshop.

A task force to develop the strategic visions and implementation for the new framework has the following charter (Reckley 2014, p. 2):

> [D]evelop a strategic vision and options for adopting a more comprehensive, holistic, risk-informed, performance-based regulatory approach for reactors, materials, waste, fuel cycle, and transportation that would continue to ensure the safe and secure use of nuclear material.

The task force added objectives and goals to the USNRC's mission statement and outlined a decision-making process (see Figure 3-2). In addition, it force reviewed other federal agencies' decision-making processes, including those of EPA and the Department of Homeland Security (DHS).

The mission includes the "protection of human health and safety," the latter being defined as the absence of danger or risk. This framework refers to controlling risk or danger to acceptable levels, not removing them altogether. Acceptable levels of risk will differ depending on stakeholder perspectives.

A Proposed Risk Management Regulatory Framework

Mission

Ensure adequate protection of public health and safety, promote the common defense and security, and protect the environment

Objective

Manage the risks from the use of byproduct, source and special nuclear materials through appropriate performance-based regulatory controls and oversight

Risk Management Goal

Provide risk-informed and performance-based defense-in-depth protections to:

- **Ensure appropriate barriers, controls, and personnel to prevent, contain, and mitigate exposure to radioactive material according to the hazard present, the relevant scenarios, and the associated uncertainties; and**
- **Ensure that the risks resulting from the failure of some or all of the established barriers and controls, including human errors, are maintained acceptably low**

FIGURE 3-2 Proposed risk management regulatory framework from the USNRC.
SOURCE: Reckley 2014.

Risk is introduced in this plan at the objective level (see Figure 3-2). Risk management requires a goal that highlights the importance of defense-in-depth (a large number of barriers would have to fail for an unwanted event to occur). The task force found similar aspects in other agencies' decision-making processes: all had a feedback or circular process, and many of the elements (identify the issue, identify the options, analyze, deliberate, implement, and monitor) were the same.

Monitoring as part of the decision-making process is relevant to the topic of this session and the workshop. Monitoring ensures that the targeted outcome is preserved, and it also allows for addressing unforeseen problems. New problems are addressed by initiating a new cycle of the process. Although not included in Figure 3-2, communication at each of the decision-making process stages is important. All stakeholders need to have the same understanding of the issues.

How does this new framework translate into regulatory change? Although the task force does not foresee a dramatic change to the current regulatory approach, some parts of the USNRC, including some of the commissioners, are concerned about implementation. To temper this concern, one should recognize that the USNRC has been moving toward a risk-informed approach for the past 3 decades.

The USNRC regulates facilities and activities widely ranging from nuclear material storage to nuclear power facilities. The level of detail in a risk analysis should fit the scale of the problem. Risk analysis to support the storage of a small amount of radioactive material should not entail the same level of detail and complexity as an analysis to support a nuclear power facility (see Figure 3-3). Traditional engineering analyses, such as deterministic approaches (e.g., the impact of a large pipe breaking at a power facility), are ways to estimate risk and evaluate the impacts. Risk analysis is one of several considerations that feed into the deliberation of regulatory decision making.

NUREG-2150 defines the new framework. It was published in April 2012, and the public comment period, originally ending in November 2013, was extended to February 2014.[6] Already, recent USNRC decisions regarding response to the Fukushima accident have incorporated aspects of risk analysis and the decision-making process. The USNRC is considering the inclusion of economic impacts (e.g., evacuation and its long-term consequences) into the analysis.

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[6] See http://www.gpo.gov/fdsys/pkg/FR-2013-11-25/html/2013-28065.htm, accessed March 12, 2014.

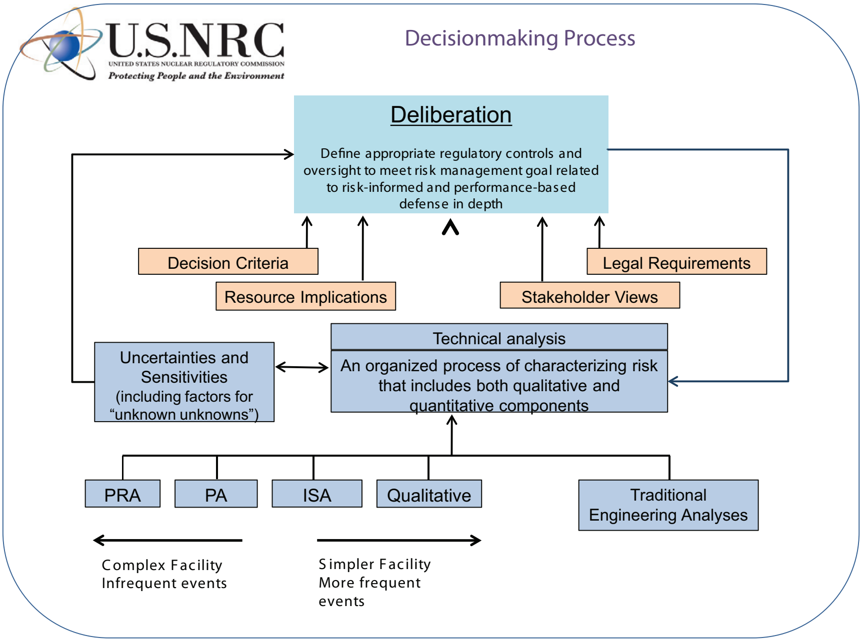

FIGURE 3-3 Decision-making process and the role of analysis, including risk assessment. Simpler facilities will have less complex analyses, while larger facilities such as nuclear power plants will have substantially more complex analyses. PRA = probabilistic risk analysis, PA = performance assessment, ISA = integrated safety analysis. SOURCE: Reckley 2014.

3.4 SUMMARY OF DISCUSSION SESSION

Performance-based versus Compliance-based Approaches. Session moderator and planning committee member Patricia Culligan (Columbia University) asked if Mr. Reckley had seen a preference for performance-based or compliance-based monitoring. Mr. Reckley responded that the nuclear power utilities prefer prescriptive monitoring such as those designed to ensure compliance. Because of costs and liabilities, the utilities prefer to clearly understand the USNRC requirements. Although performance-based standards and monitoring allow for more flexibility, they are not preferred by everyone. The ultimate performance-based program is ALARA (as low as reasonably achievable), which provides the licensee with freedom on how to achieve the lowest dose allowable.

Bill Levitan (EM) provided the DOE perspective by introducing examples of two remedies for a low-level waste (LLW) containment system that have different long-term environmental risks; one remedy was selected using performance-based criteria, the other with a prescriptive approach. For an LLW facility permitted under DOE authority, a performance-based standard of 25 mrem measured at 100 m from the boundary is used. The resulting design of the LLW facility will often utilize monitored natural attenuation and will have no liner (depending on the site for which it was designed). However, for a LLW facility permitted under RCRA or CERCLA, the remedy will often include liners because of prescriptive regulations. Ultimately, this remedy may result in increased environmental risk in future years when the liners fail. David Maloney (CH2M HILL) agreed and noted that lingering risks at some sites (e.g., Rocky Flats or Oak Ridge) are due to liners that were selected during cleanup following prescribed regulations or guidance.

Planning committee chair Paul Gilman (Covanta Energy) asked if EM has consent decrees or a tri-party agreement that has a prescriptive standard but implement a less-prescriptive, more performance-based standard. Mr. Levitan identified the Lower Watts Bar Reservoir presentation (see Petrie 2014) as one such example. Hanford is site for which a less-prescriptive approach has been introduced in a waste disposal facility. The encapsulation of contaminated material at the RCRA facility is not allowed under the prescriptive standard (regulation), which requires that the material be removed from the disposal facility, encapsulated, and then returned to the disposal facility. At Hanford, they are demonstrating that encapsulation can take place at the disposal facility to reduce time, exposure, and costs of transporting the contaminated material to another location.

Paul Gilman provided an example scenario in which stakeholders demand standards that exceed USNRC regulatory limits. The USNRC is overseeing the decommissioning of a uranium facility using ALARA, but the local residents want exposures that are lower than those determined by the facility and the USNRC. How would the USNRC—which is the regulatory authority and makes the final determination—resolve the dispute? The USNRC will engage with the stakeholders to understand and their concerns and then factor them into the decision-making process. Dr. Abu-Eid (USNRC) interjected that the decommissioning rule does have flexibility.[7] Probabilistic risk analysis could be used to evaluate decisions and options. Also, understanding of the planned land use is important when making a final decision. For example, if the land use will be restricted, then the residents and local stakeholders should have a full understanding of the restrictions. Comments and concerns are collected through public meetings and feedback.

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[7] The decommissioning rule can be found at http://www.gpo.gov/fdsys/pkg/FR-1996-07-29/pdf/96-19031.pdf.

Kevin Crowley (National Academy of Sciences staff) expressed interest in the pushback within the USNRC to the new framework. He asked for details on the type of pushback (i.e., is it fundamental to the process or is it centered on implementation?) and, if possible, on general stakeholder feedback received thus far. Mr. Reckley responded that the pushback from the USNRC primarily centers on implementation and the impact on regulations; there is not a fundamental concern about the approach. In terms of public comments, the utilities have generally been lukewarm to the new framework, because it represents change and change costs money. Even if the change is in language only (such as the requirement to include defense-in-depth in analysis), costs are associated with it. There is also some concern that formal risk assessment methodologies, such as probabilistic risk assessment (PRA), are costly to carry out. The cost-benefit is difficult for the utilities to understand. Paul Black (Neptune) commented that if deterministic risk analyses were performed thoroughly, then they would be similar in complexity and costs to PRAs. Mr. Reckley agreed and pointed out that deterministic models originally did cost a great deal—through the development of reactor cores that were melted and other experiments. But those costs have been expended and absorbed by the utilities. Dr. Black made a further point that PRA accounts for consequences better than do deterministic models.

3.5 BETHPAGE/NORTHROP GRUMMAN AIRFIELD REMEDIATION AND STEWARDSHIP ON LONG ISLAND

Richard G. Mach, Jr.

In April 2012, the U.S. Navy issued updated guidance on optimizing its environmental remediation and removal actions at U.S. Department of Navy sites. The updates represent two decades of evolution on the Navy's environmental decision making.[8] Initially, the Navy approached environmental cleanup by focusing on identifying and installing remedies as quickly as possible. This resulted in deploying many pump-and-treat systems (P&T) that operated for a long time. It is not clear that the P&T systems were effective, but they were certainly costly. The Navy has reconsidered its initial approach, recognizing that initial remedies may not be effective or optimal. The updated guidance recognizes that optimization begins with thorough site investigation. which inherently includes risk-based approaches and assessments.

The Navy's approach depends on good conceptual site models. Each

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[8] See http://dels.nas.edu/resources/static-assets/nrsb/miscellaneous/NavyOptimizationPolicy.pdf.

site is different, but risk and feasibility assessments based on the models guide the remediation decisions. The most recent changes to the Navy's approach incorporate green and sustainable remediation practices. There is a strong belief that all three sustainability pillars fit easily into the CERCLA nine criteria—economic and societal values are included in feasibility assessments.

Approaches for managing contaminated groundwater plumes are site specific, especially for large complex sites. Factors include whether the site is active or closed, large or small, and whether the contamination is contained within or outside of the site. The DOD's BRAC process resulted in many lessons learned on how to include the public in these assessments and decisions. Not only is plume management site specific, but also one treatment for the entire plume may not be appropriate for large plumes. In these cases, the plume is segmented into discrete areas. Treatment trains (combined or sequential remediation actions applied to sites with numerous or complex contaminants) are developed (e.g., P&T) through holistic thought and consideration of how to move from active to passive remediation systems (e.g., whether to contain the source or provide wellhead treatment).

Understanding the remediation goals and developing a remediation exit strategy are critical considerations early in the cleanup process. An "exit strategy" may not be defined as leaving the site entirely but it should include a mechanism for considering when to stop, modify, or change the current remedy if it is becoming less effective.[9] For example, when the amount of money spent to reduce risk increases dramatically after a large fraction of the risk has been addressed, it may be a good time to reconsider the current remedy.

A good case study demonstrating the Navy's current approach to remediation is the Bethpage Airfield. Established in the 1940s, the Bethpage Airfield is currently shut down (see Figure 3-4). The airfield was originally a Navy-owned property surrounded by a non-governmental entity (Northrop Grumman). Most of the government-owned property has been transferred and developed. The property is located in a heavily populated area with multiple water districts and multiple potentially responsible parties (PRPs) beyond the Navy and Northrup Grumman.[10] However, the Navy and Northrup Grumman remain the responsible parties for the Bethpage groundwater plume, which resulted from more than 50 years of building Naval aircraft. The main contaminants are chlorinated solvents, primarily

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[9] When effectiveness continually decreases by year, perform an optimization study to increase performance, reduce costs, or define metrics for shutdown and convert to a passive remedy.

[10] A potentially responsible party is a company or individual who had knowledge and was responsible for the contamination. More information can be found at http://www2.epa.gov/enforcement/superfund-enforcement.

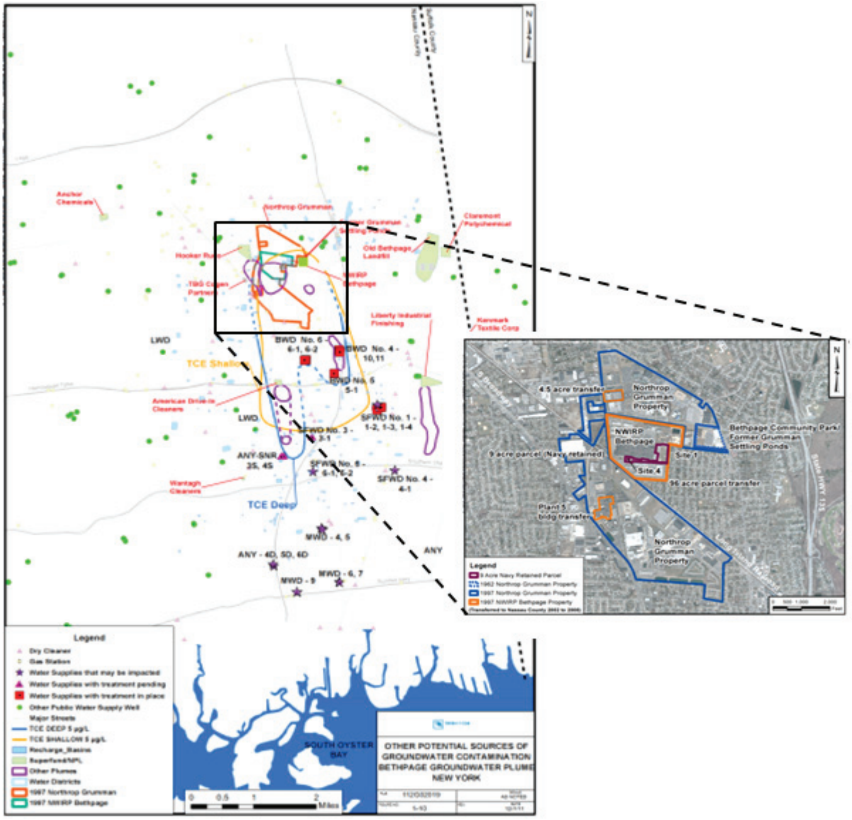

FIGURE 3-4 The Bethpage Airfield property and contamination plume. The large map shows the relative distance of the Atlantic Ocean to the Bethpage site and its contamination plumes. The insert provides details on the location of the Navy-owned property with respect to the Northrop Grumman property. Residential properties surround the site.
SOURCE: Mach 2014.

perchloroethylene (PCE) and trichloroethylene (TCE). The contaminant plume is traveling south, has separated into "fingers," and is expected to eventually reach the Atlantic Ocean (see Figure 3-4). Unlike the DOE legacy sites, radioactive contaminants are not a consideration.[11] Bethpage is not an EPA site; the state (New York Department of Conservation [NYDEC]) is the lead regulatory agency.

The plume is split into operable units (OUs): OU1 is the onsite unit

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[11] Radon has been detected during cleanup, but it is not a significant contaminant.

and includes the source(s) of contamination, OU2 is a joint offsite plume shared by the Navy and Northrup Grumman, OU3 is Northrup Grumman's offsite plume (see Figure 3-5). The original Record of Decision (ROD) for OU2 was signed by the Navy, Northrop Grumman, and NYDEC in 2003. OU2 remedies include onsite containment with P&T at the site boundaries, a large monitoring network, wellhead treatment for affected water districts, and sentry wells situated ahead of the plume's migration.

Both onsite and offsite conceptual models were developed to better understand the plume's migration. Onsite conceptual models benefitted from two factors: a concentrated and well-defined plume due to its proximity to the source and the ability to place wells in optimal locations to characterize the plume and validate the model. Offsite conceptual models were more challenging to develop and validate: the shape of the plume becomes complicated the farther it moves from the source, with many fingers and discontinuities. Monitoring for characterization and model validation is complicated by the inability to place wells in specific locations because of residential and industrial development. The rate at which the water districts pump water also affects the offsite plume. Each district can pump up to 10^6 gallons/day, but pumping varies by season (e.g., in winter months, less water is pumped). This affects the dynamics of the plume in ways that were not predicted by the original offsite conceptual models.

The current remedy for OU2 of the plume includes hot spot treatment, P&T with an exit strategy, and wellhead treatment. Wellhead treatment for affected water districts is in place and operational. Sentry wells for districts not yet affected by the plume but within its projected path are also part of the remedy. Sentry wells were established to detect contamination before it reached public water supplies. However, they are not always effective.

In one example, a private water company (Aqua New York) detected PCE in its water supply but the sentry wells did not. Wellhead treatment was installed at Aqua New York's wells to treat the PCE, and the issue was resolved. Following this incident, many water districts not yet affected by the plumes became concerned, and the U.S. Congress became involved. Water districts close to the Atlantic Ocean wanted the plume to be contained to prevent its reaching their wells.

To address the concerns, the Navy worked with congress, the districts, EPA, the U.S. Geological Survey (USGS), and the U.S. Army Corps of Engineers to perform a full plume analysis and remedy optimization. The final report issued by the Navy in June 2011 considered several alternatives:

- Searching for and treating additional hot spots
- Developing improved conceptual site models
- Improving performance of sentry wells
- Fully containing the plume

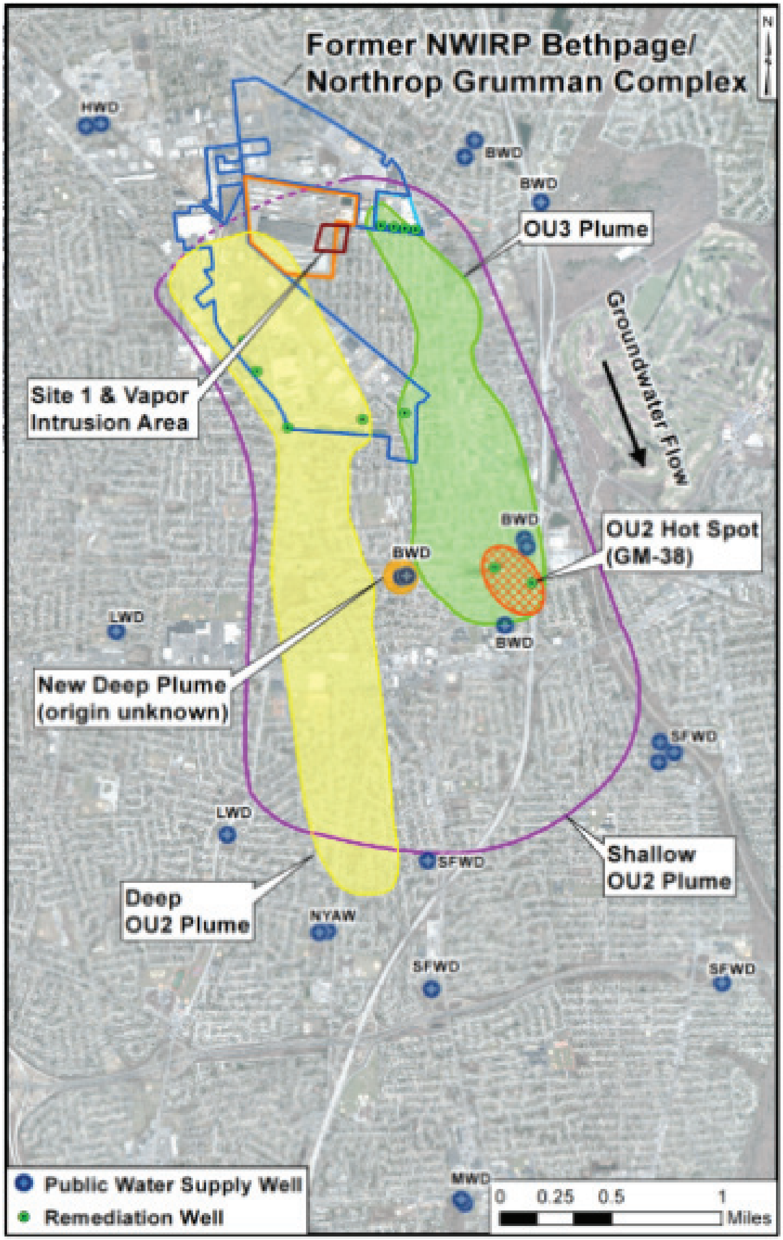

FIGURE 3-5 The Bethpage contamination plume separated into Operable Units (OUs). OU2 is shown as a shallow plume (purple outline) and a deep plume (long, yellow finger). The Navy and Northrop Grumman are the primary responsible parties for OU2. SOURCE: Mach 2014.

