Engineering and Technology Roadmap

Steven P. Schneider
Mark Gilbertson
Office of Engineering and Technology
Office of Environmental Management
U.S. Department of Energy

Throughout its existence, the Environmental Management (EM) program has required a strong technology component to accomplish its mission, one that is focused on developing technologies to enhance safety, effectiveness, and efficiency. Although the Department of Energy (DOE) has made great progress toward safely disposing of the legacies of the Cold War, much remains to be done. These past accomplishments provide a guide for future success; however, the unique nature of many of the remaining challenges will require a strong and responsive applied research and engineering program. The Engineering and Technology Roadmap was developed to address this need and guide the EM Engineering and Technology Program.

The Roadmap identifies the technical risks and uncertainties that the EM program faces over the next ten years; the strategies EM will use to reduce those risks; and the planned outcomes of implementing those strategies. Input for this Roadmap was provided by EM Federal Project Directors, Stakeholders, Site Contractors, National Laboratories and the National Academy of Science. To accomplish this work, EM has designated federal Strategic Initiative Managers who will work with Federal Project Directors to develop, refine and implement a detailed scope and schedule for each initiative, as well as identify the point at which the technologies developed will be inserted into EM cleanup projects.

The starting point for the Roadmap was technical project risk and uncertainty. Risks are defined as known technical issues that could prevent project success. Uncertainties are indefinite or unpredictable technical aspects of a project. Risks included in the Roadmap were identified in three ways:

1) By the Projects - EM's operations are performed within a culture of disciplined project management, based on DOE Order 413.3A, *Program and Project Management for the Acquisition of Capital Assets*. As such, technical risks and uncertainties affecting each cleanup project are identified early in the project life-cycle, are captured in project risk assessments, and often lead to applied technology development activities.

2) By reviews and assessments - EM utilizes experts to review the progress of its major cleanup projects and to assess the maturity of evolving technologies. These reviews include External Technical Reviews and Technology Readiness Assessments. They transcend the project's baseline and often identify opportunities for reducing technical risk through development and deployment of innovative or enhanced technologies.

3) By the sites - EM periodically asks EM sites to identify technical risks and uncertainties in the form of technical needs.

The Roadmap divides EM risks into six program areas: Waste Processing, Groundwater and Soil Remediation, Deactivation and Decommissioning (D&D) and Facility Engineering, Spent Nuclear Fuel, Challenging Materials, and Integration. Tables 1-6 show those risks and uncertainties, as well as the 13 strategic initiatives established to address those risks.

Table 1. Waste Processing Technical Risks and Strategic Initiatives

Technical Risk and Uncertainty	Strategic Initiatives
Waste Storage • Existing tanks provide limited storage and processing capacity, have exceeded their original design life, and will likely be in service for extended periods of time. • Conservative assumptions regarding behavior of waste during storage, such as flammable gas generation, restrict operations and increase costs.	***Improved Waste Storage Technology*** • Develop cost-effective, real-time monitoring of tank integrity and waste volumes to ensure safe storage and maximum storage capacity. • Improve understanding of corrosion and changing waste chemistry, including flammable gas generation, retention, release, and behavior to establish appropriate assumptions in safety analyses.
Waste Retrieval • Current waste removal and retrieval operations and monitoring technologies are costly, sometimes inefficient, and are limited by complicated internal tank design (e.g., obstructions) and conditions (e.g., past leak sites).	***Reliable & Efficient Waste Retrieval Technologies*** • Develop optimization strategies and technologies for waste retrieval that lead to successful processing and tank closure. • Develop a suite of demonstrated cleaning technologies that can be readily deployed throughout the complex to achieve required levels of removal.
Tank Closure • Achieving lower levels of residual radioactivity and improving immobilization of residual materials might be possible if there were more cost-effective and efficient closure methods for some tanks. • Final closure of some waste management areas, including closure of ancillary equipment such as underground transfer lines and valve boxes, would be facilitated by improved closure methods that would make the process more cost-effective and efficient.	***Enhanced Tank Closure Processes*** • Improve methods for characterization and stabilization of residual materials. • Develop cost-effective and improved materials (i.e., grouts) and technologies to efficiently close complicated ancillary systems. • Perform integrated cleaning, closure, and capping demonstrations.
Waste Pretreatment • Achieving effective separation of low- and high-level wastes (HLW) prior to stabilization requires improved, engineered waste processes and a more thorough understanding of chemical behavior.	***Next-Generation Pretreatment Solutions*** • Develop in- or at-tank separations solutions for varying tank compositions and configurations. • Improve methods for separation to minimize the amount of waste processed as HLW.
Stabilization • Waste loading (i.e., the amount of waste concentrated in waste containers) constraints limit the rate that HLW can be vitrified and the tanks can be closed. • Current vitrification techniques may require supplemental pretreatment to meet facility constraints.	***Enhanced Stabilization Technologies*** • Develop next-generation stabilization technologies to facilitate improved operations and cost. • Develop advanced glass formulations that simultaneously maximize loading and throughput. • Develop supplemental treatment technologies.

