Departmental Response: SEAB Task Force Recommendations on Technology Development for Environmental Management

Introduction

In May 2014, Energy Secretary Ernest Moniz charged the Secretary of Energy Advisory Board (SEAB) to provide advice as to how the United States (U.S.) Department of Energy (DOE) could more effectively ensure the development of technology necessary for the Office of Environmental Management (EM) to complete its mission, cleanup of legacy waste sites. The SEAB formed a Task Force on Technology Development for Environmental Management (Task Force) to examine and report on:

(1) Opportunities and barriers for science and technology development for cleanup;

(2) Means to implement a program to develop such technologies; and

(3) Funding of the program.

In its December 2014 report, the Task Force noted that successful completion of the cleanup of the EM sites will likely require advances in science and technology and that these advances can provide the means for completing the EM mission more swiftly, more inexpensively, more safely, and more effectively. As the Task Force noted, technology offers that opportunity.

The Task Force further noted that new technology for the EM mission is not just an *opportunity*, but, in reality, a *necessity*—observing that, "new technology is necessary because there are significant challenges associated with the cleanup work ahead."

The conclusion of the Task Force was that the EM mission will have difficulty meeting its commitments unless new approaches to technology management are pursued. As a result, the Task Force called on DOE to take immediate and specific actions to address the many inherent technical risks and to execute the EM mission in a safe and efficient manner without further delay and added costs.

This report outlines the recommendations of the SEAB Task Force, provides DOE's assessment of those recommendations, and summarizes actions being undertaken by DOE. This report also describes the management framework for integrating technology into the EM program as a business norm and as a mission imperative.

Background

The Task Force came to its recommendations within the context of the breadth and scope of the EM mission: to complete the safe cleanup of the environmental legacy brought about from five decades of nuclear weapons development and government-sponsored nuclear energy research.

In 1984, a federal district court ruled that the Resource Conservation and Recovery Act of 1976 applied to nonradioactive hazardous waste at one of DOE's facilities. Following the court's 1984 ruling, DOE also began coming into full compliance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (as amended) and other environmental regulations. At the end of the Cold War in 1989, DOE began the mission of cleanup and restoration of sites contaminated by the nuclear weapons complex by establishing the Office of Environmental Restoration and Waste Management, which is now the Office of Environmental Management. Also in 1989, the Hanford Site, the Savannah River Site, the Oak Ridge Reservation, and other DOE facilities were included on the National Priority List and entered into cleanup agreements with their respective States and the U.S. Environmental Protection Agency (EPA). As DOE began to assess the magnitude of the cleanup mission over the next few years, the scope grew to span over 7,000 contaminated sites among 15 major facilities and over 100 other smaller facilities across the nation.