The study found, with consensus among the participants, that the original ROD presented a responsible, smart, and protective remedy. Better characterization of the plume was needed, and additional hot spots should be identified. Full containment of the plume was not an option. This study resulted in changes to the current remedy to OU2, including paying existing wellhead treated facilities to pump at a constant rate year round to keep flows more predictable and to stabilize the plume.

Treating contaminated groundwater at the public water systems—i.e., at the point of human use—is a creative solution to a very complex problem. Most offsite cleanups are technically challenging, but asking the questions "When do you treat the plume?" and "Where do you treat the plume?" may prompt interesting answers that can help to define creative solutions. In this case, do you return all of the groundwater to drinking-water standards, or do you treat it at the public water districts when you are ready to drink the water?

3.6 SUMMARY OF DISCUSSION SESSION

Vapor Intrusion. Rula Deeb (Geosyntec) asked whether there were any vapor intrusion issues with any of the residences surrounding the site. Mr. Mach responded that few homes have been affected because the plume is not close to the surface. However, approximately 10-16 homes have soil affected by vapor intrusion. The Navy has worked with NYDEC and Department of Health to establish remedies and monitoring.

Litigation. Planning committee member Michael Kavanaugh (Geosyntec) asked whether litigation and equipment failure were part of the risk calculation. Mr. Mach responded that he did not know whether or how litigation risk was accounted for in the risk calculation but noted that litigation is part of the current solution. New York public water systems require their personnel to acquire, install, and operate any wellhead treatment system attached to a public water system. The Navy cannot use cleanup money to pay the public water districts to purchase or operate wellhead treatment equipment. The current solution is for water districts to place a claim against the U.S. government. A settlement agreement is worked out in which the Navy pays capital and operation and maintenance (O&M) costs to the public water systems for the wellhead treatment equipment. The exception is Aqua New York; the Navy is building and operating the wellhead treatment system for that location because it is a private company.

Technical Impracticability (TI) Waivers. Dr. Kavanaugh noted that an interesting aspect of this case study is the apparent public acceptance of "the plume is too big to contain" argument—that containing it would not be technically practicable. He also noted that the Navy is not a strong supporter of TI waivers. He asked whether Bethpage is a clever way around this issue. How might others, including EM, deal with this situation? Mr. Mach responded that TI waivers were not part of the approach for the Bethpage remedy. Rather, the Navy presented a solution that made sense for a massive plume. Although the public water districts affected by the plume did not initially support the wellhead treatment remedy, the wells were already being treated for other contaminants. The proposed solution was understood and eventually accepted by all affected districts.

The Navy has a saying: "TI/RI"-technical impracticability/regulatory impossibility. The TI process is difficult and not worth pursuing from the Navy's perspective. Another approach is to provide program managers with tools to consider other options when defining remedies. For example, the use of MCL in the aquifer implies that the aquifer is the receptor. Another option is to apply the standard to groundwater at the drinking point. In the Bethpage remedy, wellhead treatment is used to eliminate the exposure at the point of use, and water as a resource is still respected.

Robin Anderson (EPA) pointed out that pressure is important to improving technologies and remedies for sites without a clear path to full remediation, such as in the Bethpage example. What mechanisms are in place to push for new technologies or alternate solutions? Mr. Mach noted that the Navy's Optimization Policy requires continual assessment and reviews with third-party evaluations. The Navy is always looking for better solutions and pathways for new technologies.

Dr. Deeb recalled an example from Workshop 1. Steve Cobb's presentation on the Anniston Army Depot remediation provided a similar problem with a similar solution as the Bethpage case study. If a zone of the plume cannot be treated, as has been shown in the Bethpage remedy, then draw a circle around it and revisit it every 5 years to see if a solution exists, but consider using a TI waiver. This would have alleviated the requirement for the Army to find the source of the contamination—an activity for which it had already spent tens of millions of dollars.

Dr. Deeb asked Ms. Anderson how TI waivers could be a viable option for EPA in such cases. Ms. Anderson responded that TI waivers have an inherent perception problem. The implication is that, unless there is constant pressure to overturn a TI waiver, it will not be overturned. Mr. Mach agreed with this assessment, noting the Navy's decision to not pursue TI waivers is partially due to the current stigma attached to them. Creative solutions to address the contamination at large, complex sites are possible without TI waivers and include plans that are responsive to stakeholder concerns.

Intrinsic Value of the Environment. Dan Goode (USGS) commented that, in the Bethpage example, the environment is left out of the solution.

Was someone representing the environment in the Navy study or the negotiations for the final remedy? Mr. Mach noted that, although ecologic receptors were considered in the remedy, few were identified (the plume is deep, at 800 feet below the surface). Studies have shown that once the plume reaches the ocean, the environmental risk minimal for discharge of chlorinated solvents into surface water is minimal. Bill Levitan (EM) noted that the Bethpage case study is another example of a performance-based solution: the intrinsic value of groundwater is included in the assessment. In this case, the value of groundwater on Long Island is derived from the drinking.

Conceptual Models. Robin Anderson (EPA) asked about the effectiveness of the OU2 remedy and whether data have shown that the plume has detached from the source. Mr. Mach responded that models and data show that the plume is starting to detach but not enough data exist to confirm separation. The ROD for OU3 recently signed by Northrup Grumman and NYDEC has the same remedy as OU2, suggesting that NYDEC is comfortable with the remedy's effectiveness.

Ming Zhu (EM) emphasized the importance of modeling in decision making. In this presentation, the original offsite conceptual models predicted that the public water systems would not be affected for 40 years, but the contamination showed up in 10 years. He asked, "What lessons did this experience teach you?" Mr. Mach responded that the optimization team determined the initial models to be wrong for several reasons, most importantly that the model was designed for a particular piece of the plume but was extrapolated beyond that point. The optimization team recommended more accurate and localized models be developed.

3.7 INSTITUTIONAL CONTROLS ON LOWER WATTS BAR RESERVOIR

Roger Petrie

The Lower Watts Bar Reservoir was constructed by the Tennessee Valley Authority (TVA) between 1939 and 1942 for the purposes of navigation, power generation, flood control, recreation, and irrigation. It has also been a source of drinking water for the local communities. Most of the land along the Lower Watts Bar Reservoir is privately owned. Numerous rivers, creeks, and streams feed into the reservoir. Dams located along the rivers affect their flow rates and flow directions. Upstream of Lower Watts Bar are several potential sources of contamination to its water, soil, and sediments including the Oak Ridge Reservation (ORR, Figure 3-6).

In the late 1980s, there was rising concern that the sediments in Lower

Watts Bar Reservoir may have been contaminated because of prior releases from DOE nuclear weapons development operations at ORR. By 1989, ORR was placed on the National Priorities List as a CERCLA site requiring investigation by EPA. In an effort to protect the public, an Interagency Working Group (IAWG) consisting of DOE, EPA, the State of Tennessee (the State), TVA, and the Army Corps of Engineers (the Corps) was formed in 1991. The IAWG put in place institutional controls on sediment in Lower Watts Bar Reservoir to protect the public from potential human health risks. In 1992, the Federal Facility Agreement (FFA) for the Oak Ridge Reservation was signed by DOE, EPA, and the State. The FFA governs the CERCLA cleanup of the Oak Ridge Reservation and any offsite areas impacted by DOE operations in Oak Ridge.

One of the first offsite areas addressed under the agreement was Lower Watts Bar Reservoir. As with the Bethpage example (see Mach 2014), at the time there was no formalized framework for addressing remediation of

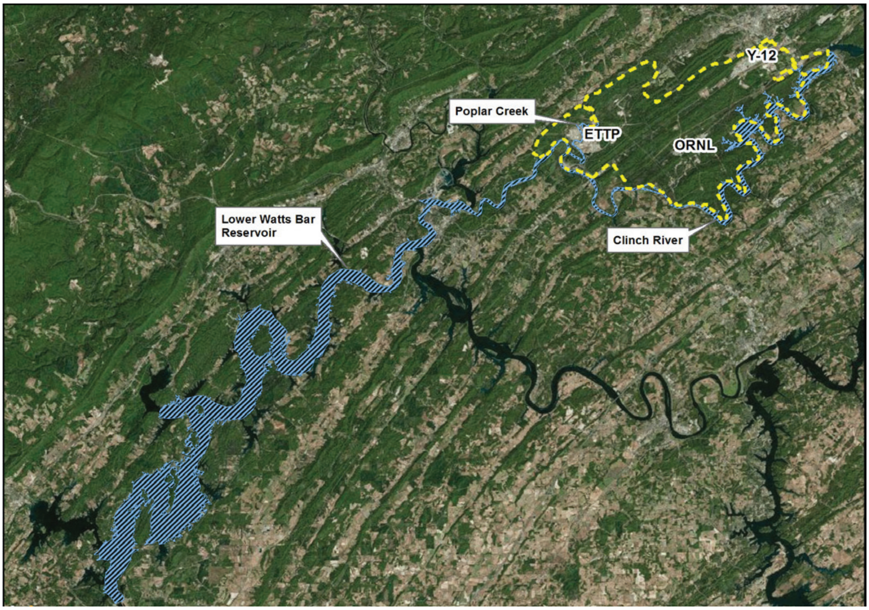

FIGURE 3-6 Locations of the Lower Watts Bar Reservoir, Clinch River, Poplar Creek, and the Oak Ridge Reservation (ORR) (site boundary shown in dotted line). ORR's major facilities are shown: East Tennessee Technology Park ([ETTP] previously K25), the Oak Ridge National Lab ([ORNL] previously X10), and Y12. SOURCE: DOE, http://energy.gov/sites/prod/files/2014/01/f6/LowerWattsBarRes_0.pdf.

contaminants from offsite sources. The selected remedy for Lower Watts Bar Reservoir was to control human exposure to sediments through institutional controls. Because the IAWG was already in place, it became part of the selected remedy. The Record of Decision for Lower Watts Bar Reservoir was signed in 1995. In 2001, a unified 5-year CERCLA review schedule for all sites and programs was established, focusing all programs into a single review cycle. There have been two additional reviews (in 2006 and 2011).

To better understand the constituents of the contamination of the sediment, one must understand the history of DOE activities at Oak Ridge. ORR had three main facilities: Y12, Oak Ridge National Laboratory (ORNL, previously X10), and ETTP (previously K25, see Chapter 1 in this volume, Oak Ridge Reservation). A myriad of contaminants were released from these facilities during past nuclear weapons production operations. However, cleanup efforts have focused on a subset of the contaminant list: mercury, cesium (for radioactive by-products), and PCBs. This subset of representative contaminants is used to gauge the presence of other contaminants.

Y12 was originally used to enrich uranium. Significant quantities of mercury were used in the lithium separation process prior to enrichment. Y12 is the main source of mercury contamination at and around ORR. Twenty-four million pounds of mercury were vouchered/accepted at Y12. It is estimated that 0.5 million pounds of mercury remain in buildings; 0.5 million pounds were released to East Poplar Creek and nearby soil; and approximately 1.2 million pounds are "unaccounted for."[12] Mercury continues to leak and seep from storm drains. In 1954, the volume of mercury released to East Poplar Creek was approximately 72,000 pounds/year. In 2000, this amount had been reduced to about 30 pounds/year.

Initial studies and experiments on reprocessing and extracting/purifying plutonium were performed at X10. ORNL is located where X10 used to operate and is the main source of the cesium contamination. Many radioactive and hazardous by-products from these experiments were released to White Oak Creek, which feeds directly into the Clinch River. Cesium has been detected in sediment throughout the Clinch River and Lower Watts Bar Reservoir (and other places). A sediment retention dam was built at the mouth of White Oak Creek; it has been effective in reducing the rate of cesium releases into the Clinch River but has not stopped them completely.

The gaseous diffusion plant at K25, currently the ETTP, used vast amounts of electricity to enrich uranium. PCBs were used in the power system components (e.g., condensers, capacitors, transformers). Because

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[12] Barrels of mercury were counted and vouchered upon delivery at Y12. However, not all of the barrels were full (i.e., a percentage of the barrel could have been partially full), which was not noted in the vouchering process. Some fraction of 1.2 million unaccounted for mercury was missing upon delivery.

of the many PCB oil spills on site, K25 is the main source of PCB contamination for Oak Ridge. PCB contamination spread from K25 to Poplar Creek, which also feeds directly into the Clinch River and Lower Watts Bar Reservoir.

The area downstream of Oak Ridge was split into two operable units (Clinch River/Poplar Creek and Lower Watts Bar Reservoir) to address remediation challenges. Costs for full remediation of the sediment within both operable units were estimated to be between $30 and $60 billion (1995 dollars), a large fraction of EM's overall cleanup budget of $200 billion.

Alternatives to full remediation of sediment were explored. It was determined that cesium was the largest human exposure pathway for sediment with acceptable risk set at 11 picocuries per gram (pCi/gm) (The risk calculation assumed that sediment is dredged from the rivers or creeks and placed onto land. This land was then used to plant vegetables and crops for human consumption). Sediment maps were generated by sampling for cesium along the reservoir. The presence of dams affects flow rates and directions, which affects sediment deposition patterns within the reservoir.

As mentioned previously, the IAWG was established to protect the public from exposure risk from sediment disturbances. Any activity on the reservoir that potentially disturbs sediment requires IAWG approval. The application for approval requires the following information:

- Review the proposed action (size, location, elevation)
- Collect historical data on vicinity of project
- Evaluate levels of cesium in samples
- Decide whether further investigation is needed
- Determine whether DOE action is required to reduce risk

DOE's involvement is not needed for the vast majority of the applications. However, DOE action is sometimes required. For example, the Tennessee Department of Transportation had taken sediment samples from a bridge excavation and left its samples in the yard of a resident. DOE investigated and determined that cesium activity in the sediment was below the established acceptable risk levels.

What happens if the risk exceeds acceptable levels? This depends on whether the land is public or private. Neither DOE nor the IAWG has authority to restrict citizens from activities on private property. In a hypothetical example, a citizen plans to build a dock that would disturb sediment contaminated above the 11 pCi/gm level. In this case, DOE would have to confirm that workers were protected while building the dock and would be responsible for disposing of the contaminated debris from the project.

The IAWG has determined that mercury and cesium contamination are co-located in the sediments and exposure pathways. Therefore the protective measures established for cesium (i.e., institutional controls of sediment) also apply to mercury. However, the exposure pathway for the third representative contaminant, PCB, is through ingestion of fish. The record of decision requires that samples of fish, surface water, and sediment be tested annually for PCBs. The fish sample is collected from several species including largemouth bass, striped bass, hybrid (striped and white) bass, and snapping turtles. Subsistence fishermen make up a small percentage of the population along the Lower Watts Bar Reservoir, but environmental justice requires that their protection be considered. Therefore fishing advisories have been issued along the Clinch and Tennessee Rivers to reduce the risk of PCB exposure.

There are several challenges for remediation: multiagency consensus, identification of contaminant source terms, long-term funding, and public acceptance. Two groups within the IAWG, the Corps and TVA, are not signatories to and are not bound by the Oak Ridge Reservation FFA, which can add difficulty to building consensus for decision making. The fish advisories are established by the Tennessee Department of Environment and Conservation (TDEC), which is not required to make them consistent with the Lower Watts Bar Reservoir's Record of Decision (this example also highlights the challenge of managing multiple and potentially conflicting remediation decisions within a single state agency because TDEC is also a signatory to the FFA).

There are multiple sources of contamination. TVA's Kingston Fossil Plant, for example, is an upstream source of mercury as well as ORR.[13] It is estimated that 25 percent of the PCB contamination came from DOE activities at ORR, the remaining 75 percent from other industries. The main contaminants are long-lived, and the current remedies require long-term funding. Cesium-137 (Cs-137 is the main contaminant) has a half-life of 30 years, and PCBs and mercury do not decay or degrade. Current remedies assume the federal government will continue to maintain protective actions for hundreds of years.

Finally, public opinion and perception impact the final remedies. Risk may inform proposed remedies, but public values determine the remedy selections. Understanding and interpretation of risks vary across citizens groups. For example, the following risks of exposure are presented at a local town hall meeting: There is a 10^{-4} to 10^{-6} risk of cancer due to contaminated sediments and there is a fish advisory against eating striped bass. Parents and grandparents may interpret that risk to mean, "My child/grandchild will get cancer if he or she swims in the reservoir." On the other

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[13] In 2008, a retaining wall at the Kingston Fossil Plant, collapsed releasing 2.5 million cubic yards of fly ash across hundreds of acres. The fly ash contaminated the river and homes. Fly ash contains mercury among other hazardous chemicals.

hand, commercial fishermen and new property/land owners may interpret the risk to mean, "My job is in jeopardy," or "The value of my home has dropped."

In the final record of decision for the Lower Watts Bar Reservoir, no one group was happy but perhaps that means it was the right decision for everyone.

3.8 SUMMARY OF DISCUSSION SESSION

Protectiveness of the Remedies. Michael Kavanaugh (Geosyntec) asked if the CERCLA 5-year reviews have established that the remedy is protective and whether any group questions the protectiveness. Mr. Petrie confirmed that the reviews have shown the remedy is effective at protecting human health and the environment. However, commercial fishermen feel the remedy is overly protective and that it adversely impacts the economic value of the reservoir; this has not been seen in the economic analyses.

The following example provided by Mr. Petrie highlighted the intersection of public opinion, awareness, and knowledge and the protectiveness of proposed remedies: The Lower East Fork Poplar Creek Flood Plain Record of Decision[14] had established a reference acceptable dose limit of 500 parts per million (ppm) of mercury based on ecological risk. The public was concerned about the overall disruption and cost of the proposed remedy and asked for a less disruptive and consequently less protective solution. The original reference dose was calculated assuming the exposure to mercury was due entirely to its most toxic form (organic mercury or methylmercury). A more realistic model assumed the majority of the mercury is in the form of elemental and inorganic mercury (other naturally occurring forms of mercury) not solely as methylmercury. A re-calculation of reference dose determined the acceptable limit to be 400 ppm. The remedy for this dose resulted in less disruption of the sediments and lands; as a consequence, the overall costs were reduced. A 5-year review indicates the mercury uptakes in the environment are larger than expected, so the modified remedy may not have been as protective as originally thought.