Table 2. Groundwater and Soil Remediation Technical Risks and Strategic Initiatives

Technical Risk and Uncertainty	Strategic Initiatives
Sampling and Characterization • Current sampling techniques and characterization technologies result in costly, time-consuming characterization programs, may leave large gaps in plume delineation, and may lead to uncertainty in the selection of cleanup strategies. • Incomplete understanding of contaminant subsurface behavior results in long-term uncertainty regarding risks to human health and the environment.	***Improved Sampling and Characterization Strategies*** • Develop advanced sampling and characterization technologies and strategies for multiple contaminants (organics, metals and radionuclides) in challenging environments (e.g., around subsurface interferences, at intermediate and great depths, and in low and high permeability zones). • Use basic and applied research to gain a better understanding of contaminant behavior in the subsurface and to provide defensible prediction of risk.
Modeling to Guide Cleanup • Existing models provided limited capability to represent complex hydrogeology, biogeochemistry, chemical reactions, and transport. Improved models are needed to reduce risk and uncertainty in predicting contaminant fate and transport and to provide an improved technical basis for optimizing the selection, design and implementation of remedies.	***Advanced Predictive Capabilities*** • Develop advanced models that incorporate chemical reactions, complex geologic features, and/or multiphase transport for multiple contaminants (organics, metals and radionuclides) in challenging environments to provide an improved technical basis for selecting and implementing remedies. • Determine mechanisms and rates of release of contaminants from low porosity/permeability zones. • Develop models that integrate data from various monitoring forms to design long-term effective monitoring systems.
Treatment and Remediation • In-situ treatment and stabilization technologies provide cost, human health and ecological benefits, but require additional development and demonstration to realize their full potential and to be accepted by the regulatory community. • Ex-situ technologies may be necessary to remove, treat, isolate and dispose of contaminants in certain situations, but current ex-situ treatment technologies may result in high cleanup costs and unacceptable risks to workers.	***Enhanced Remediation Methods*** • Develop, demonstrate and implement advanced in-situ and ex-situ methods which reduce costs, increase effectiveness and reduce risks to human health and the environment. • Improve understanding of in-situ degradation of chlorinated organics and immobilization of radionuclides and metals to facilitate development and use of advanced, cost-effective in-situ technologies and use of natural processes. • Provide the technical basis for use of monitored natural attenuation (MNA) of organics, radionuclides, and metals in the subsurface, including use of MNA in conjunction with other methods (e.g., barrier technology). • Develop safe, cost-effective strategies to treat and remediate legacy materials in historical waste sites, as appropriate.