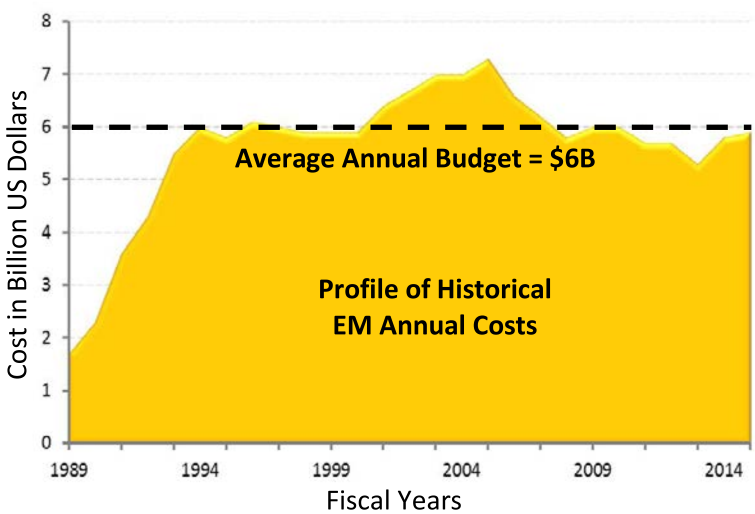

Figure 1. Total Historical EM Cost

Today, over $152 billion has been spent, and cleanup at 91 of 107 major sites has been completed. The average annual budget from fiscal year 1989 to 2015 is $6 billion, as shown in Figure 1. Over those last 25 years, technological solutions were critical to that success. In fact, EM's first major investment area was in site characterization, because very little information was available on chemical and radioactive contaminants' fate in the natural environment, and even less was known on the associated human health and ecological effects. EM was uniquely challenged, as few technologies existed for the cleanup of sites that were contaminated with materials and wastes having any combination of chemically reactive, toxic, and radioactive constituents. In many cases, no technological solution existed. As DOE began to address the Cold War legacy, technology development, demonstration, and deployment quickly became a cleanup imperative; it became a core competency and core capability for EM.

In the current era of the EM mission, the focus has shifted to the disposition of radioactive liquid tank waste, including over 90 million gallons of high-level waste. Despite this focus change, EM will continue to clean up impacted natural soil and water resources and treat and dispose of radioactive solid waste. EM will continue to disposition special nuclear materials and safely store spent nuclear fuel. EM will also continue to safely operate and maintain its operating facilities and associated infrastructure.

In the upcoming decade, many of EM's installed remedial systems will be approaching the end of their original design life (such as 30-year engineered caps and covers installed over shallow land burial sites and waste units having residual contamination). EM will be required to assess the effectiveness and long-term protectiveness of those remedial systems; studies and technology demonstrations will likely be needed to accomplish those evaluations.

Technologies will be needed to assess the integrity of EM's aging nuclear facilities and to ensure their continued operability and safety. Several key nuclear facilities are operating beyond their original design life. EM continues to safely operate them to accomplish mission objectives. However, maintenance costs are increasing due, in large part, to facility aging. Original components are getting increasingly difficult to repair and replace due to the limited availability of parts. EM is now forced to make incremental upgrades.

The last few decades of the EM mission will involve the deactivation and decommissioning (D&D) of over 2,400 nuclear and nonnuclear facilities, thousands of miles of piping, and the disposal of large amounts of radioactive waste and demolition debris. This remaining scope is the second largest of the EM program. Because of EM's expertise in D&D, many excess and surplus facilities currently in other DOE program offices may be ultimately transferred to EM. This potentially huge pipeline of facilities is not captured in EM's lifecycle baseline.

The current EM lifecycle baseline reveals a cost estimate of about $235 billion to complete the *remaining* work by 2065. Without investment in technology development, the cost profile as represented in Figure 2 will have to be increased and extended. There is about $28 billion of scheduled work that exceeds the historical average annual budget of $6 billion.

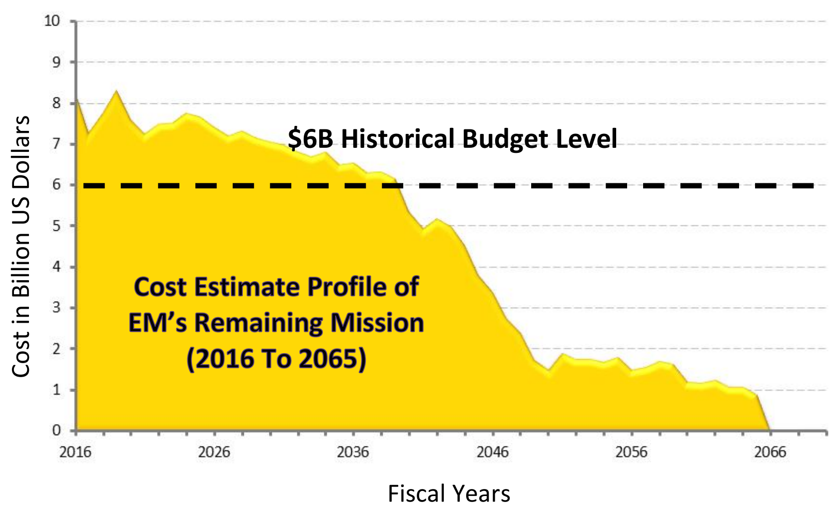

Figure 2. Profile of the Cost Estimate for Remaining EM Mission (2016 to 2065)

The remaining work to complete EM's mission, examples of which are shown in Figures 3 through 8, represents some of the most complex and technically challenging cleanup efforts in the world. For EM's continued success, technology must remain an imperative. EM must exploit all opportunities, including collaboration with other technologists. With technological advancements being made in many non-DOE industry sectors, expertise resides in other federal agencies, small businesses, universities, and other private technology centers.