A workshop attendee asked about the Lower East Fork Flood Plain decision and asked for additional information on the public's decision to push for a less protective remedy. Mr. Petrie responded that the most vocal opponents had property that would have been affected by the initial remedy. Other members of the public thought that the cost of the remedy was not justified. In general, the public's initial reaction to an ecological risk is to assume that a deer (e.g., Bambi) or similar animal species will suffer from the uptake of contamination. In reality, the assessments indicate that

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[14] See http://energy.gov/sites/prod/files/2014/01/f6/LowerEastForkPoplarCreek_0.pdf.

less sympathetic species will be impacted the most; the animals identified in the analysis of mercury uptakes for the Lower East Fork Flood Plain were spiders and starlings. The public is not as concerned about the risk to these creatures as they are to some others.

Fish Monitoring Program. A workshop attendee asked about the fish monitoring program. Mr. Petrie responded that fish monitoring was previously performed annually by multiple groups—TVA, DOE, U.S. Fish and Wildlife Service, the State of Tennessee—resulting in comments by local stakeholders that "the biggest threat to fish in the reservoir was the scientists performing environmental monitoring." A Fish Tissue Committee was established to review analyses, assign work, and share data among these groups. This has increased the amount of data available to any one of the tissue committee partnering agencies for analyses. Eric Pierce (ORNL) noted that the fish analysis has evolved to the point of catch-and-release after a tissue sample is taken.

Best Practices. Dr. Kavanaugh asked what best practices might be identified on risk-informed remedy selection. Mr. Petrie responded by focusing on the novel aspect of the decision-making processes that were developed to establish the remedy. The risk-informed decision process was a necessity because of several factors: initial impractical cost estimate of $30 billion to $60 billion, sediments being buried and continued to be buried, and no existing standards for contaminated sediments in Tennessee. Notably, the fish advisories were based on risk formulae for ingestions. But other factors beyond risk were weighed in the decision-making process—such as public and community values.

A workshop attendee noted that all of the pieces of a sustainability approach—consideration of risk to health and environment weighed against economic and societal values—can be found in this case study. It was suggested that the sustainability approach was "backed into" in the process. Mr. Petrie agreed and noted that similar sustainability approaches are currently being used to guide remediation decisions for new sources of contamination (such as mercury contamination from the Kingston plant fly ash release).

4

Monitoring

Many of the Department of Energy's (DOE's) legacy waste sites will have contamination and wastes remaining on site that will require long-term monitoring and control. The focus of the third session of the workshop was monitoring and institutional controls for long-term stewardship. The topic was introduced by Craig Benson, director of sustainability research and education and chair of civil and environmental engineering and geological engineering, University of Wisconsin and member of the Consortium for Risk Evaluation with Stakeholder Participation (CRESP).

Examples and case studies of long-term monitoring programs were provided by

- Dave Geiser, director and acting deputy director of DOE's Office of Legacy Management (LM), and
- Mary Flora, environmental compliance and area completion projects for Savannah River Nuclear Solutions, LLC.

Rula Deeb, principal, Geosyntec, moderated the session.

This chapter provides summaries of the key points made by each of these individuals and by participants in the subsequent discussion sessions. These statements reflect the viewpoints of the individual speakers, not the consensus views of the workshop participants or of the National Academy of Sciences.

4.1 STRATEGIES FOR LONG-TERM MONITORING AND STEWARDSHIP

Craig Benson

For containment systems, one must "trust but verify" to confirm that the system is protecting human health and the environment. This can be done by confirming that compliance levels have been met (compliance monitoring) or that systems are performing as designed (functional monitoring). Groundwater wells, which are commonly used for compliance monitoring, are not always the best way to determine whether a system is functioning as designed. Monitoring for compliance is standard practice for many sites (see Table 4-1 below). The regulators dictate (e.g., through tri-party agreements, consent orders, or Federal Facility Agreements [FFAs]) where and when to monitor the containment systems. The problem with this approach is that a failure of the system is detected too late and without enough information to fix the problem.

A preferable approach is to focus on confirming the performance of the containment system through functional monitoring. Monitoring by

TABLE 4-1 Compliance Versus Functional Monitoring

Type of Monitoring	**Compliance:** the common monitoring strategy	**Function:** uncommon strategy
Why	Because somebody made us do it	To confirm that feature is functioning as expected
Where	Where they tell us to monitor	At location near feature
When	When they tell us to monitor	Adequate frequency to characterize behavior
Advantages		Confidence in methods and procedures Evaluate and/or calibrate predictive capability
Disadvantages and Shortcomings	Impact of deficiency detected long after inception Casual deficiency ambiguous Limited or no information about mechanisms (no lessons learned)	May not meet regulatory requirements May not understand mechanisms (requires more info)

SOURCE: Modified from Benson 2014.

function takes place at critical locations and at frequencies dictated by the design of the system and may include unconventional measurements. This approach identifies underperforming systems before they fail and provides data to improve models, designs, and decision support. Data collected at key locations can add confidence in a system's design or provide a better understanding of previously unknown mechanisms contributing to underperforming containment systems. The challenge is that functional monitoring may not meet regulatory requirements.

Lysimeters can be used to measure moisture and other parameters in containment systems. For example, a containment system in Sacramento, California, was designed to control water percolation to less than 0.1 mm/year. A functional monitoring program—including lysimeters—provided insight into a previously unknown mechanism that contributed to excessive water percolation within the design.[1]

The system was installed and, at the surface, appeared to be functioning well with grass and vegetation growing as expected and with no reported problems. However, lysimeter measurements occasionally showed jumps in percolation rates on the order of 100 mm/year (a factor of 1,000 higher than the system specifications). Additional measurements were made, and historical weather data analyzed. Increased percolation during the spring and summer was correlated with unusually wet, preceding winter months during which the soil did not dry out.

These additional data were used to update models and the source terms for percolation. Modifications were made to the system to function as originally designed. The effect of higher-than-normal precipitation during the rainy season on the soil's water capacity during dry months has also impacted other designs and has improved the overall understanding of containment systems.

The basic requirements of a sustainable, long-term containment system are a remote monitoring capability, reliable hardware, and flexible deployment. Dr. Benson suggested that remote, automated monitoring should be used whenever possible because relying on onsite visits is problematic. When data are available on-demand (e.g., with frequent updates available online) problems can be diagnosed early.

For example, a successful automated, remote-monitoring program was implemented at the Resource Conservation and Recovery Act (RCRA) cap at the Fernald site. The objectives of the monitoring project were to verify performance of the containment systems, provide early warning of problems, and increase stakeholder confidence in the remedy. The features of the functional monitoring system were

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[1] See pages 7-11 of Dr. Benson's presentation: http://dels.nas.edu/resources/static-assets/nrsb/miscellaneous/benson.pdf.

- surface access,
- a variety of high-reliability sensors (transducers, reflectometer, thermal sensors), and
- data logging and data access via Web-interface.

The Fernald RCRA cap monitoring system provided remote access to many different types of measurement data, enabling analysis to be carried out to find any problems that arose (see Figure 4-1).

The greatest challenge for long-term stewardship is monitoring of remedies. Monitoring must be effective, reasonably priced, and well-defined. Long-term monitoring systems that combine remote monitoring with a design compatible with natural surroundings are more likely to be effective, require minimal maintenance, and, therefore, be reasonably priced.

Two examples highlight the importance of well-designed long-term monitoring systems (e.g., combining remote monitoring with naturally compatible designs). In the first, a Uranium Mill Tailings Radiation Control Act (UMTRCA) disposal cell has been designed with a layer of stone on the cover to inhibit the development of vegetation. Still, removal of vegetation is required to maintain the effectiveness of the remedy. Annual control measures such as the spraying of vegetation will continue as long as the disposal cell is in place (in this case, for perpetuity).

The second example is the Monticello Disposal Cell. The cover for the disposal cell was designed to be compatible with its natural surroundings. Native vegetation was designed into the cover along with functional monitoring. The result is a sustainable cover with water control. The cover has been functioning for more than 20 years and has proven to be effective and performing as designed (< 1 mm/year percolation). (As a side note, a retrofit to the UMTRCA disposal cell example discussed above is under consideration. The retrofitted design introduces a cover compatible with the natural surroundings.)

4.2 SUMMARY OF DISCUSSION SESSION

Fernald Status and Remote Monitoring. Planning committee member Patricia Culligan (Columbia University) asked about the status of the Fernald monitoring system. Dr. Benson responded that, because it was experimental, it has been removed. It was not planned as part of the long-term stewardship of the site, but it did effectively demonstrate the importance of remote monitoring.

Functional Monitoring/Stakeholder Engagement. Carol Eddy-Dilek (Savannah River National Laboratory [SRNL]) works on a technical assistance program for EM in which teams of scientists travel to nuclear legacy

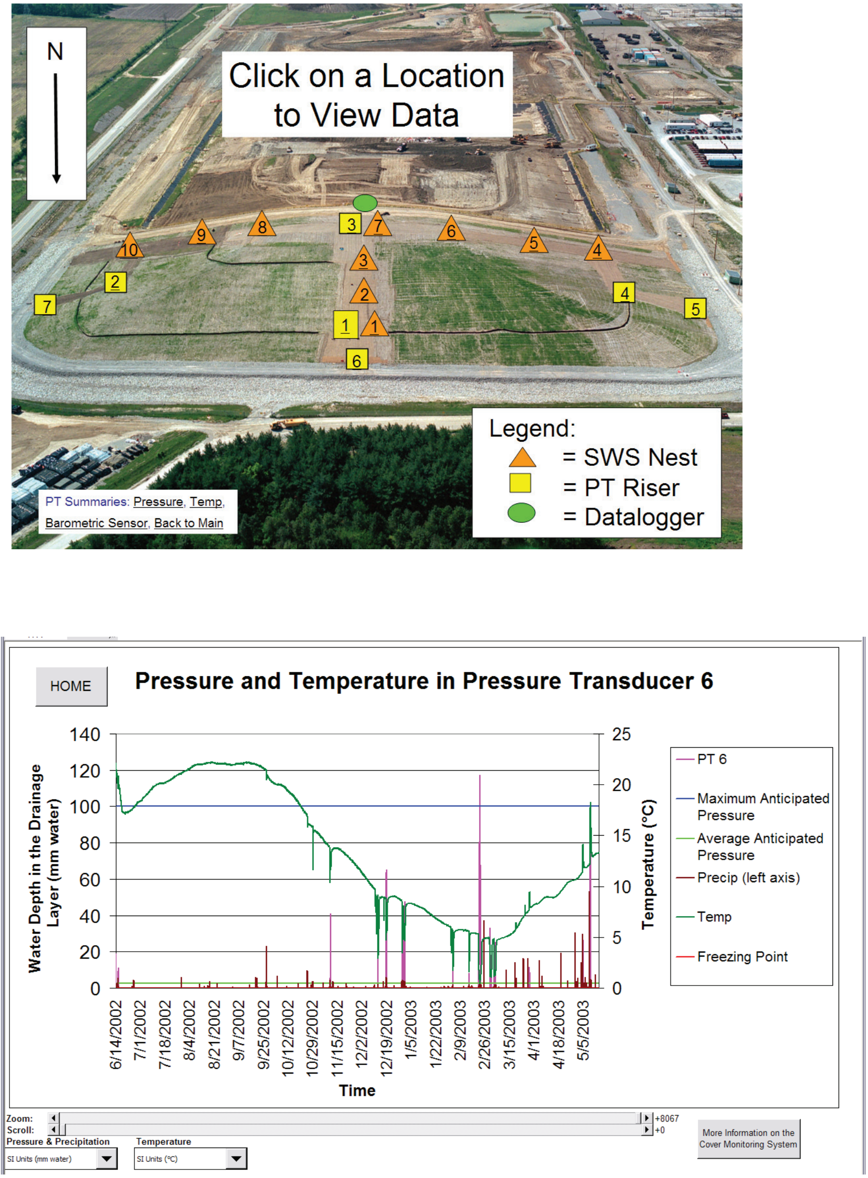

FIGURE 4-1 Remote monitoring system interface and sample data installed at the On Site Disposal Facility (OSDF) at the Fernald site.
SOURCE: Benson 2014.

sites to resolve technical remediation problems. Based on her experience, she strongly supports "monitoring by function" and provided several examples that have impacted site remediation. A metal contamination problem at the Savannah River Site (SRS) highlights the usefulness of functional monitoring. The pump-and-treat system remedy for the metal contamination plume costing $1 million/year had become ineffectual. An option to treat the plume by adding a base to strip out the acids was presented by DOE to South Carolina Department of Health and Environmental Control (DHEC) and the Environmental Protection Agency (EPA). One of the challenges to the proposed remedy was monitoring the effectiveness of this new approach on the very large plume. It was decided to measure controlling variables, such as the pH, which were not normally monitored (e.g., through sampling of wells). If the pilot demonstration of the new remedy and its monitoring program show effectiveness, then regulators have agreed to accept and support the new remedy. Functional monitoring of the controlling variables as Dr. Benson has mentioned is critical for understanding of the behavior of the plume and the success of this pilot study.

Another example of functional monitoring is a monitoring and modeling program at an LM UMTRCA site. A uranium mining and tail processing facility has residual contamination from acid and carbonate leaches used during operations. Contamination levels in groundwater have been erratic for more than 20 years and have not been consistent with existing site models. A newly proposed hypothesis is that the large, contaminant source term in the vadose zone contaminates the groundwater as it rises and falls with seasonal flooding. The flooding injects contaminants from the vadose zone, and increased levels of contaminants later appear in the groundwater. Functional monitoring allowed the hypothesis to be developed and models to be updated. However, the physical and chemical processes behind the hypothesis were not initially easy to explain to the stakeholders.

Simplified conceptual models and commonly understood analogies were found to be critical tools when discussing scientific concepts with stakeholders. Block diagrams of the sources and sinks of the contamination connected by weighted arrows illustrate the main processes and contributors within a given site. In the example above, a simplified site model was introduced, and a technical analogy was used when discussing the proposed vadose zone injection hypothesis with stakeholders (in this case, members of tribal nations). The analogy of salt buildup in soil with periodic natural cleansing is a concept and process the stakeholders understood. If the processes can be understood, then the discussions for cleanup options become easier.

Failure of Containment Systems. Planning committee member Michael Kavanaugh (Geosyntec) commented that containment systems are well understood and asked Dr. Benson what the remaining unknown properties and mechanisms might be. He also recalled that an NRC (2000) report suggested that DOE should plan for containment systems to fail[2] and wondered whether this is still an appropriate assumption. Dr. Benson replied that the design and construction of containment systems is fairly well understood. However, not much is known about how long they will last or their failure mechanisms. Regulations from the 1970s and 1980s were developed for systems that had not yet been built. The regulatory structure has not progressed along with the knowledge and experience that has been gained with respect to containment systems. As for the assumed failures of systems, care should be taken in using the term "fail." Failure is interpreted as an on/off condition, when in reality containment systems are likely to degrade gradually; usually they do not suddenly and catastrophically fail. Containment systems designed incompatibly with their natural surroundings degrade faster than compatible systems. Some systems in the arid west of the United States are so compatible with natural systems that they are expected to last on the order of 200 years.

Eric Pierce (Oak Ridge National Laboratory [ORNL]) supported the concept that containment barriers do not instantaneously "fail" and wondered how one might convince regulators about this fact. Dr. Benson suggested that better compilation and sharing of failure rate and failure mode data would increase confidence and acceptance by the regulators.

Robin Anderson (EPA) provided a counter-example to demonstrate that containment systems can fail earlier than anticipated. A permeable reactive barrier (PRB) installed at the Monticello mill tailings site in Utah was designed to last for 70 years but stopped working after 7 years. Dr. Benson offered a different perspective on this example, which highlighted the importance of functional monitoring. Stan Morrison (Morrison 2006) studied the failure of the PRBs at Monticello through careful measurements and monitoring. He is credited for developing better methods to predict precipitation mechanisms in PRBs and to estimate their lifetimes. This is a great example of functional monitoring leading to improved understanding of an innovative remedy.

Monitoring of Sustainability. Paul Black (Neptune and Company, Inc.) pointed out that the types of monitoring systems discussed in this session are for only one part of the sustainability triad. Changes in stakeholder

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[2] "The committee believes that the working assumption of DOE planners must be that many contamination isolation barriers and stewardship measures at sites where wastes are left in place will eventually fail, and that much of our current knowledge of the long-term behavior of wastes in environmental media may eventually be proven wrong. Planning and implementation at these sites must proceed in ways that are cognizant of this potential fallibility and uncertainty" (NRC, 2000, p. 5).

and economic values should also be monitored to identify when decisions should be revisited in the future. Dr. Benson agreed and added that true sustainability analysis starts with remediating the waste but extends beyond that. A life cycle analysis (LCA) may help to understand how to integrate other factors such as stakeholder and economic values. He provided the following example: remediation of the Fox River in northern Wisconsin (which was contaminated by industrial discharges from paper mills) required that the river be dredged and the dredged sediment be transported to a northern Michigan disposal facility. The trucks containing the contaminated sediment passed through four states: Wisconsin, Illinois, Indiana, and Michigan. The remedy protected the Fox River, but an LCA that considered broader sustainability values may have resulted in a different remedy.

Timeframes. Paul Black supported the idea of reducing the timeframes that are routinely used to estimate the lifetime of remedies. He suggested that estimates should be limited to several hundred years because this is as far into the future that can reasonably be predicted. This timeframe should be a "rolling" timeframe, with monitoring to identify changes in the effectiveness of the remedy (or factors exterior to the remedy such as stakeholder values). An exit strategy or "stopping rule" is also needed. Mr. Levitan commented that models and estimates that project several hundreds of years into the future account for a very small fraction of the decay lives of the long-lived radioactive contaminants.

Expense of Functional Monitoring. Marolyn Parson (South Carolina Citizen Advisory Board) noted that compliance monitoring is required by regulation and agreements. How does one convince sites to spend extra money on additional functional monitoring or to replace compliance-based monitors with functional monitors? Craig Benson acknowledged this difficulty. He highlighted Carol Eddy-Dilek's comments on building confidence with stakeholders to allow for measurements to be made in addition to legally mandated compliance monitoring. It may be time to rethink current regulatory monitoring requirements because they focus on compliance instead of monitoring for function.

Mary Flora (Savannah River Nuclear Solutions) suggested that part of the regulatory requirement to monitor is to understand the contaminants' movement to confirm an effective remedy. An effective monitoring program needs an accurate "big picture." Therefore, identifying and measuring leading indicators is an important and useful task because they can provide forewarning and an opportunity to address problems early. Functional monitoring may be of interest to regulators and decision makers for these reasons.

Models. Dawn Wellman (Pacific Northwest National Laboratory [PNNL]) commented that DOE and PNNL have recognized the need to look at the full system of a site using monitoring understand how and confirm whether the remedies are working. A document, "Scientific Opportunities for Monitoring at Environmental Remediation Sites" (Bunn 2012), has been developed by DOE. It is used as a foundational document to better understand the remediation and monitoring systems at the Hanford site.

Bill Levitan (EM) asked how one determines which leading indicators are needed to validate model assumptions. Dr. Benson replied that leading indicators will differ depending on the site and the remedy. Models provide predictions based on assumptions and can identify which variables may be used as leading indicators. However, the models, their assumptions, and their proposed leading indicators need validation with measurements collected through functional monitoring.

Ming Zhu (EM) agreed on the importance of models and their validation. He noted that an interagency working group is considering how to make better use of monitoring data that have been collected over the years from the remediated sites. The Federal Interagency Steering Committee on Multimedia Environmental Modeling (ISCMEM)[3] current signatories include DOE, EPA, U.S. Nuclear Regulatory Commission (USNRC), the National Resources Conservation Service, the National Science Foundation, U.S. Army Corps of Engineers, and the USGS.

Importance of Science in Remediation Decisions. Dan Goode (USGS) quoted a NRC study, *Science and Technology for DOE Site Cleanup* (NRC 2007), which echoed comments by Mary Flora, Carol Eddy-Dilek, and Dawn Wellman on the need for science to guide complex remediation decisions.