Table 3. D&D and Facility Engineering Technical Risks and Strategic Initiatives

<table>
<tr><th>Technical Risk and Uncertainty</th><th>Strategic Initiatives</th></tr>
<tr><td>Characterization
• Limited techniques for detection, quantification and localization of penetrating radiation, radioactive contamination (e.g., Pu, U, tritium), chemicals (asbestos, beryllium, metals, organics, caustic and acidic solutions, and lead paint), and biological contaminants (mold, dead birds and rodents, and animal feces) increase the risk of personnel exposure to hazardous conditions.</td><td rowspan="3">Adapted Technologies for Site-Specific and Complex-Wide D&D Applications
• Develop and deploy improved characterization and monitoring technologies for detecting and quantifying penetrating radiation, radioactive, and biological contaminants.
• Develop and deploy improved deactivation, retrieval, size-reduction, and stabilization technologies that provide adequate personal protection and effectively achieve end-state requirements.
• Develop and deploy advanced remote and robotic methods to rapidly access and assay facilities to determine optimal D&D approach.
• Establish the scientific and technical basis for end-state conditions to satisfy federal, state, and local stakeholders.</td></tr>
<tr><td>Deactivation, Decontamination, and Demolition
• Hazardous conditions involving radionuclides, heavy metals, and organic contaminants result in worker safety issues and lead to use of cumbersome personal protective equipment and D&D approaches.
• Inadequate historical knowledge of past operations and contamination (and other hazards) drive conservative and costly D&D approaches.</td></tr>
<tr><td>Closure
• End-state requirements for D&D of process facilities are not adequately defined.</td></tr>
</table>

Table 4. Spent Fuel Technical Risks and Strategic Initiatives

<table>
<tr><th>Technical Risk and Uncertainty</th><th>Strategic Initiatives</th></tr>
<tr><td>Spent Fuel Storage
• Storage of vulnerable SNF types (e.g., aluminum-clad) and conditions (SNF and basins) are subject to continued deterioration, and may impact repository acceptance.</td><td rowspan="3">Improved SNF Storage, Stabilization and Disposal Preparation
• Improve monitoring of fuel condition, cladding integrity, and basin integrity.
• Develop efficient, cost-effective stabilization technologies and processes based on spent fuel types.
• Develop advanced neutron absorber materials for use inside disposal packages to meet long-term criticality control needs.</td></tr>
<tr><td>Spent Fuel Stabilization
• Present facilities and methods are not designed for processing all SNF types.</td></tr>
<tr><td>Disposal Packaging Preparation
• Geologic disposal of SNF requires assurance of criticality control over long timeframes.
• Current plans identify the need for a canister closure weld in a high radiation environment for which commercial systems do not exist.</td></tr>
</table>

Table 5. Challenging Materials Technical Risks and Strategic Initiatives

Technical Risk and Uncertainty	Strategic Initiatives
Storage • Improved inventory analyses, monitoring and storage systems are needed for unique TRU wastes and special nuclear materials.	***Enhanced Storage, Monitoring and Stabilization Systems*** • Develop advanced characterization, monitoring, and inventory analysis methods; and improved storage systems for multiple material forms including contaminants. • Develop advanced processes for stabilization and waste form qualification.
Stabilization and Disposition • Some materials have no defined path for disposal in their current condition.	

Table 6. Integration Technical Risks and Strategic Initiatives

Technical Risk and Uncertainty	Strategic Initiatives
Assessing Long-Term Performance • Inadequate fundamental understanding of wasteform performance and contaminant release, transport, and transformation processes result in inadequate conceptual models potentially leading to selection and design of non-optimal remedial actions. • Inadequate long-term monitoring and maintenance strategies and technologies to verify cleanup performance could potentially invalidate the selected remedy and escalate cleanup costs.	***Enhanced Long-Term Performance Evaluation and Monitoring*** • Develop increased understanding of long-term wasteform performance integrated with transport of contaminants to support broad remedial action decisions and cost-effective design and operation strategies. • Develop and deploy cost-effective long-term strategies and technologies to monitor closure sites (including soil, groundwater, and surface water) with multiple contaminants (organics, metals and radionuclides) to verify integrated long-term cleanup performance.
Transportation and Disposal Packaging • Disposal and transportation restrictions include flammable gas limitations, material characteristics and configuration. Existing data is insufficient to quantify the effects of potential sources of hydrogen, deflagration events, degraded fuel, impurities, and other conditions for challenging materials.	***Improved Packaging of SNF, TRU Waste and Nuclear Materials*** • Develop improved packaging and conduct tests and/or analyses to meet regulatory requirements. • Improve inventory and characterization data.

In conclusion, the Engineering and Technology Roadmap presents an integrated approach to reducing the technical risks and uncertainties facing the EM program in a manner consistent with its disciplined approach to project management. The risks include challenges in waste processing, groundwater and soil remediation, deactivation and decommissioning, spent nuclear fuel, challenging materials, and integration. The EM Engineering & Technology Program will address these risks, and will use applied research and engineering to improve technologies and processes at sites across the country.