> There are many impediments to the use of new technologies at the site [Oak Ridge Reservation]…
>
> …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 [Oak Ridge National Laboratory] (NRC, 2007, p. 42).

Currently, science has been removed from groundwater issues at ORR. In the 1980s, ORNL had a world-class groundwater monitoring center. But large contracts between DOE and conglomerates of companies have separated science performed at the national labs (i.e., ORNL) from the cleanup. A long-term funding mechanism that would support the type of science

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[3] See http://iemhub.org/groups/iscmem/, accessed on February 19, 2014.

required to address these challenges is needed. In the 1980s and 1990s the USGS participated with ORR on groundwater issues but the USGS is no longer involved. The USGS is another federal government resource that could help with communication to provide unbiased analysis of data and technical information to stakeholders.

Dawn Wellman agreed that science and functional monitoring are needed. Most monitoring at sites is groundwater based—having additional monitoring information, for example, from the vadose zone would provide another source of information on little-known processes within that region.

4.3 INFRASTRUCTURE ISSUES AND TECHNOLOGY APPROACHES FOR ACHIEVING SUCCESSFUL "ROLLING STEWARDSHIP"

Dave Geiser

The Office of Legacy Management was established in 2003 to carry out the long-term stewardship for DOE sites at which active remediation had been completed. LM's mission covers long-term surveillance and maintenance of sites, records and information technology (IT) systems, community outreach, and management of lands and assets. LM began with 33 sites, currently manages 90, and is expected to have 120 sites under its management by 2020. The sites are spread over 28 states and territories including Puerto Rico and Hawaii. Nine of these sites require onsite personnel for management, the rest require periodic visits. All sites need record management services. Almost one-third of LM sites have beneficial uses, which include grazing, wildlife, industrial, and/or community use. Previously, DOE focused efforts on keeping the public (and others) away from the nuclear weapon development facilities, but now the public is encouraged to visit many of those same sites. It is a testament to DOE's Office of Environmental Management's (EM's) efforts that some of these sites are now useful community resources (see Fernald case study below).

The largest cost for LM's long-term stewardship activities is groundwater monitoring—with 2,000 wells and approximately 7,000 samples collected for analysis annually. Record keeping and IT system maintenance is another significant effort—storing 100,000 cubic feet of records, responding to 1,500 requests/year and getting 1,800 hits/day on LM's Geospatial Environmental Mapping System (GEMS) website.[4]

The following eight sites serve as case studies to highlight the breadth of issues addressed by LM:

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[4] See http://gems.lm.doe.gov/imf/sites/gems_continental_us/jsp/launch.jsp.

- Weldon Springs, Missouri,
- Rocky Flats, Colorado,
- Amchitka, Alaska,
- Pinellas, Florida,
- Tuba City, Arizona,
- Wayne Site, New Jersey,
- Mound, Ohio, and
- Fernald, Ohio.

Several of the case studies highlighted noteworthy aspects of LM management challenges.[5] LM encourages public use of the sites. The Weldon Springs site is a good example (see Figure 4-2). The site was originally used by DOE for uranium processing and U.S. Army explosives production. The main contaminants were uranium, nitrates, and trichloroethene (TCE). The remediation of the site created a 45-acre disposal cell (the cap can be seen as a large, white pentagon in Figure 4-2). Long-term closure controls include groundwater monitoring, monitored natural attenuation, and institutional controls. Current land use includes a visitor's center and hiking/biking trail. Weldon Springs is adjacent to a large public high school. The track team uses the disposal facility cap as a hill for part of its workouts. A raised, viewing platform erected by LM is a local sightseeing attraction because it allows for clear views of the surrounding area.

LM also encourages cooperative agreements with local stakeholders. The site in Amchitka, Alaska (see Figure 4-3) (part of the Aleutian Islands) is LM's most remote site. Three underground nuclear weapons tests resulted in tritium contamination of the site. Long-term controls of the site include groundwater, surface water, and biota monitoring (on a 5-year cycle). The site is within a wildlife refuge managed by the U.S. Fish and Wildlife Preserve. LM has a cooperative agreement with the Aleutian Pribilof Island Association and the local Aleutian tribes for assistance with logistics and travel to/from the site. Another example of a site with a cooperative agreement with a local stakeholder is one in which a local land-owner maintains fencing around the DOE site bordering his land in exchange for harvesting hay from the site.

LM's most densely populated site is the Pinellas, Florida site (see Figure 4-4). The site was originally used by DOE to manufacture electrical systems and electronics packages. The main contaminants are organic solvents and metals; there are no radioactive contaminants. Long-term controls include groundwater monitoring, monitored natural attenuation, and institutional controls, including the purchase of subsurface rights to

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[5] For more information on each of the case studies, see the full presentation at: http://dels.nas.edu/resources/static-assets/nrsb/miscellaneous/Geiser.pdf.

FIGURE 4-2 Aerial photo of the current Weldon Springs site. The neighboring high school's tennis courts can be seen in the lower right corner of the picture (see text). SOURCE: Geiser 2014.

adjacent parcels. The land was sold to Pinellas County for redevelopment purposes in 1997. It is currently an active industrial area with higher employment than when operated by DOE. A large, groundwater plume under the site extends into adjacent properties. The plume is fed by a subsurface contaminant source located beneath one of the largest commercial buildings on the site (Building 100, see Figure 4-4). The plume cannot be remediated without demolition of the building. In this case, a final decision was made to treat the plume without addressing the source term so that the commercial property may continue to generate revenue and support the local economy.

The Tuba City, Arizona, site was presented as an example of a sustainable solution at a remote location with challenging tribal nation rights issues (see Figure 4-5). The site contains a former uranium mill, which processed approximately 800,000 tons of uranium ore resulting in uranium and radon gas contamination. Wastes remaining onsite are stored in a 50-acre disposal cell. Long-term stewardship includes groundwater monitoring

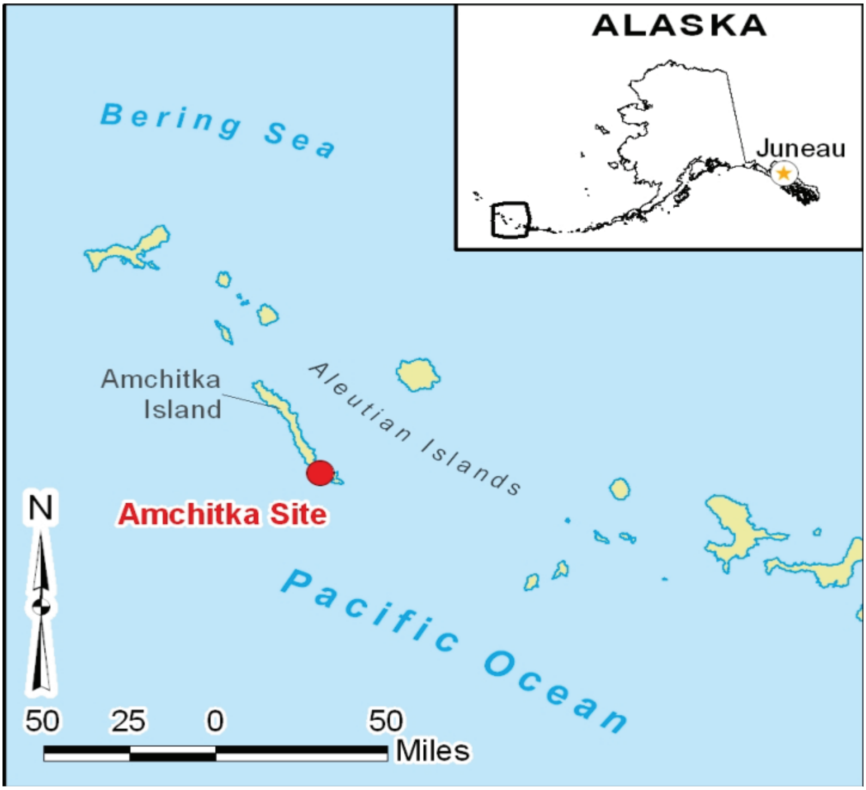

FIGURE 4-3 The Amchitka, Alaska, site is LM's most remote site.
SOURCE: Geiser 2014.

and a groundwater pump and treat remedy. Located in sparsely populated desert, the site uses photovoltaic power to support groundwater well remediation and monitoring. Cultural challenges include treaty rights and language barriers with the local tribal nations (e.g., Navajo Nation). The desert terrain and climate add to the challenges including severe storms, road washouts, increased sedimentation, and potential impacts to disposal cell integrity.

Lessons learned over the 10 years of LM's experience with these sites can be separated into "site lessons learned" and "programmatic lessons learned."

Site Lessons Learned:

- Understand and work within the regulatory structure for each site. Comply with the remedy decision but also consider local, applicable laws and regulations.

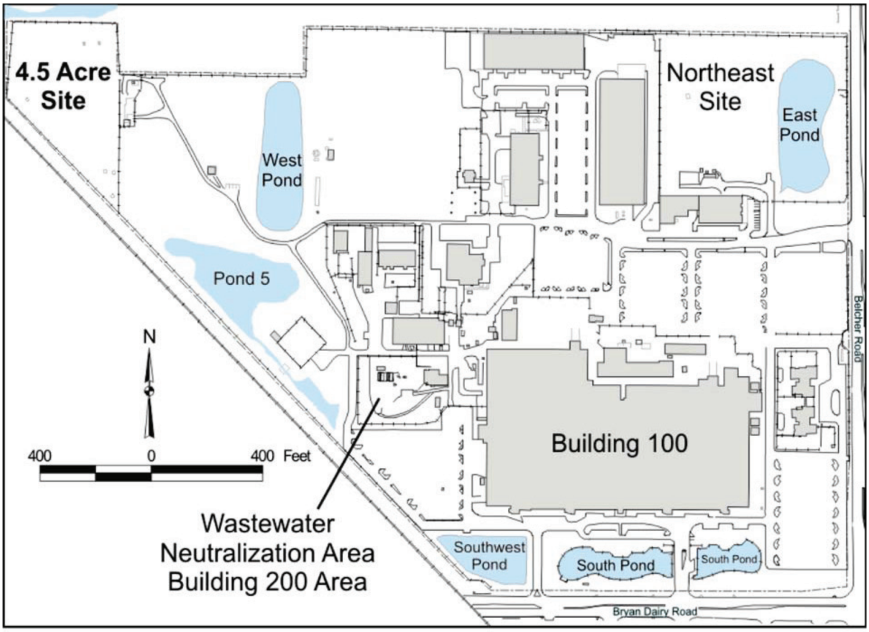

FIGURE 4-4 The Pinellas, Florida, site is LM's most populated site. The groundwater plume is fed by a contamination source located beneath Building 100 (see text).
SOURCE: Geiser 2014.

  - Local requirements may conflict with federal ones (e.g., locals want weeds removed from covers but it is not required by federal).
- Stay current with changes in demographics, local land use, and politics. A remedy designed for one set of conditions may not be protective over time.
  - Maintain relationships with the local community. During site visits, plan to visit the mayor, the fire department, and/or the police/sheriff. Understand who is buying or selling property near the sites, and whether there are plans to build in the future.
- Create a transparent culture where you invite the public to learn about the site. Engage neighboring land owners, local governments, and the community. Do this at the frequency, and with the communication tools and formality, that the community desires.
  - Communicate with the public. An interesting rule of thumb: "The more you communicate, the less interested the public becomes." This is a challenge when one of LM's goals is to encourage site use by the public.

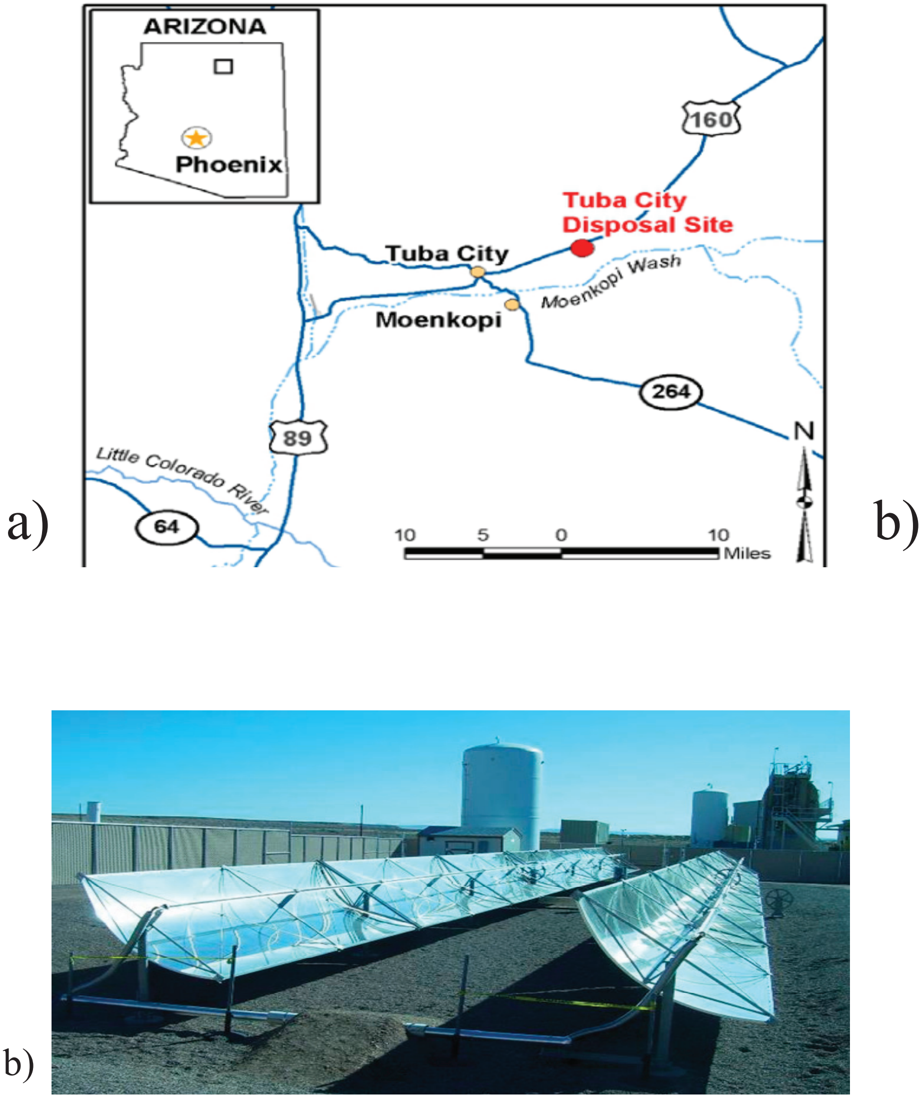

FIGURE 4-5 The Tuba City site is located in northeastern Arizona on the western edge of the Navajo Nation (a). A solar voltaic field provides part of power for ground water treatment system and is tied to the local grid (b).
SOURCE: Geiser 2014.

  - Adjust communication strategies to fit the site and the local community. An example is Riverton, Wyoming, where the local community socializes at the local bars. With some hesitation, the site managers and LM did go to the bars in order to reach the locals (but did not drink alcohol).
- Pursue beneficial reuse of the site within the restrictions of the environmental remedy. Informed site use can enhance the effectiveness of other long-term stewardship activities.
- Establish institutional controls (ICs) that can be effective when properly managed and applied. Legally enforceable controls should be used when necessary. In many cases, administrative ICs are enforced by local governments; effective partnership is important.
  - Although they should be used, ICs should never be the first level of protection. Also know that at the local level, the police respond to intruders at the site—not the federal government.
- Long timeframes mean that natural events must be considered in remedy selection and in modeling site performance. Assume the subsurface models are likely to be improved (e.g., when the 100-year flood occurs it will impact the existing site model).
- Plan for, and be able to transition, site managers. Make knowledge management a priority.
  - Knowledge management is critical. Educate, train, and empower your staff.

Programmatic Lessons Learned:

- Maintaining the remedy means maintaining infrastructure (roads, vehicles, power) at each site.
- Using common approaches across sites saves cost and improves performance.
- Long-term protection of human health and environment requires knowledge of changes in regulations, policies, knowledge, and advances in technology.
- Encourage cross-site teams, share information, and promote lessons learned. Rotate staff through all sites so they have knowledge of every site and are familiar with the local population. However, the staff rotation period should be no more than 5 years at a single site.
- Records are important—more than most people realize. Consolidate to one location. Make digital copies only when pulling a file (it is not cost-effective to digitize all records). Use commercial software for records management.

- Make all data and reports available to the public (internet and public meetings) following appropriate quality assurance reviews.
- Use data to improve scientific understanding (e.g., RCRA degradation data from 5-year reviews). Invest in science and technology in targeted areas that impact remedy performance over the long term. Share the results with the public and the scientific community.

4.4 SUMMARY OF DISCUSSION SESSION

Institutional Controls and Timeframes. Rateb (Boby) Abu-Eid (USNRC) noted that the USNRC assumes a timeframe in its performance analyses to determine when to move from active to passive remediation. This is currently under debate—whether it should be 100 or 300 years. He asked what timeframes LM has assigned, if any, to its decisions. Mr. Geiser responded that nearly all of the ICs at LM sites are passive. Most are realty instruments such as deed restrictions or access agreements, which provide legally enforceable controls at the sites. The ICs are not assigned a specific duration. Other types of passive ICs, such as fences and signs, require maintenance. Active ICs are the most expensive, for example the visitor centers at the Fernald and Weldon Springs sites. They are part of the ROD and will remain there as long as they are useful to the communities. It is difficult to predict public use and perception into the future.

Models. Dr. Abu-Eid next asked about how monitoring data are used in models. Mr. Geiser responded that in general the models work well and that there is very little movement of the contaminants at their sites.

Successful Public Outreach. Kevin Crowley (National Academy of Sciences staff) noted that one of LM's lessons learned was that the public seemed to lose interest when information about the sites was made readily available. This was seen at WIPP [Waste Isolation Pilot Plant]. This could be a signal of public trust and could be considered a "success" that should be considered a best practice. Mr. Geiser agreed with the observation about the public's level of interest.

Mechanisms to Change to Stewardship Activities. Dr. Crowley further noted that cleanup and stewardship are dynamic and that change should be expected. Consequently, the public should be prepared for change as a normal part of the process. However, the public currently sees change as a way to "get around" existing agreements. Mary Flora's Core Team Process presentation outlined a process that allowed decision makers to revisit issues as more data became available and knowledge increased. He asked whether LM had a similar process and whether there been any notable changes to stewardship at the sites during its 10 years of operation.

Mr. Geiser responded that LM has a process to drive stewardship change. This process has two fundamental goals that may seem initially to be in conflict with each other. The first goal is to attain 100 percent regulatory compliance at all of the sites. The second goal is to reduce operating and maintenance costs (surveillance and maintenance) by 3 percent every year. All LM site managers, contractors, and program manager have these two goals as common performance measures in their evaluations every year and, as an agency, measures against these goals are reported every year.

These goals are driving the optimization of existing remedies at all LM sites. Numerous examples of stewardship changes have come about as a result. Monticello has been previously highlighted by others in this workshop. Many pump-and-treat systems have been transferred to monitored natural attenuation. Another site has eliminated monitoring altogether. And the total number of wells that are monitored per year at LM sites is declining (more wells are decommissioned every year than are added).

4.5 THE CORE TEAM PROCESS: MAKING RISK-INFORMED DECISIONS FOR ON-SITE MONITORING

Mary Flora

The Core Team Process was introduced at the first workshop. In this workshop, the SRS site-wide monitoring program is presented as a case study to highlight how risk has been used in the decision-making process. The process is designed to promote consensus-based decisions on complex remediation issues at the SRS site. Over the past few years, SRS has been moving from the front-end (determining the remedies) to the back-end (long-term management) of the remediation process.

The SRS cleanup began in the 1980s. In 1989, SRS was added to the National Priority List. The FFA was signed in 1993 by DOE, EPA, and South Carolina's DHEC. Cleanup activities have focused on soil and groundwater, deactivation and decommissioning of inactive facilities, and closure of tanks. Most of the work is overseen by DHEC and EPA. The USNRC is also involved in waste tank closure.

Although the FFA was signed in 1993 it took several years to figure out how to work together effectively. In 1999, the remediation progress had reached a standstill—communication during negotiations was at an all-time low and a new process was needed. The Core Team Process was established to improve communication between the FFA signatories.

The Core Team operates using four principles of environmental restoration:

1. **Building an effective Core Team is essential.**
   All participants have authority to make decisions. Their management has entrusted them to make decisions that will not be subsequently overturned within their management structure.
2. **Clear, concise, and accurate problem definition is critical.**
   Scoping documents are shared among all Core Team members before meetings. These documents lay out the problem, the facts behind it, and the topics on which decisions will need to be made.
3. **Early identification of likely response actions is possible, prudent, and necessary.**
   Take incremental steps to solve a problem, recognizing that there may be a need to take further action later.
4. **Uncertainties are inherent and will always need to be managed.**
   This principle allows the team to admit mistakes and modify original decisions when needed.

These principles are posted in the meeting rooms to serve as reminders for all parties. When these steps are followed, the final decisions are embraced by all parties. The benefits include a traceable and documented history of decision making; an increased and common understanding of the link between decisions and technical activities; a clear understanding of knowns and unknowns; and an increased confidence that issues will be identified and managed through time. Decisions can be defended. Decisions "stick" for a longer time because of member buy-in, a common understanding of the problem(s), and well-documented background material. The output of the Core Team Process is timely communication, agreements based on trust, and documentation outlining the scientific and technical underpinnings of each decision.

The current status of the soil and groundwater remediation program at SRS can be gauged by the number of operable units that have been addressed to date. Of the 515 total operable units, 400 have completed remediation. Those that remain have complex and challenging problems (see Figure 4-6). In addressing soil and groundwater contamination, there is continual pressure to move, when appropriate, from active to passive systems. Currently 30 passive and 9 active remediation systems exist at SRS.

More than 2,500 monitoring wells have been installed throughout the site. Some have been in operation for more than 20 years. Their depths vary from 2 to 350 feet. They have been installed during different remediation campaigns without a site-wide plan or systematic approach. For example, Area M has more than 50 compliance wells (see Figure 1-2). Because of the combination of several factors, including the history of the groundwater monitoring program, the amount of data collected, and the lack of a site-wide groundwater monitoring plan, an optimization program

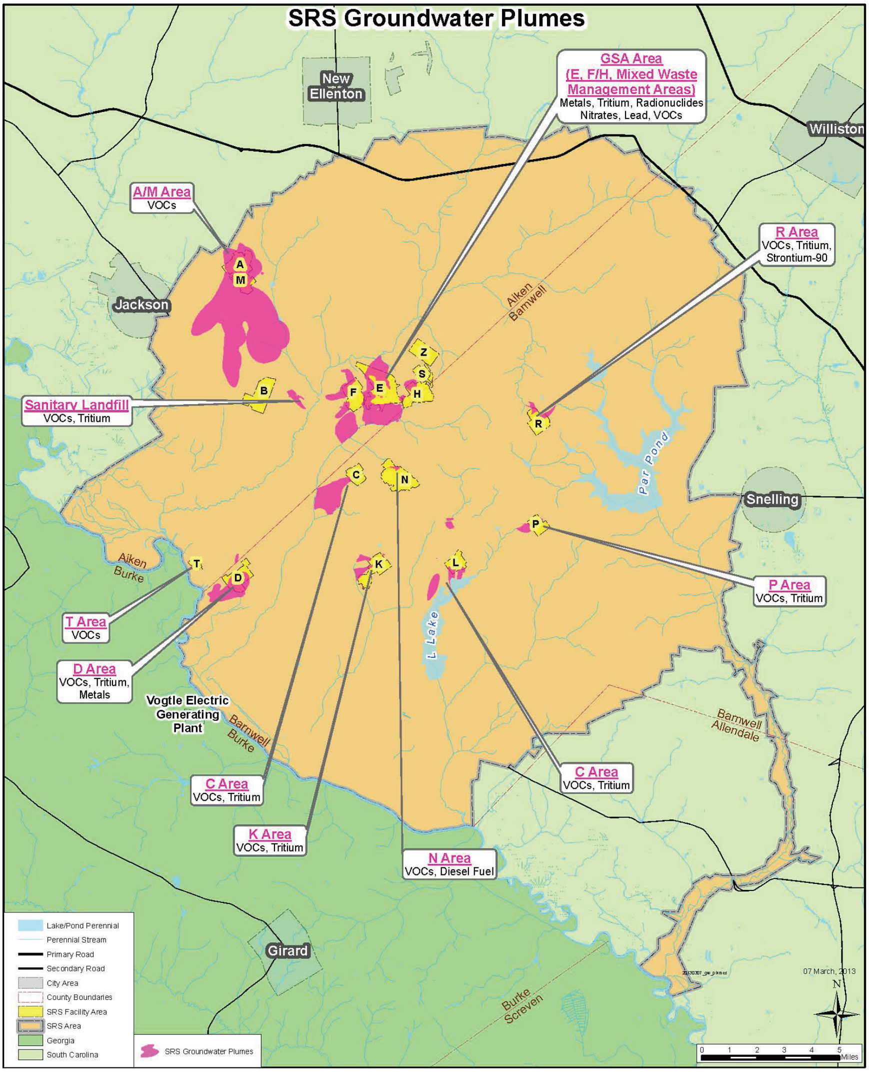

FIGURE 4-6 Soil and groundwater contaminated sites at SRS. Contaminated regions are shown in pink. They correspond to the major past activities at the site (see Figure 1-2 for a description of areas designated in yellow).
SOURCE: Flora 2014.

was proposed. DOE approached the other Core Team members, EPA, and DHEC with a proposal to review the well monitoring program, citing operating *Principle 4: Uncertainties are inherent and will always need to be managed*. The Core Team recognized the opportunity to improve current groundwater monitoring activities and accepted the proposal to evaluate a set of five topics (*Principle 2: Clear, concise and accurate problem definitions are critical*):

1. Monitoring vs. Regulatory Requirements
   Does the current monitoring program meet regulatory requirements? Do any of the proposed changes meet regulatory requirements?
2. Spatial Optimization
   Are the current well locations optimal for monitoring? Are there locations where no wells exist but should?
3. Temporal Assessment
   Is the data collection frequency appropriate to gauge performance of the remedy?
4. Analyte Assessment
   What analytes should be analyzed to assess remedy performance? Has the list changed over the lifetime of the well? Should any be added or removed from the current list?
5. Reporting Assessment (frequency)
   Should reports be produced annually, semiannually, or at a different frequency?

Each topic was scientifically analyzed, and the results were shared among Core Team members prior to the meetings in which decisions are made. The consideration of each topic during the meetings was based on scientific results, and decisions were made based on a goal to improve the monitoring program. All analyses and decisions were documented.

Consensus was reached, and final decisions were made and documented for all five of the proposed topics.[6] In some cases, the monitoring requirements were relaxed (e.g., fewer wells were needed in some locations, lower frequency reporting and measurement could be made, and modifications were made to regulatory documents as needed), but in others it was found that additional monitoring was needed (e.g., increased sampling rate for wells near a remedy undergoing change, or installation of additional wells in locations lacking monitoring).

The site-wide groundwater monitoring optimization program is a multiyear effort. Further optimization will continue for the next few years. So far,

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[6] Details on the analysis and results can be found within the presentation: http://dels.nas.edu/resources/static-assets/nrsb/miscellaneous/flora.pdf.

the decisions have held. The lessons learned are the following: engage the team members early, and base decisions on technical evaluations to which all team members have equal access. Based on the success of the Core Team Process for improving the site-wide groundwater monitoring program, it has recently been expanded into liquid waste management at SRS.

4.6 SUMMARY OF DISCUSSION SESSION

Additional Case Studies Involving the Core Team Process. John Tseng (retired DOE) expanded on Mary Flora's presentation and provided two additional examples of Core Team Process success stories. Tank closure at SRS usually takes 4 to 5 years. (Tanks 18 and 19 at SRS took this long to close.) The Core Team recognized that an alternative process would be needed if FFA milestones were to be met for the remaining tanks. The Core Team established an accelerated process, which reduced the closure time by almost a full year; currently it is being used for Tanks 5 and 6. The other example is the development of a Quality Assurance (QA) program for residue characterization from SRS's hot cells to meet DHEC expectations. No protocol governed the QA process and analysis for sampling residue from hot cells. The Core Team Process was used to develop a QA sampling program with a step-by-step procedure supported by the full team. The new QA procedure is in the final stages of testing and validation.

Move from Active to Passive Remediation. Michael Kavanaugh (Geosyntec) asked whether there was a well-defined process for moving from active to passive remedies and whether there was push-back from the regulators when passive remediation was proposed. Ms. Flora responded that a change from active to passive remediation is considered when an active system has either met its cleanup goal or has lost its effectiveness. Active systems are expensive; they use power, and they have many moving parts that can fail. In moving to passive systems the Core Team considers options such as solar power or selecting equipment with fewer moving parts. SRS works directly with the regulators and is clear about the desire to move from active to passive systems. Sometimes the regulators will identify active systems that have become ineffective and are no longer a good return on investment.

Models. Rateb (Boby) Abu-Eid (USNRC) asked how monitoring data are used to develop models. Ms. Flora explained that active modeling is performed for all well networks at SRS. SRNL, an independent entity, performs the modeling. The regulators have their own models. The SRNL and regulator models are validated and compared against each other, which provides further confidence among team members that the data and models are good.

Challenges of Expanding the Core Team Process to Other Sites. Bill Levitan (EM) noted that DOE has expanded the Core Team Process into at least eight different sites, but its successful adoption is dependent on the individual team members. It requires buy-in from everyone on the team for it to work. The Core Team Process was introduced but not successfully implemented at the Hanford site, for example.

Monitoring Data for Improving Site Models. Patricia Culligan (Columbia) tried to bridge the two sets of Session 3 talks by connecting the concept of functional monitoring, testing, and modeling proposed by Craig Benson to LM stewardship and SRS's groundwater monitoring programs. Dr. Culligan suggested that LM's data sets might be used to build confidence in existing models for the regulators and the public. Although the increased monitoring and data collection would temporarily increase LM's budget, it would likely pay benefits in the future. Paul Gilman (Covanta Energy) supported this idea and noted that expanded monitoring would only be needed for systems for which data are not already available. The functional monitoring data for these systems would fill an important knowledge gap.

Dave Geiser responded that additional data are collected on the surface for many of the existing remedies. For example, onsite inspectors walk along detailed transects (inspections following a defined grid) across disposal cells to confirm the containment systems are working as expected. For the Fernald and Weldon Springs sites, leachate measurements are taken to confirm a decrease of leaching in time. Furthermore, there have been studies of soils near disposal cells to monitor changes in contaminant levels. Whereas these individual monitoring efforts are not agency-wide and are not as extensive as the measurements taken by Dr. Benson's University of Wisconsin group, they do add additional information when the remedy is not working as expected.

5

Best Practices

Over the 2-day workshop, three discussion sessions focused on identifying best practices for making remediation decisions (see Appendix C). In the final session of the workshop, titled "Identification of Best Practices for Improving Remediation/Closure/Post-Closure of Challenging Sites," a panel of speakers identified best practices or tools for making remediation decisions. The panel represented a broad range of backgrounds and perspectives: tribal, federal, regulatory, state, practitioner, and citizen stakeholders. Following the speakers' comments, the moderator and planning committee chair Paul Gilman (Covanta Energy) opened the floor for attendees' comments.

This chapter provides summaries of the key points made by workshop participants during the "best practices" discussion sessions. These statements reflect the viewpoints of the individual speakers, not the consensus views of the workshop participants or of the National Academy of Sciences.

5.1 SUMMARY OF BEST PRACTICES DISCUSSION SESSIONS

Several themes emerged from the discussion of best practices over the course of the workshop:

- Sustainability and Optimization,
- Flexibility in Regulations and CERCLA,
- Stakeholder Involvement and Communication,
- Shared Lessons Learned,
- Multiagency Decision-Making Processes,

- Modeling,
- Functional Monitoring, and
- Timeframes.

Sustainability and Optimization. Several participants identified the use of sustainability principles to balance and optimize multiple objectives to guide remediation decisions as a best practice. Planning committee member Patricia Culligan (Columbia University) cited the New York City public schools' decision to change the light fixtures at a rate that would not require teacher layoffs as a good solution. This demonstrates how one might optimize benefit while also addressing risks to health and the environment (see Goldstein 2014, or NRC 2011, p. 117). When balancing the three pillars of sustainability (environmental, societal, and the economic considerations), a win-win-win solution is rarely achievable. Rather, trade-offs between the stakeholders should be expected and can be achieved through detailed discussions and occasionally lengthy negotiations. The resulting decision is an optimization and balancing of all three pillars.

Craig Benson (University of Wisconsin) recommended a more deliberate use of the word "sustainability." Throughout the workshop's presentations and discussions it has not been clear that sustainable analysis is being performed in the full sense of the word. For example, life cycle analysis, a broader analysis consistent with sustainability principles, should be more widely utilized.

Michael Kavanaugh (Geosyntec) suggested that there is a need to focus on the life cycles of the sites and to have a clearer understanding of the status within the life cycle for each site. The recent National Research Council (NRC) groundwater report (2013) recommended a transition assessment that could lead to changes in the remedy (e.g., moving from active to passive remediation such as containment systems). Because some fraction of contaminated sites cannot be cleaned up to unrestricted use and unlimited exposure standards, a clear path forward should be defined for these sites. If those sites are placed into a "wait-and-see" mode, then the challenge becomes one of keeping pressure on new technology development to solve difficult contamination problems. Paul Gilman (Covanta Energy) suggested that the national laboratories might naturally provide this pressure.

Flexibility in Regulations and CERCLA. The workshop discussions recognized that the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) allows for flexibility in remediation decisions and for the incorporation of sustainability principles. Roger Petrie (State of Tennessee, Department of Environment and Conservation) stressed the importance of flexibility in the Federal Facility Agreements (FFAs) and CERCLA. Milestone schedules are renegotiated frequently. Priorities also change—especially for complex sites with contaminant sources that are not contained. Initial assumptions made to guide decisions may ultimately be proven incorrect or require modification. Models are also updated. All of these issues point to the need for flexibility in agreements. CERCLA is very flexible—this is why Tennessee chose it over Resource Conservation and Recovery Act (RCRA) regulations for many sites. CERCLA does not overlook standards, but it does allow the flexibility to adjust them while cleanup is taking place.

Mary Flora (Savannah River Solutions) agreed with the importance of CERCLA's flexibility. The Savannah River Site (SRS) prefers to use CERCLA over RCRA when there is an option to do so. This movement away from prescriptive approaches is supported by site regulators (South Carolina's Department of Health and Environmental Control [DHEC] and the Environmental Protection Agency [EPA]). SRS had been practicing sustainability—the consideration of societal, economic, and environmental impacts—in its decision-making process, even though it has not been identified as "sustainability" by the Core Team members. CERCLA readily allowed for a sustainable approach to decision making.

Stuart Walker (EPA) agreed that CERCLA offers flexibility and noted that site remedies have evolved significantly over the past 20 years. Mr. Walker cited historical, groundwater remedy selection data,[1] which show how the types of remedies have changed since administrative reforms were introduced by EPA in 1995.[2] Prior to 1995, the percentage of sites using pump-and-treat (P&T) as a groundwater remedy was high (approximately 90 percent). Following the release of the administrative reforms, which included land-use guidance, the percentage of P&T remedial systems has subsequently dropped to 25 percent.

Paul Black (Neptune and Company, Inc.) suggested that "fuzziness" in standards should be considered a best practice. Standards that are very short and provide a performance objective would be ideal. Guidance documents should be process oriented and provide advice on how to meet the regulations.

Rateb (Boby) Abu-Eid (USNRC) agreed that U.S. regulations are too specific and suggested as an alternative a risk-based method developed by the Europeans (e.g., the United Kingdom) referred to as a "safety case."[3]

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[1] Information on trends in groundwater remedies is available in the Superfund Remedy Report (SRR), Fourteenth Edition: http://cluin.org/asr/. In particular, Figure 11 on page 12 shows a decrease in the percentage of remedies that used pump and treat from the late 1980's (90 percent) to 2010's (25 percent).

[2] See http://www.epa.gov/superfund/contacts/sfhotlne/admin.pdf.

[3] For more information on the safety case approach see: http://www.hse.gov.uk/nuclear/operational/tech_asst_guides/ns-tast-gd-051.pdf.

The safety case could be applied in the Environmental Impact Statement (EIS) or safety analysis.

Stakeholder Involvement and Communication. Willie Preacher (Shoshone-Bannock tribe) supported the idea of tribal nations being involved in long-term stewardship as a best practice. If implemented, then tribal nations could influence what happens at sites over the long term. Tribal nations would like to team with DOE on site-related issues and are looking for opportunities to do so.

Mr. Preacher also stressed the importance of early and frequent communication between tribes and the Department of Energy (DOE). Transparency and communication should be established and maintained. One challenge within the Shoshone-Bannock tribes is turnover within the seven-member tribal council (the tribe's governing body) which is elected every 2 years. New councils may not understand the remediation issues, which can introduce challenges to communication.

Paul Black agreed that communication is critical. Openness and transparency in communication can be accomplished through decision analysis tools. These tools provide justification for decisions that are made. It is also helpful to find community stakeholders who keep focus on the problem (e.g., mayor, community group).

Dave Geiser (DOE Office of Legacy Management [LM]) suggested that a best practice is to establish a common vision and goal for the site. DOE's Office of Environmental Management (EM) has had major successes at the Weldon Spring, Fernald, Rocky Flats, and Mound sites. At all of these sites, the end states were clearly communicated and agreed upon. This may mean many public meetings with the local community. DOE attempted a risk-based approach to identifying end states for its sites, but this approach did not receive regulator or stakeholder acceptance. Regardless, the concept of defining a common end state should still be considered a best practice.

Mr. Geiser also identified a communication challenge: There is misunderstanding—even within DOE—that DOE will "go away" when cleanup is complete and sites are transitioned to long-term stewardship. The scope of activities for long-term stewardship needs to be well understood by all parties.

Dave Geiser suggested that EM's current approach for preparing sites for long-term stewardship is a best practice. Prior to transfer over to LM, EM has "right-sized" the remedy for long-term stewardship, defined the steps needed to take if the remedy fails, and has assigned a clear post-closure operator.

Shared Lessons Learned. The sharing of lessons learned between sites was repeatedly identified as a best practice. William Reckley (USNRC) stated that one of USNRC's best practices, called "operating experience," is a way to share both successes and failures throughout the nuclear power reactor community. Mary Flora supported the idea of sharing information across sites, agencies, and companies as a best practice.

Dr. Abu-Eid highlighted a best practice resulting from experience with decommissioning commercial nuclear power plants in the United States: publish and share lessons learned on a web site. With help from the Nuclear Energy Institute (NEI), the decommissioning lessons learned were published and were very useful in establishing a unified approach, final status survey, decontamination, and site release.[4]

A workshop attendee identified regular meetings between DOE staff from different remediation sites as a best practice. These meetings would train staff by sharing lessons learned and best practices. However, travel between sites has been curtailed by budget cuts. Mr. Geiser agreed with the importance of training and sharing information across sites. This practice keeps federal managers informed and aware of issues and concerns at other sites. Dr. Kavanaugh noted that companies have recognized the value of knowledge management—both implicit and explicit information—and how it is shared.

Rula Deeb (Geosyntec) added that the sharing of lessons learned was a common, broad category from both workshops. In Workshop 1, the focus was on risk communication to the public. In Workshop 2, the focus shifted to knowledge transfer. This workshop series should initiate efforts to share these best practices and continue the dialogues that have been started.

Multiagency Decision-Making Processes. The Core Team Process as a general approach to multiagency decision making at complex sites was discussed throughout both workshops. Richard Mach (U.S. Navy) noted that the best practice underlying the Core Team Process is identifying potentially successful teams, teaching them to be successful, and enabling them to make common sense decisions.

Mary Flora commented that a critical aspect of the Core Team is that its members are empowered to make decisions. The Core Team Process is built on values of trust, transparency, and the acknowledgement that decisions may change. There is no finger pointing when mistakes are made and decisions have to change. SRNL is often used to provide technical independent viewpoints.

Marolyn Parson (Savannah River Site's Citizen Advisory Board) identified the Core Team Process as a best practice. The public has confidence

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[4] Two manuals were created out of the lessons learned: the Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP, http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1576/initial/) and the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM, http://www.epa.gov/radiation/marssim/).

that EPA and the state of South Carolina, as members of the Core Team, fairly represent their concerns during negotiations and discussions. Therefore, the Savannah River Site's Citizen Advisory Board fully supports decisions made through the Core Team Process.

Roger Petrie highlighted the multiagency decision-making process at Oak Ridge Reservation (ORR) as a best practice (i.e., the interagency working group). Mr. Petrie acknowledged that involving multiple agencies in the decision-making process was previously highlighted as one of the remediation program's biggest challenges (see Chapter 3), but it is also the program's biggest strength. The multiagency team makes more resources available than any one agency could; allows for more ideas to be introduced and a broader interpretation of standards; and ultimately results in a wider acceptance of decisions (i.e., it is difficult for an agency to criticize a decision when it was included in the decision-making process).

Modeling. Several attendees identified the use of site models in decision making was identified as a best practice. Ming Zhu (EM) suggested that advanced modeling work taking place at DOE national labs could be useful in discussing and addressing the problems. Federal agencies are sharing information and best practices (Federal Interagency Steering Committee on Multimedia Environmental Modeling [ISCMEM]) in which risk assessment is a big component. Additionally, interagency activities foster interactions that eventually help with decision making (see previous best practices for "Shared Lessons Learned" and "Expanding Core Team Principles to Other Sites").

Paul Black noted that conservatism should be removed from the site models. He provided "peak of the mean" as an example of conservatism and a non-physical approach to modeling. Peak of the mean analysis introduces an artificial increase in radioactivity, because it assumes a barrier being turned "off" suddenly and completely at a given time into the future. The result is a regulation developed on an artificial construct, because barriers do not suddenly turn off.

Functional Monitoring. Several workshop attendees mentioned functional monitoring to increase public confidence and improve modeling as a best practice. Craig Benson suggested that for situations in which the public and regulators are skeptical of a proposed remedy, the use of functional monitoring can increase confidence in remedy performance (e.g., recall the Monticello case study, see Chapter 3).

Thomas Nicholson (USNRC) agreed with this comment and provided an example of a well-run monitoring program to guide resolution of a contentious issue. Spent fuel pools were leaking into the Hudson River. All parties recognized the merit of a long-term monitoring program throughout the site and along the river, despite strong disagreements on other issues. A trusted functional monitoring program allowed for a decision on the final remedy.

Mark Fuhrmann (USNRC) offered some additional comments about monitoring sites. Current performance assessments assume that a containment system's barrier will fail after 500 years, after which time the system will fail completely. A best practice would be to monitor those systems internally for indications of degradation. As an example application, electrodes and internal monitoring equipment can be placed into storage tanks. He suggested that in situ monitoring of the integrity of the containment systems might be a good idea. John Tseng (retired DOE) noted that in situ monitoring has been used previously in EM cleanups—for example, in disposal cells at SRS and in the subsurface at the Hanford site (e.g., soil conductivity measurements).

Timeframes. Many workshop participants suggested that remediation analyses should be based on 100-200 year timeframes, not 10^4-10^6 year timeframes as is common practice at present. This was highlighted by Paul Black, William Reckley, Rateb (Boby) Abu-Eid, and Mark Fuhrmann.

Paul Black suggested that the timeframe used to calculate "peak dose" should be significantly shorter. For example, the models used to estimate dose for depleted uranium (DU) are normally extended to the time when peak activity occurs. Peak activity for DU occurs 2.1 million years in the future. The dose estimation models assume someone will be there to receive it. He recalled Dr. Goldstein's comments from the first session: dose to humans should not be estimated beyond several hundred years.

Another workshop attendee agreed that remediation analyses should not try to solve the 2.1-million-year problem. Rather, one should aim for a 100-year timeframe, stabilize the contamination as best as possible, and allow for future generations to revisit the remedy. Some countries have adopted this approach by storing their waste in stainless steel and concrete—allowing for 100 years of safe storage—to be revisited by future generations who may choose to adjust the remedy with new technology and knowledge.

William Reckley and Rateb (Boby) Abu-Eid discussed the timeframes that USNRC uses in its risk calculations. The timeframe depends on the facility type: hundreds of years for nuclear power plants (waste confidence ruling), 10^4-10^6 of years for deep geologic storage. For low level waste, no timeframe is given but the guidance is 10^4 years. Environmental impact assessments have no time limit assigned.

Decision and Probabilistic Risk Analyses. Paul Black would like to see risk-informed decision making used more often in remediation decisions. He noted that probabilistic risk analysis (PRA) is a better practice than deterministic risk analysis to assess environmental remedies. PRA provides a systematic approach for assessing risk. Dr. Black suggested that identifying the main variables of the PRA through sensitivity analysis and realistic modeling of the problem is a best practice.

Solicit Expert Advice. Several attendees stated that recognizing the need for expert advice is another best practice. Dr. Abu-Eid noted that when the USNRC needed expertise on decommissioning a building unlike anything else in the United States, it sought advice from Britain—which had decommissioned a similar type of building. Craig Benson noted that experts can provide independent input on practical ways to solve problems (e.g., the national labs and the Consortium for Risk Evaluation with Stakeholder Participation [CRESP, http://www.cresp.org/]). Several attendees noted that stable, long-term funding of science is needed to support experts. Paul Black stated that expert solicitation is part of the decision analysis tool. The skeleton of the decision analysis tool requires expert input through elicitation.

Intrinsic Value of Environmental Resources. One topic was highlighted as a lesson learned rather than a best practice. Dan Goode (USGS) noted that in the decision-making approaches presented at the workshop (e.g., the USNRC framework), the advocate for the environment is missing. "Preserving" is written down (e.g., see the National Environmental Policy Act) but environmental and economic values are not weighed equally. There is a need to better define how economic and environmental values are evaluated and included in risk assessment, as well as a way to assess intrinsic value of the resources.

6

Summary of the Workshop Series Goals

To close the workshop, William (Bill) Levitan (Office of Environmental Management) re-introduced the goals and objectives of the workshop series and asked for perspectives from the attendees. The discussion was guided by the re-introduction of the topics outlined within the statement of task (see Figure 6-1). Participants were asked to comment on how well the topics were addressed by the workshop and whether best practices had been identified. Because a significant percentage of the participants had attended both workshops, these attendees were asked to tailor their comments to include both workshops.

The following comments are grouped by the bulleted topics in Figure 6-1.

TOPICS 1 AND 2

Planning committee member Patricia Culligan (Columbia University) noted that the first bullet shown in Figure 6-1 should include monitoring beyond environmental conditions—as Paul Black had suggested earlier. Economic and social considerations should also be monitored through new metrics.

Carol Eddy-Dilek (Savannah River National Laboratory) supported functional monitoring over compliance monitoring as a best practice for establishing in situ monitoring locations. Compliance monitoring will not provide the information that is needed to make decisions for complicated sites (e.g., sites with multiple contaminant sources).

Four Main Topics of the Workshop Series:

1. Holistic approaches for remediating sites with multiple contaminant source terms and multiple post-closure uses, including criteria for selecting point-of-compliance and point-of-use monitoring locations.
2. Effective post-closure controls, including monitoring, engineered controls (e.g., engineered barriers), and natural controls (natural barriers and passive in situ remediation).
3. Approaches for assessing the long-term performance of site remedies and closures, especially technically advanced approaches that reduce performance uncertainties and the need for post-closure controls on land use, resource management, and intruder prevention.
4. Approaches for incorporating a sustainability framework into decision making regarding site remediation, closure, and post-closure control of contaminated sites.

FIGURE 6-1 The four main topics of the workshops as outlined in the statement of task (see Appendix A).
SOURCE: Levitan 2014.

TOPIC 3

For the third bullet, Dr. Culligan noted that a clear and reasonable definition of "long-term" is needed. Fifty to 200 years is reasonable, but millions of years is not practical. Dr. Culligan suggested that EM should determine at what timescale sustainability approaches should be applied (e.g., life cycle analysis).

Dr. Culligan identified Dave Geiser's example of continued public engagement after a site has been closed as a best practice. As a post-closure activity, one must be prepared to encourage public involvement in the site. For example, if the public actively uses the site for recreation, wildlife, or industry, then it must be comfortable with the effectiveness of the remedy.

Several workshop attendees noted that public perception is strongly affected when classified information is redacted from documents. Roger Petrie provided an example: the K25 project at Oak Ridge Reservation (ORR) had redacted information, which had very little impact on the final remedy but did impact how the deactivation and decommissioning took place, largely because of the public's unease with missing information. Bill Levitan noted that from EM's perspective, little information should be restricted from public access. Dave Geiser commented that LM does not store classified information, but several staff members hold clearances that allow access to classified nuclear test information, which is needed to confirm remedies are working.

Carol Eddy-Dilek highlighted DOE's Legacy Management data management system, the Geospatial Environmental Mapping System (GEMS),[1] as a best practice for data transparency and for assessing and monitoring long-term remedy performance. All Department of Energy (DOE) sites should save/release information in a similar way by moving remediation data to a more open, accessible system.

TOPIC 4

Craig Benson (University of Wisconsin) suggested that to include sustainability concepts into the broader context of EM's decision-making process, the last bullet in Figure 6-1 should be moved to the top. A "reset" of regulations and regulatory approaches has been suggested as a way to adopt disruptive—as opposed to incremental—change. Rethinking the current regulatory strategy while balancing options in a transparent way (as suggested by the last bullet) may be needed as the nation becomes increasingly resource constrained.

Bill Levitan (DOE EM) supported the idea of moving this bullet to the top of the list because it would address a recent Executive Order directing agencies to identify additional risks that climate change introduces and to develop a suitable governmental response.[2]

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[1] See http://gems.lm.doe.gov/imf/sites/gems_continental_us/jsp/launch.jsp.

[2] See http://www.whitehouse.gov/the-press-office/2013/11/01/executive-order-preparing-united-states-impacts-climate-change.

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Appendix A

Statement of Task

Statement of Task: An ad hoc committee will organize two public workshops on best practices for risk-informed remedy selection, closure, and post-closure control of radioactive and chemically contaminated sites that cannot be remediated for unrestricted release. The workshops will bring together federal and state agency decision makers responsible for contaminated site cleanup and closure decisions, federal and state regulators, key stakeholders, and other technical experts to explore the following topics through presentations, case studies, and discussions:

- Holistic approaches for remediating sites with multiple contaminant source terms and multiple post-closure uses, including criteria for selecting point-of-compliance and point-of-use monitoring locations.
- Effective post-closure controls, including monitoring, engineered controls (e.g., engineered barriers), and natural controls (natural barriers and passive in situ remediation).
- Approaches for assessing the long-term performance of site remedies and closures, especially technically advanced approaches that reduce performance uncertainties and the need for post-closure controls on land use, resource management, and intruder prevention.
- Approaches for incorporating a sustainability framework into decision making regarding site remediation, closure, and post-closure control of contaminated sites.

The workshops will also explore best-in-class remediation, closure, and post-closure approaches that are being developed and applied by recognized leaders in the community of remediation practice; regulatory practices that promote effective, risk-informed decision making; and future opportunities to improve these approaches and practices.

Appendix B

Biographies of Planning Committee and Staff

PLANNING COMMITTEE

PAUL GILMAN (*Chair*) joined Covanta in 2008 as Covanta Energy's first senior vice president and chief sustainability officer. He is responsible for Covanta's safety, health, and environmental compliance programs and for sustainability initiatives that further reducing Covanta's environmental impact while increasing the use of its technologies. Before joining Covanta, Dr. Gilman was the director of the Oak Ridge Center for Advanced Studies. He served as the assistant administrator for research and development and science advisor at EPA from 2002 to 2004. Prior to joining EPA, he was director for policy planning at Celera Genomics. Dr. Gilman was previously the executive director of life sciences and agriculture divisions of the National Research Council of the National Academies of Sciences and Engineering. In addition, Dr. Gilman has held several senior government positions, including associate director of the White House Office of Management and Budget (OMB) for Natural Resources, Energy, and Science, and executive assistant to the secretary of energy for technical matters. He has 13 years of experience working on the staff of the U.S. Senate in several capacities, including as a Congressional Science Fellow sponsored by the American Association for the Advancement of Science.

PATRICIA CULLIGAN is professor of civil engineering and engineering mechanics and the associate director of the Institute for Data Sciences and Engineering at Columbia University. Her research focuses on applying geoengineering principles to understand and control the migration of contaminants from waste disposal sites. She studies the behavior of miscible contaminants and nonaqueous phase liquids and colloids in soil and fractured rock and the effectiveness of in situ remediation strategies for the cleanup of waste sites. She also has interest and experience in the design of land-based disposal sites for waste materials. Dr. Culligan has received numerous awards, including Massachusetts Institute of Technology's Arthur C. Smith Award for Undergraduate Service (1999), the National Science Foundation Career Award (1999), and Columbia University's Presidential Award for Outstanding Teaching (2007). She is also the author or coauthor of more than 80 journal articles, book chapters, and refereed conference papers. Dr. Culligan has a Ph.D. degree in civil engineering from Cambridge University, England. She has served on several National Research Council committees and is currently a member of the Nuclear and Radiation Studies Board.

MICHAEL KAVANAUGH (NAE) is a principal of Geosyntec Consultants, Inc., an engineering and consulting firm with offices throughout the United States and abroad. His research interests have included hazardous waste management, soil and groundwater remediation, process engineering, industrial waste treatment, technology evaluations, strategic environmental management, compliance and due diligence auditing, water quality, water and wastewater treatment, and water reuse. He has served as chair to the National Research Council's (NRC) Board on Radioactive Waste Management and the Water Science and Technology Board. Dr. Kavanaugh is a registered chemical engineer in California and Utah, a diplomat (DEE) of the American Academy of Environmental Engineers, and a member of the National Academy of Engineering. He received his B.S. in chemical engineering from Stanford University and his M.S. and Ph.D. from the University of California, Berkeley.

JEFFREY WONG is chief scientist for the California Department of Toxic Substances Control (DTSC) at the California Environmental Protection Agency in Sacramento, California. For more than 20 years, he has managed DTSC's efforts in environmental measurements, biological and exposure monitoring, toxicology and risk assessment, and pollution prevention approaches and technologies; he is currently leading efforts focused on nanotechnologies, other emerging contaminants, and green chemistry. Prior to his work in the DTSC, Dr. Wong was involved in forensic investigations for the Department of Justice and pesticide toxicity evaluation for the Department of Food and Agriculture. Dr. Wong has served on several committees for the National Academies, including the Committee on Uranium Mining in Virginia and Committee on Environmental Remediation at Naval Facilities. He has also served on panels for the U.S. Environmental Protection Agency and U.S. Department of Energy. He was appointed by President

Clinton to serve on the Nuclear Waste Technical Review Board. Dr. Wong earned his Ph.D. at the University of California, Davis.

NATIONAL ACADEMY OF SCIENCES STAFF

DOMINIC BROSE is a program officer for the Science and Technology for Sustainability Program (STS) at the National Research Council–National Academy of Sciences, where he leads the urban sustainability workshop series. Prior to STS, Dr. Brose was with the Institute of Medicine (IOM) of the National Academies, where he collaborated on science policy reports addressing the potential for adverse health effects from exposure of select military personnel to environmental contaminants. Previously, he was an environmental scientist at ToxServices, LLC, where he evaluated client product formulations against human health and environmental screening criteria for the Environmental Protection Agency's (EPA's) Design for the Environment (DfE) program. Dr. Brose received his B.S. in environmental science from Purdue University and his M.S. and Ph.D. in soil chemistry from the University of Maryland.

KEVIN D. CROWLEY is senior board director of the Nuclear and Radiation Studies Board (NRSB) at the National Research Council–National Academy of Sciences in Washington, DC. He is responsible for managing the NRSB's work on nuclear safety and security, radioactive waste management and environmental cleanup, and radiation health effects. He is also the principal investigator for a long-standing cooperative agreement between the National Academy of Sciences and the U.S. Department of Energy to provide scientific support for the Radiation Effects Research Foundation in Hiroshima, Japan. Dr. Crowley's professional interests and activities focus on safety, security, and technical efficacy of nuclear and radiation-based technologies. He has directed over 20 National Research Council studies on these and other topics. Before joining the National Research Council staff in 1993, Dr. Crowley held teaching/research positions at Miami University of Ohio, the University of Oklahoma, and the U.S. Geological Survey. He holds M.A. and Ph.D. degrees, both in geology, from Princeton University.

JENNIFER HEIMBERG is a senior program officer of the Nuclear and Radiation Studies Board (NRSB) at the National Research Council–National Academy of Sciences (NAS) in Washington, DC. Prior to joining the NAS in 2011, Dr. Heimberg worked at the Johns Hopkins University Applied Physics Laboratory (APL) for nearly 10 years. She has directed two studies at the NAS on non-proliferation (2012) and global nuclear detection assessment issues (2013). While at APL she established and grew its program with the Department of Homeland Security's Domestic Nuclear Detection Office (DNDO) and served as its program manager through early 2011. Dr. Heimberg's background is broad and physics-based, including system integration of optical networks, experiments on near-frictionless carbon coatings, development of novel atomic force sensors and microscopes, and low-temperature basic physics studies on heavy fermion superconductors. She received her Ph.D. in physics from Northwestern University.

MARINA MOSES is currently the director of the American Academy of Microbiology in the American Society for Microbiology. Dr. Moses previously served as the director for the Science and Technology for Sustainability (STS) Program in the Policy and Global Affairs Division of the National Research Council–National Academy of Sciences (through May 2, 2014). In this capacity, she directed the Roundtable on Science and Technology for Sustainability. Under her leadership, the STS Program issued the consensus report, *Sustainability and the U.S. EPA*, and recently released a multi-sponsored study, *Sustainability for the Nation*. Prior to joining the National Academies, Dr. Moses served on the faculty of The George Washington University School of Public Health and Health Services in the Department of Environmental and Occupational Health. Previously, Dr. Moses held senior scientific positions in the Environmental Management Division of the U.S. Department of Energy and the New York City office of EPA's Superfund Program. Dr. Moses received her B.S. (chemistry) and M.S. (environmental health sciences) degrees from Case Western Reserve University. She received her Dr.P.H. (environmental health sciences) degree from Columbia University School of Public Health.

Appendix C

Workshop 1 Agenda

Best Practices for Risk-Informed Remedy Selection, Closure and Post-Closure Control of Contaminated Sites: A National Academies Workshop

October 30-31, 2013
The National Academies of Science Building
Lecture Room
2100 C Street NW
Washington, D.C.

The purpose of this workshop is to bring together federal and state agency decision makers responsible for contaminated site cleanup and closure decisions, federal and state regulators, key stakeholders, and other technical experts to examine holistic approaches for remediating sites with multiple contaminant sources and post-closure uses. The workshop will also examine approaches for incorporating a sustainability framework into decision making regarding site remediation, closure, and post-closure control of sites.

Wednesday, October 30, 2013

8:30 AM **Welcome and Introduction**
Paul Gilman (Chair, Planning Committee), Senior Vice President and Chief Sustainability Officer, Covanta Energy

8:40 AM **Keynote(s): DOE Presentation**
Alice Williams, Associate Principal Deputy Assistant Secretary, Office of Environmental Management, Department of Energy

9:00 AM **Framing the Issue: Challenges to Regulatory Flexibility**
Moderator: Jeffrey Wong, Chief Scientist, Department of Toxic Substances Control, California Environmental Protection Agency (Member, Planning Committee)

Carolyn Huntoon, Independent Consultant and former Assistant Secretary for Environmental Management, Department of Energy

Larry Camper, Director, Division of Waste Management and Environmental Protection, Nuclear Regulatory Commission

9:50 AM **Discussion**

10:15 AM BREAK

10:30 AM **Framing the Issue: Challenges to Risk-Informed Decision Making**
Moderator: Paul Gilman (Chair, Planning Committee), Senior Vice President and Chief Sustainability Officer, Covanta Energy

Stephen Cobb, Chief, Governmental Hazardous Waste Branch, Land Division, Alabama Department of Environmental Management

Anna Willett, Director, Interstate Technology & Regulatory Council, Environmental Council of the States

11:20 AM **Discussion**

11:50 AM **Morning Summary**
Paul Gilman (Chair, Planning Committee), Senior Vice President and Chief Sustainability Officer, Covanta Energy

12:00 PM LUNCH

1:00 PM **Holistic Approaches to Remediation: Overcoming Barriers at Hanford and Savannah River**
Moderator: Patricia Culligan, Professor, Civil Engineering and Engineering Mechanics, Columbia University (Member, Planning Committee)

Michael Truex, Earth Systems Science Division, Pacific Northwest National Laboratory

Jeffrey Griffin, Associate Laboratory Director,
Environmental Stewardship Directorate, Savannah River
National Laboratory

1:50 PM **Discussion**

2:30 PM BREAK

2:45 PM **Holistic Approaches to Remediation: Alternate End States**
Moderator: Rula Deeb, Principal, Geosyntec Consultants

John Applegate, Walter W. Foskett Professor of Law and
IU Executive Vice President for University Academic
Affairs, Indiana University

David Maloney, Director, Technology, CH2M HILL

3:25 PM **Discussion**

4:15 PM **Summary Discussion**
Participant 1
Participant 2

4:50 PM **Wrap-up**
Paul Gilman (Chair, Planning Committee), Senior Vice
President and Chief Sustainability Officer, Covanta Energy

5:00 PM ADJOURN

Thursday, October 31, 2013

8:30 AM **Welcome and Re-Cap of First Day**
Paul Gilman (Chair, Planning Committee), Senior Vice
President and Chief Sustainability Officer, Covanta Energy

8:40 AM **Incorporating Sustainability into Decision Making for Site Remediation**
Moderator: Rula Deeb, Principal, Geosyntec Consultants

Geoffrey Fettus, Senior Project Attorney, Nuclear Program,
Natural Resources Defense Council

Nick Garson, President, The Sustainable Remediation Forum, Inc.

Buddy Bealer, Sustainable Remediation Initiative

9:50 AM **Discussion**

10:40 AM **Federal Agency Perspective on Incorporating Sustainability into Site Remediation**
Moderator: Jeffrey Wong, Chief Scientist, Department of Toxic Substances Control, California Environmental Protection Agency (Member, Planning Committee)

Maureen Sullivan, Director, Environmental Management, Office of the Deputy Under Secretary of Defense, Department of Defense

Walter Mugdan, Director, Emergency and Remedial Response Division, Environmental Protection Agency Region 2

11:30 AM **Discussion**

12:15 PM **Summary and Wrap-up**
Paul Gilman (Chair, Planning Committee), Covanta Energy

12:30 PM ADJOURN

Appendix D

Workshop 1 Speaker Biographies

JOHN APPLEGATE was named Indiana University's (IU's) first vice president for planning and policy in July 2008. In March 2010, his portfolio was expanded and his title changed to vice president for university regional affairs, planning, and policy. In February 2011, he became executive vice president for regional affairs, planning, and policy. In 2013, he became executive vice president for university academic affairs. Within this role, Mr. Applegate ensures coordination of university academic matters, strategic plans, external academic relations, enterprise systems, and the academic policies that enable the university to most effectively bring its vast intellectual resources to bear in serving the citizens of the state and nation. The regional affairs mission of OEVPUAA [Office of the Executive Vice President for University Academic Affairs] is to lead the development of a shared identity and mission for all of IU's regional campuses that complement each campus's individual identity and mission. In addition, Mr. Applegate is responsible for public safety functions across the university, including police, emergency management, and environmental health and safety. In 2006, Mr. Applegate was appointed Indiana University's first Presidential Fellow, a role in which he served both President Emeritus Adam Herbert and current President Michael McRobbie. A distinguished environmental law scholar, Mr. Applegate joined the IU faculty in 1998. He is the Walter W. Foskett Professor of Law at the Indiana University Maurer School of Law in Bloomington, and he served as the school's executive associate dean for academic affairs from 2002 to 2009. He holds a law degree from Harvard Law School and a bachelor's degree in English from Haverford College.

BUDDY BEALER is leading the Sustainable Remediation Initiative (SRI), a not-for-profit group working to promote sustainable remediation throughout the United States. SRI is a collaborative effort of the Sustainable Remediation Forum (SURF), the Interstate Technology and Regulatory Council (ITRC), and API Energy. Mr. Bealer is employed by Shell and is the soil and groundwater policy and advocacy region manager for the Americas. He works with global staff, consultants, industry, and regulators to support the development of policy based on current science. He joined Shell in 1988 and has held positions as a district engineer, environmental engineer, sales manager, and project manager. From 1997 to 2001, he managed a New Jersey environmental remediation consulting office. Mr. Bealer was a charter member (2009) to the ITRC's Green and Sustainable Remediation Team and is an active board member of SURF, an advisory board member of the Pennsylvania State University Sustainability Institute, and a contributing author to several Sustainable Remediation papers. He earned a B.S. in mechanical engineering from the Pennsylvania State University in 1988 and an M.B.A. from the University of Connecticut in 1997.

LARRY CAMPER has more than 36 years of experience, both in public and private sectors, within the nuclear industry. In the private sector, Mr. Camper occupied several positions of increasing management responsibility, including director of technical operations, executive vice president, and president, within a rapidly growing consulting firm that provided a broad spectrum of technical services in health physics, environmental science, radioactive waste management, and radio-pharmaceutical management. While in the private sector, Mr. Camper served as a radiation safety officer and was qualified by several states as a radiation safety expert. In addition, he was appointed by the governor to serve on the State of Maryland Radiation Control Advisory Board. In 1989, Mr. Camper returned to the USNRC as a project manager within the Division of Waste Management. In 1990, Mr. Camper became the section leader for the Medical and Academic Section, and in 1995, he was promoted to branch chief of the Medical, Academic, and Commercial Use Safety Branch, Division of Industrial and Medical Nuclear Safety. In 1999, he was appointed as the branch chief, Decommissioning Branch, Division of Waste Management. In 2003, Mr. Camper was appointed as the deputy director for the Licensing and Inspection Directorate in the Spent Fuel Project Office. Mr. Camper assumed his current duties in 2005, and he serves as the U.S. Representative to the Waste Safety Standards Advisory Committee of the International Atomic Energy Agency and as a member of the Board of Directors and the Program Advisory Committee for the Waste Management Symposia. Mr. Camper received a B.S. degree in radiological science and an M.B.A.

from The George Washington University. Mr. Camper is a graduate of the NRC Senior Executive Service Candidate Development Program.

STEPHEN COBB is the chief of the Governmental Hazardous Waste Branch of ADEM's Land Division, which is responsible for implementation of ADEM's various hazardous waste permitting, compliance, and cleanup programs at local, state, and federal government facilities, which include those owned or operated by the Department of Defense (DOD), Tennessee Valley Authority (TVA), and other federal agencies, various departments and agencies of the State of Alabama, public colleges and universities, local governments, and fund-lead Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priority List (NPL) sites. During his ADEM career, he has worked in progressively challenging roles as a hazardous waste permitting and corrective action project manager, as supervisor of the Resource Conservation and Recovery Act (RCRA) hazardous waste permitting and corrective action program, and as program manager for permitting, corrective action, compliance and enforcement, and for hazardous waste notifications for RCRA, CERCLA, Voluntary Cleanup, and Brownfields programs. He is a licensed professional engineer and a certified public manager, with bachelor's and master's degrees in agricultural engineering from Auburn University. Mr. Cobb has actively participated in various Environmental Protection Agency (EPA)–state workgroups on hazardous waste management and cleanup issues since the early 1990s. Mr. Cobb has also been an active participant in the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) for many years, including serving for 6 years (2004-2010) as the chair of the Hazardous Waste Subcommittee and 1 year each as vice president (2009-2010), president (2010-2011), and past president (2011-2012). Since 2000, Mr. Cobb has actively participated in national forums with DOD regarding numerous environmental permitting and waste cleanup issues, including Chemical Weapons Demilitarization, Federal Facilities Cleanup, Formerly Used Defense Sites, and Munitions Response as a part of his responsibilities with ADEM.

RULA DEEB is a principal at Geosyntec in Oakland, California. Dr. Deeb's technical expertise includes the cross-media fate and transport of contaminants and the remediation of complex soil and groundwater sites impacted by non-aqueous phase liquids. She received her Ph.D. from the University of California (UC) at Berkeley in civil and environmental engineering. Following the completion of her graduate work, she taught environmental engineering principles at Stanford University. As a post-doctoral fellow at UC Berkeley, she developed and implemented research programs in collaboration with scientists and engineers at other universities, consulting firms, and the U.S. Air Force on the remediation of sites impacted with contaminant mixtures. In 2000 she joined Malcolm Pirnie, Inc., where she managed commercial, federal, and municipal projects and clients and served as a technical specialist on key projects company-wide. Following the acquisition of Malcolm Pirnie by ARCADIS in July 2009, she served as vice president and technical director for external outreach in ARCADIS' Environment Division. Dr. Deeb is heavily engaged in the National Academy of Engineering Frontiers of Engineering program, which brings together emerging engineering leaders from industry, academia, and government to discuss pioneering technical work and leading-edge research in various engineering fields and industry sectors. She is the recipient of the 2008 Berkeley Engineering Innovation Young Outstanding Leader Award and is a Board Certified Environmental Engineering Member of the American Association of Environmental Engineers.

GEOFFREY FETTUS is a senior project attorney for the Natural Resources Defense Council's (NRDC's) nuclear program. His litigation and advocacy work focuses on the beginning and end of the nuclear fuel cycle, including issues associated with uranium mining and radioactive waste disposal. A graduate of the University of Wisconsin Law School and Haverford College, Mr. Fettus worked as an assistant attorney general in New Mexico and for a public interest law firm in New Mexico before joining NRDC in 2001.

NICK GARSON is a project manager in the Boeing Environmental Remediation Group, located in Renton, Washington. He is registered as a professional geologist with the State of Washington. He works on a wide range of environmental investigation and remediation projects involving such contaminants as chlorinated solvents, metals, petroleum compounds, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). He leads Boeing's Sustainable Remediation Program and is currently serving as president of the Sustainable Remediation Forum. Mr. Garson holds a B.S. in geology from St. Lawrence University, M.S. in geology from the University of Montana, and an M.B.A. from Seattle University.

JEFFREY GRIFFIN is the associate laboratory director for environmental stewardship at the Savannah River National Laboratory (SRNL). In this position, he is responsible for the management, growth, and development of the SRNL research and development portfolio in environmental stewardship. Dr. Griffin has a Ph.D. in nuclear chemistry from the Georgia Institute of Technology. He joined SRNL in 1987 and has served in positions of increasing responsibility, primarily in the areas of high-level waste processing, radiochemistry, analytical chemistry, and nuclear materials measurements. Dr. Griffin's directorate provides strategic support to Department of Energy (DOE) Headquarters Office of Environmental Management and also provides key technical support to environmental restoration and waste management programs, not only at the Savannah River Site, but also at other DOE sites and international areas of concern. The directorate maintains core competencies in chemical process development, radioactive waste characterization and treatment technology, materials development and analysis, modeling, remediation technologies and strategies, and remote systems and robotics.

CAROLYN HUNTOON is an independent consultant with expertise in the fields of energy and aerospace. She advises governmental entities and private companies on the cleanup of nuclear weapons by-products, handling of large volumes of highly radioactive nuclear wastes, safeguarding materials that could be used in nuclear weapons, development and deployment of new technologies to address intractable cleanup problems, and remediation of extensive surface and groundwater contamination. Dr. Huntoon consults on space policy and physiologic responses to space travel. Before becoming a consultant, she had a distinguished career of more than 30 years with the federal government serving at both DOE and the National Aeronautics and Space Administration (NASA). Most recently, Dr. Huntoon served Presidents George W. Bush and William Clinton as DOE's assistant secretary for environmental management, a Senate-confirmed position. In this role, Dr. Huntoon oversaw DOE's cleanup of the nation's nuclear weapons complex at 113 sites in 30 states and 1 territory. Additionally, she was responsible for the management of seven of DOE's field offices (Idaho, Savannah River, Richland, Carlsbad, Ohio, Rocky Flats, and the Office of River Protection at Hanford). Dr. Huntoon served in various scientific and management positions at NASA, including as director of the Johnson Space Center in Houston, Texas, and special assistant to the administrator of NASA in Washington, DC. In addition, she served as an executive in residence in The George Washington University Project Management Program and spent 2 years at the White House in the Office of Science and Technology Policy where she was responsible for several interagency science programs. Dr. Huntoon received her undergraduate degree from Northwestern State College, Natchitoches, Louisiana, and her M.S. and Ph.D. degrees from Baylor College of Medicine, Houston, Texas.

DAVID MALONEY has served since 1997 as technology director for CH2M Hill's remediation work at DOE nuclear sites, where he is responsible for identifying, developing, and deploying new technology to improve on safety, cost, and schedule. On the Rocky Flats closure project, he partnered with the EM-50 Science and Technology Program to create a risk-/cost-based approach that became a model and a Congressional Line Item for the weapons complex known as the Rocky Flats Initiative—delivering more than $350 million and more than 1 year of savings in the past 5 years alone. This approach comprises closely integrated contract, regulatory, and technology innovation and close partnership between the technical program and operations. Prior to CH2M Hill, Dr. Maloney's career focused on development of sustainable infrastructure—energy, water/wastewater, and waste management—in 25 countries, where he worked in the roles of finance, investor-owner-operator, performance standards, facility regulations and licensing, and design-build-operate. For 2 years he served as assistant to the general manager, Energy and Environment Programs, at Argonne National Laboratory, where he focused on technology transfer to industry.

WALTER MUGDAN serves as director of the Emergency and Remedial Response Division at EPA's Region 2 office, located in New York City. He heads a staff of 220 employees responsible for the Region's "Superfund" toxic waste cleanup, emergency response, and Brownfields programs. Previously he headed the Region's Division of Environmental Planning & Protection, where his staff of about 180 scientists, engineers, and planners managed the Region's air, water, hazardous waste and environmental review programs. Prior to that appointment, he served as deputy regional counsel and then regional counsel for Region 2, where he headed a staff of 80 attorneys. He joined EPA in 1975 as a staff attorney and subsequently served in various supervisory positions in the Office of Regional Counsel, including chief of the units responsible for Superfund, RCRA, Toxic Substances Control Act, and the Clean Air Act.

MAUREEN SULLIVAN serves as director of environmental management at the Office of the Deputy Under Secretary of Defense (lnstallations & Environment). She oversees development of environmental programs, policy, and strategic plans for DOD activities throughout the United States. She leads DOD activities in compliance with environmental laws, prevention of pollution, management of natural and cultural resources, and cleanup of contaminated sites. Ms. Sullivan also is responsible for the DOD Native American program. She is the DOD federal preservation officer and the alternate DOD member of the President's Advisory Council on Historic Preservation. Ms. Sullivan has served in various leadership positions as a member of the Office of the Secretary of Defense Environmental staff for the past 18 years, and she possesses wide-ranging experience in numerous DOD programs to include Pollution Prevention, Environmental Compliance, Historic Preservation, and the Clean Air Act. She served as the DOD representative to the Office of Management and Budget Interagency Panel, which negotiated the final Ozone and Particulate Matter National Ambient Air Quality Standards in 1997. She also served as the DOD Liaison to the President's Council on Sustainable Development. Ms. Sullivan contributed significantly to authoring Executive Order 13148, "Greening the Government Through Leadership in Environmental Management," which President Clinton signed on April 22, 2000. She also helped draft Executive Order 12856, "Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements." After President Clinton signed Executive Order 12856, she was detailed to EPA's Office of the Administrator to guide initial implementation. Her total DOD career spans 29 years. Prior to joining the Office of the Secretary of Defense, she held positions with the Defense Logistics Agency in Virginia, Michigan, Ohio, and Germany, where she worked in hazardous waste management, international environmental activities, and pollution prevention.

MICHAEL TRUEX is a senior program manager, Environmental Systems Group at Pacific Northwest National Laboratory (PNNL). He has 21 years of experience at PNNL in subsurface remediation research and field applications. His experience includes providing clients with technical support for remediation decisions through technology assessments, applications of numerical fate and transport modeling, and feasibility and treatability assessments. Mr. Truex specializes in evaluation and application of in situ remediation and attenuation-based remedies. Field experience includes work at Department of Energy, Department of Defense, and private remediation sites.

ANNA WILLETT is the director of the Interstate Technology & Regulatory Council (ITRC). She has been involved in ITRC since 2003, first as a member of the In Situ Bioremediation and Bioremediation of DNAPLs Teams and later as the Industry Representative on the ITRC Board of Advisors. Ms. Willett joined ITRC from Comprehensive Environmental Utility Services, LLC (CEUS), where she was a senior vice president and partner. She was previously a senior engineer concentrating on remediation engineering and project management with Haley & Aldrich, Inc., a national environmental engineering firm. Earlier in her career, she was responsible for the design, implementation, and evaluation of pilot- and full-scale in situ remediation projects as a research and development manager for Regenesis, a specialty chemical company that serves the remediation industry. Over the course of her career, Ms. Willett has evaluated a wide range of contaminated sites to determine technical and cost-effective cleanup strategies for specific site conditions. Her expertise includes chemical and biological treatment processes for groundwater and soil, as well as environmental chemistry and microbiology. She has contributed to more than 60 presentations and publications on remediation and has presented at a wide range of national and international conferences. She holds an M.S. in chemical engineering from Northwestern University and a B.S. in biological engineering from Cornell University. She is a registered professional engineer.

ALICE WILLIAMS is currently the associate principal deputy assistant secretary for the U.S. Department of Energy (DOE) Office of Environmental Management (EM). She is responsible for providing oversight of the EM Mission Units and ensuring integration across the mission areas at both DOE Headquarters and the field. Prior to her current position, Ms. Williams served as the Livermore Site Manager for the National Nuclear Security Administration. In this capacity, she was responsible for the operations, oversight, and contract administration of the Lawrence Livermore National Laboratory. With a federal staff of approximately 100 positions, she performed federal oversight of safety, security, infrastructure, environmental management, and business and contract management of the multi-program laboratory with an annual budget of approximately $1.6 billion. Ms. Williams has more than 25 years of federal service, having worked in positions both in the field (Idaho Operations Office and Ohio Field Office/West Valley Demonstration Project) and at DOE Headquarters (Office of New Production Reactors, Office of Environmental Management, and the National Nuclear Security Administration/Associate Administrator for Infrastructure and Environment). She has been instrumental in some of DOE's major initiatives to develop innovative solutions to complex environmental issues, including rail transport of used nuclear fuel, facility decommissioning, and the development of land use plans. Prior to joining the federal government, she worked for EG&G at the Idaho National Engineering Laboratory and participated in the analysis of the Three Mile Island-Unit 2 Accident, development of reactor operating safety parameters, and building the company's Work-for-Others portfolio. She received a B.S. in chemistry from Montana State University and a master's of engineering degree in chemical engineering from the University of Idaho.

Appendix E

Workshop 2 Agenda

Best Practices for Risk-Informed Remedy Selection, Closure and Post-Closure Control of Contaminated Sites: Workshop 2

January 9-10, 2014
The Keck Center, Room 100
The National Academies
500 5th Street NW
Washington, D.C.

This workshop will focus on the following topics:

- Promotion of effective and efficient risk-informed decision making,
- Approaches for assessing long-term performance of site remedies and closures,
- Effective post-closure controls and the assessment of long-term stewardship options,
- Identification of best practices for improving remediation/closure/post-closure of challenging sites.

Thursday, January 9, 2014

8:30 AM **Welcome, Highlights of Workshop 1, and Charge to Workshop 2 Participants**
Paul Gilman (Chair, Planning Committee), Senior Vice President and Chief Sustainability Officer, Covanta Energy

- DOE's Environmental Management Perspectives on the Workshops
  Mr. William (Bill) Levitan, Associate Deputy Assistant Secretary for Site Restoration for Department of Energy's (DOE's) Environmental Management

9:10 AM **Discussion**

9:30 AM **Session 1: Effective and Efficient Risk-Informed Decision Making**
Moderator: Michael Kavanaugh, Principal, Geosyntec Consultants (Planning Committee)

- History of Risk and Sustainability in Decision Making for Complex Sites
  Bernard Goldstein, Professor Emeritus, Department of Environmental and Occupational Health, University of Pittsburgh

10:00 AM **Discussion**

10:30 AM BREAK

10:45 AM **Session 1 Case Studies: Risk Assessments and Decision-Making Frameworks**
Moderator: Michael Kavanaugh

- Federal Facility Cleanup Dialogue Series and Brownfields Discussions
  Reggie Cheatham, Director of the Federal Facility Restoration and Reuse Office, Environmental Protection Agency

- Risk-Based Approaches for Remediation Decisions
  Paul Black, Ph.D., Principal, Neptune

11:30 AM **Discussion**

12:00 PM **Morning Summary**
Paul Gilman (Chair, Planning Committee)

12:10 PM LUNCH

1:15 PM **Session 2: Approaches for Assessing Long-Term Performance of Site Remedies**
Moderator: Patricia Culligan, Professor, Civil Engineering and Engineering Mechanics, Columbia University (Planning Committee)

- Long-Term Land Use and Opportunities to Affect Decisions
  Willie Preacher, Tribal DOE Program, Shoshone-Bannock Tribes

- A Risk-Management Framework for Decision Making
  William Reckley, Branch Chief in the Japan Lessons Learned Project Directorate, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission

2:00 PM **Discussion**

2:30 PM BREAK

2:45 PM **Session 2 Case Studies: Approaches for Assessing Long-Term Performance of Site Remedies**
Moderator: Patricia Culligan

- Bethpage/Northrop Grumman Airfield Remediation and Stewardship on Long Island
  Richard Mach, Jr., Director of Environmental Compliance and Restoration Policy in the Office of the Deputy Assistant Secretary of the Navy

- Institutional Controls on Lower Watts Bar Reservoir
  Roger Petrie, Federal Facility Agreement (FFA) Projects Manager for the DOE Oversight Division of the Tennessee Department of Environment and Conservation

3:30 PM **Discussion**

4:15 PM **Summary and Round Robin Discussion**
Paul Gilman (Chair, Planning Committee)

5:00 PM ADJOURN

Friday, January 10, 2014

8:30 AM **Welcome and Re-Cap of First Day**
Paul Gilman (Chair, Planning Committee)

9:00 AM **Session 3: Effective Post-Closure Controls, Monitoring, and Long-Term Stewardship (LTS)**
Moderator: Rula Deeb, Principal at Geosyntec Consultants

- Strategies for Long-Term Monitoring and Stewardship
  Craig Benson, Director of Sustainability Research and Education and Chair of Civil and Environmental Engineering and Geological Engineering, University of Wisconsin; and member of the Consortium for Risk Evaluation with Stakeholder Participation (CRESP)

9:30 AM **Discussion**

10:00 AM BREAK

10:15 AM **Session 3 Case Studies: Post-Closure Controls, Monitoring, and LTS**
Moderator: Rula Deeb

- Infrastructure Issues and Technology Approaches for Achieving Successful "Rolling Stewardship"
  Dave Geiser, Director and Acting Deputy Director of DOE's Office of Legacy Management

- The Core Team Process: Making Risk-Informed Decisions for On-site Monitoring
  Mary Flora, Director, Savannah River Nuclear Solutions

11:15 AM **Discussion**

11:45 AM LUNCH

1:00 PM **Identification of Best Practices for Improving Remediation/Closure/Post-Closure of Challenging Sites**
Moderator: Michael Kavanaugh

- Identify "best-in-class" ideas for site remediation and long-term stewardship, either from the workshop or past remediation experiences, 5 minutes each
  Tribal: Willie Preacher
  State: Roger Petrie (TN)
  Regulator: William Reckley
  Federal: Dave Geiser

Practitioners: Mary Flora/Craig Benson/Paul Black
Citizen Stakeholder: Marolyn Parson

1:45 PM **Discussion**

2:00 PM BREAK

2:15 PM **Summary and Round Robin Discussion**
Paul Gilman (Chair, Planning Committee)

- Identification of best-in-class practices discussed in both workshops

3:00 PM **Wrap-up**
Paul Gilman (Chair, Planning Committee)

3:15 PM ADJOURN

Appendix F

Workshop 2 Speaker Biographies

CRAIG BENSON serves as director of sustainability research and education and chair of civil and environmental engineering and geological engineering at the University of Wisconsin at Madison. Dr. Benson has a B.S. from Lehigh University and M.S.E. and Ph.D. degrees from the University of Texas at Austin. He has been conducting experimental and analytical research in geoenvironmental engineering for nearly three decades, with the primary focus in sustainable infrastructure, beneficial use of industrial by-products, and environmental containment for the solid waste, hazardous waste, and mining industries. His research includes laboratory studies, large-scale field experiments, and computer modeling. Dr. Benson has received several awards for his work, including the Ralph Peck Award, the Huber Research Prize, the Alfred Noble Prize, and the Croes (twice), Middlebrooks, Collingwood and Casagrande Awards from the American Society of Civil Engineers. Dr. Benson is a member of the ASCE Geo-Institute (GI) and is former editor-in-chief of the ASCE/GI *Journal of Geotechnical and Geoenvironmental Engineering*. He currently serves as vice president and president elect of the ASCE/GI Board of Governors and is vice chair of the Executive Committee of ASTM Committee D18 on Soil and Rock. Dr. Benson is a member of the National Academy of Engineering and the Academy of Distinguished Alumni at the University of Texas at Austin.

PAUL BLACK is principal, co-founder and current CEO of Neptune and Company, Inc. (Neptune), an environmental consulting company that specializes in the technical disciplines of statistics, decision analysis, risk assessment, ecology, environmental modeling, quality assurance (QA), and chemistry. Dr. Black has more than 20 years of experience applying statistics to a wide range of environmental problems. He is the manager of Neptune's Decision Analysis, Modeling and Statistics Group. The main focus of the group is to provide consulting services in environmental decision analysis, covering environmental modeling, cost-benefit (economic) analysis, options analysis, statistics, probability, elicitation, earth sciences, and probabilistic human health and ecological risk assessment. Dr. Black has performed work for the Environmental Protection Agency (EPA), Department of Energy (DOE), Department of Defense (DOD), and Food and Drug Administration (FDA), as well as many state and local groups. Dr. Black received an M.S. and Ph.D. in statistics from Carnegie Mellon University. He earned a B.Sc. (with honors) from the University of Lancaster, United Kingdom.

REGGIE CHEATHAM is the director of EPA's Federal Facilities Restoration and Reuse Office (FFRRO). Prior to joining FFRRO, Mr. Cheatham served as the director of EPA's Quality Staff in the Office of Environmental Information (OEI); the director of the Environmental Analysis Division in the Office of Information Analysis and Access, OEI; the deputy director of the Regional Support Division (Superfund Enforcement), Office of Site Remediation Enforcement in the Office of Enforcement and Compliance Assurance (OECA); and Chief of the Chemical Industry Branch, in the Office of Compliance, OECA; and as an environmental engineer for both the Federal Facilities Enforcement Office, OECS and the RCRA Enforcement Division, Office of Solid Waste and Emergency Response (OSWER). Prior to joining EPA, Mr. Cheatham worked as a quality control/civil engineer in the construction industry and served in the U.S. Army. He holds a B.S. in civil engineering and an M.S. in environmental engineering from The George Washington University.

MARY FLORA earned a B.S. degree in geology from West Virginia University in 1979. After graduation she worked as an engineering geologist for the West Virginia Department of Highways while completing environmental sciences coursework at the West Virginia College of Graduate Studies. She began working at Savannah River Site (SRS) in 1988 in the groundwater and environmental protection program. During her SRS career she has worked in a variety of management functions including Area Completion Projects Environmental Compliance and Regulatory Integration; Soil & Groundwater Project Development; SRS Public Involvement; and SRS Program Integration and Planning. Today, Ms. Flora is the director of environmental compliance and area completion projects for Savannah River Nuclear Solutions, LLC. In this position, she is responsible for regulatory compliance, soil and groundwater assessment/remediation, and deactivation and decommissioning (D&D) activities at the Savannah River Site.

DAVE GEISER is the director and acting deputy director of the DOE's Office of Legacy Management. He started work in the Office of Legacy Management in 2003 as director of the Office of Policy and Site Transition. From 1991 to 2003, he served in the DOE's Office of Environmental Management in several capacities: international programs, high-level waste research and development, complex-wide planning and integration, deployment of new technology, and policy and guidance for long-term environmental stewardship. He graduated from Cornell University with a B.S. in chemical engineering and received his commission in the U.S. Navy in 1981. He served in the Navy for 8 years as a nuclear-trained officer on the USS *Daniel Webster* and at the Naval Sea Systems Command. After leaving the Navy, Mr. Geiser received a master's of engineering administration degree from The George Washington University and joined Science Applications International Corporation. During his 3 years with SAIC, he spent 2 years in Paris, France, evaluating European waste management practices.

BERNARD (BERNIE) GOLDSTEIN is professor emeritus of environmental and occupational health at the University of Pittsburgh Graduate School of Public Health; he has also served as the dean of the Graduate School of Public Health. He was the founding director of the Environmental and Occupational Health Sciences Institute, a joint program of Rutgers, the State University of New Jersey and the University of Medicine and Dentistry of New Jersey (UMDNJ)–Robert Wood Johnson Medical School from 1986 to 2001. He is a physician and is board certified in internal medicine, hematology, and in toxicology. He is the author of more than 200 articles and book chapters related to environmental health sciences and to public policy. Dr. Goldstein was assistant administrator for research and development at the EPA from 1983 to 1985. His past activities include member and chairman of the National Institutes of Health Toxicology Study Section; the EPA Clean Air Scientific Advisory Committee; and the National Board of Public Health Examiners. He is a member of the Institute of Medicine. He has served as chair or member of numerous Institute of Medicine or National Research Council committees. Dr. Goldstein has also served as president of the Society for Risk Analysis, as vice president and editor-in-chief of the Scientific Committee on Problems of the Environment, and as a member of the National Advisory Environmental Health Sciences Council.

WILLIAM (BILL) LEVITAN serves as associate deputy assistant secretary for the Office of Site Restoration and acting director of the Office of Environmental Compliance within DOE's Office of Environmental Management (EM). He joined EM at headquarters in 1993, and from 2005 to 2009 he served as the executive officer for EM, reporting to the assistant secretary of EM. During his tenure at DOE, he has also served as director of the Office of Planning and Analysis and the Office of Project Planning and Controls and has had responsibilities for waste management and laboratory program management for the Hanford Site and cross-cutting EM coordination for the Oak Ridge Reservation. From 1977 to 1993, he worked at two environmental consulting/engineering firms—Dames & Moore (until 1987) and NUS Corporation. He received his B.A. in natural sciences from the Johns Hopkins University and his M.S. in marine studies (environmental toxicology) from the University of Delaware.

RICHARD G. MACH, JR. is the director of environmental compliance and restoration policy in the Office of the Assistant Secretary of the U.S. Navy (Energy, Installations, and Environment) and has more than 20 years of environmental experience working for the Navy. He has held his current position since April 2006, acting as a principal policy advisor for the Navy and Marine Corps on environmental programs, including compliance with environmental laws and regulations, cleanup of contaminated sites, and pollution prevention and sustainability. Mr. Mach began his civil service for the Navy in 1992 at Naval Facilities Engineering Command (NAVFAC), Southwest Division, where he was a remedial project manager in charge of cleanup and compliance projects for various Navy bases in southern California. His next assignment was as the Base Realignment and Closure (BRAC) environmental coordinator for Hunters Point Shipyard. In this position, Mr. Mach was responsible for the $60 million/year cleanup program at the base to support eventual transfer to the City of San Francisco. After 2 years, Mr. Mach was selected to become the cleanup program and munitions response program manager for NAVFAC Headquarters. In this position, he led several NAVFAC workgroups to develop and implement improved environmental policy, guidance, and strategies to optimize the Navy's cleanup program and to implement better technologies Navy-wide. After 4 successful years in this position, Mr. Mach was selected for his current position.

ROGER PETRIE is the Federal Facility Agreement (FFA) projects manager for the DOE Oversight Division of the Tennessee Department of Environment and Conservation (TDEC). In this capacity, he represents the state in the CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) cleanup of the DOE Oak Ridge Reservation. Before joining TDEC in 1997, he worked in the Environmental Sciences Division of Oak Ridge National Laboratory (ORNL). He worked for the Aquatic Biology Division of the Tennessee Valley Authority before joining ORNL. Mr. Petrie has B.S. and M.S. degrees in wildlife and fisheries science from the University of Tennessee. Mr. Petrie participates in the Environmental

Council of the States through the Federal Facilities Forum and was appointed to the ITRC Board of Advisors in 2012.

WILLIE PREACHER is a member of the Shoshone-Bannock Tribes, a federally recognized Indian Tribe. He serves as a Tribal representative for various national, state, and local organizations, including the National Conference of State Legislatures' State and Tribal Government Working Group, the DOE Transportation Stakeholder Forum, and the DOE Environmental Management Site-Specific Advisory Board for Idaho National Laboratory. Mr. Preacher is currently employed as the director of the Tribal/DOE Agreement-in-Principle Program and previously worked at the Idaho National Laboratory for 30 years. He resides in Blackfoot, Idaho.

WILLIAM RECKLEY is a branch chief in the Japan Lessons Learned Project Directorate within the Office of Nuclear Reactor Regulation at the U.S. Nuclear Regulatory Commission (USRNC), where he is responsible for assessing possible changes in USNRC requirements and programs to address lessons learned from the accident at the Fukushima Daiichi nuclear power plant in Japan. Since joining the USNRC in 1987, Mr. Reckley has held a number of progressively responsible positions in several offices including the former Office for Analysis and Evaluation of Operational Data, the Office of Nuclear Reactor Regulation, and the Office of New Reactors, where he worked on developing the licensing infrastructure for small and medium-sized reactors—including advanced reactor concepts. In addition to working on numerous specific licensing activities, Mr. Reckley has contributed to various generic projects such as revising emergency action levels, improving licensing processes, and preparing guidance documents for USNRC staff, licensees, and applicants. Prior to joining the USNRC, Mr. Reckley worked for Duke Power Company in the safety analysis and licensing support organization. Mr. Reckley holds a B.S. in nuclear engineering from the University of Maryland.

Appendix G

Participant List

WORKSHOP 1 PARTICIPANTS

Rateb (Boby) Abu-Eid
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Note: Speakers denoted by a single asterisks. Moderators denoted by double asterisks.

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Hope Lee
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William Levitan
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David Maloney
CH2M HILL

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Patricia Culligan**
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David Geiser*
U.S. Department of Energy, Office of Legacy Management

Kurt Gerdes
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Alexandra Gilliland
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Bernard Goldstein*
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Michael Kavanaugh**
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Hope Lee
Pacific Northwest National Laboratory

Patricia Lee
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William Levitan*
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Richard Mach, Jr.*
U.S. Navy

David Maloney
CH2M HILL

Justin Marble
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Deborah Morefield
U.S. Department of Defense

Thomas Nicholson
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Marolyn Parson
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Eric Pierce
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John Tesner
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K. Michael Thompson
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John Tseng
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Dawn Wellman
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Appendix H

Acronyms

ALARA	As low as reasonably achievable
API	American Petroleum Institute
ARP	Actinides Removal Process
BLM	Bureau of Land Management
BRAC	Base Realignment and Closure program
CAB	Citizen advisory board
CAG	Community Advisory Group
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CRESP	Consortium for Risk Evaluation with Stakeholder Participation
CSO	Combined sewer overflow
D&D	Deactivation and decommissioning
DHEC	Department of Health and Environmental Control
DNAPL	Dense non-aqueous phase liquid
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DQOs	Data Quality Objectives
DUF6	Depleted uranium hexafluoride
DWPF	Defense Waste Processing Facility

EIS	Environmental impact statement
EM	DOE Office of Environmental Management
EMAB	DOE Environmental Management Advisory Board
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
ETTP	East Tennessee Valley Technology Park
FFA	Federal Facility Agreement
FFERD	Federal Facilities Environmental Remediation Dialogue
FWS	U.S. Fish and Wildlife Service
HAW	High activity waste
HEU	Highly enriched uranium
HLW	High-level waste
IAEA	International Atomic Energy Agency
IAWG	Interagency working group
IC	Institutional control
ICDF	Idaho CERCLA Disposal Facility
IDF	Integrated Disposal Facility
INL	Idaho National Laboratory
IRG	Independent Review Group
ISA	Integrated safety analysis
ISCMEM	Interagency Steering Committee on Multimedia Environmental Modeling
IT	Information technology
ITRC	Interstate Technology and Regulatory Council
LANL	Los Alamos National Laboratory
LAW	Low activity waste
LLW	Low-level waste
LM	DOE Office of Legacy Management
LNAPL	Light non-aqueous phase liquid
MARLAP	Multi-Agency Radiological Laboratory Analytical Protocols Manual
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCL	Maximum containment level
MCU	Modular Caustic-side Solvent Exchange Unit
MFFF	Mixed Oxide Fuel Fabrication Facility
MLLW	Mixed low-level waste
MOX	Mixed oxide

NCP	National Contingency Plan
NEPA	National Environmental Policy Act
NNSA	DOE National Nuclear Security Administration
NPL	National Priority List
NRC	National Research Council
NRCS	National Resource Conservation Service
NYDEC	New York Department of Environmental Conservation
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
ORWBG	Old Radioactive Waste Burial Grounds
OSDF	On-Site Disposal Facility
OU	Operable unit
P&T	Pump and treat system
PA	Performance assessment
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyls
PCE	Perchloroethylene
PNNL	Pacific Northwest National Laboratory
PRA	Probabilistic risk assessment
PRB	Permeable reactive barrier
PRP	Primary Responsible Party
QA	Quality assurance
RAO	Remedial action objectives
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation and Feasibility Study
ROD	Record of decision
RPM	Remediation Project Manager
RWMC	Radioactive Waste Management Complex
SAM	Sustainability Assessment and Management
SARA	Superfund Amendments and Reauthorization Act of 1986
SBW	Sodium bearing waste
SDF	Saltstone Disposal Facility
SNF	Spent nuclear fuel
SPF	Saltstone Production Facility
SRS	Savannah River Site
SSAB	Site-Specific Advisory Board
SURF	U.S. Sustainability Remediation Forum
SWPF	Salt Waste Processing Facility

TCE	Trichloroethylene
TEF	Tritium Extraction Facility
TI	Technical impractibility
TRU	Transuranic waste
UMTRCA	Uranium Mill Tailings Radiation Control Act
USGS	U.S. Geological Survey
USNRC	U.S. Nuclear Regulatory Commission
WAG	Waste Area Group
WIPP	Waste Isolation Pilot Plant