Figure 3. Safely storing highly radioactive liquid waste in over 200 underground tanks.

Figure 4. Retrieving over 90 million gallons of chemically reactive radioactive liquid waste.

Figure 5. Solidifying radioactive, chemically hazardous waste for long-term disposal.

Figure 6. Remediating 93 square miles of contaminated groundwater.

Figure 7. Decommissioning thousands of facilities and structures.

Figure 8. Maintaining a stable and skilled workforce over the next few generations.

Opportunities and Barriers

Task Force Recommendations and Considerations

Throughout their report, the Task Force describes the more significant barriers currently facing EM technology management and offers opportunities for EM to consider.

Systems Approach. The Task Force recommends that an overall systems approach be taken to fully integrate new technologies and solutions into EM's mission activities. The "aim should be to develop approaches that optimize the entire system, not just one stage of the cleanup," and technology investments should account for lifecycle impacts and benefits. For game-changing technologies, the Task Force states that "it is important to pursue technologies that do not threaten to create risk for the baseline technologies that are applied at the sites, but rather that promise less risk in their application."

Regulatory Framework. The Task Force recognizes that in order for the infusion of "new technologies to be effective, it must fit into a policy and regulatory regime." Potential constraints and impediments must be identified early and addressed, especially as the regulatory agreements differ among the various States. The Task Force notes, for example, that "in order to facilitate the application of technology, it may be necessary to obtain changes in regulatory requirements."

Engagement with Academia. To support the development of new technologies, the Task Force further recommends that DOE create an EM university program to engage faculty, postdocs, and graduate students in the pursuit of the EM mission in order to provide a pipeline of new ideas, to access advances in engineering and science, and to provide a cadre of educated personnel for participation in the EM program in the decades ahead. The Task Force suggests EM benchmark and leverage DOE's own Nuclear Energy University Program.

The Task Force suggests that EM "consider other efforts to build the skilled workforce it will need on into the future…" and that EM "engage undergraduates in EM projects over the summer (with an eye to possible future employment), pursue workshops involving academia and industry concerning EM challenges and solutions, and promote programs to encourage current employees to pursue advanced degrees."

Engagement with Other Technologists. The Task Force recommends that for incremental technologies (presented in the next section), "because some of the cleanup challenges confronting DOE are not unique, EM should seek to engage with other agencies, such as [the Department of Defense] DoD and [the National Aeronautics and Space Administration] NASA, in the pursuit of technology. There are also opportunities to harvest advances made elsewhere in DOE that would facilitate the EM mission. For example, work at the [Office of Fossil Energy] National

Energy Technology Laboratory on corrosion may bear directly on EM's work." Similarly for high-impact technologies (presented in the next section), EM "should include the DOE national laboratories (who have been significant advocates of this approach), other federal laboratories (e.g., [Naval Research Laboratory] NRL, [National Institute of Standards and Technology] NIST), the universities, and contractors. In fact, the efforts might appropriately involve partnerships among these groups."

Engagement with Key Stakeholders. The Task Force recommends EM's engagement "extend beyond regulators, program offices, and the existing contractor community and include the relevant stakeholders. The stakeholders include citizen groups and elected officials and other political figures interested in the affected sites." In this context, the Task Force advocates early and frequent communications such that realistic expectations and costs are understood and the benefits of new approaches are fully appreciated.

Contractor Incentives. The Task Force suggests that contractual "incentives be considered in order to encourage the application of new technologies; contractors might be allowed to reap some of the savings and be protected from some of the risks that derive from the implementation of new technology." In short, technology "push" arising from the development of technical advances should be coupled with technology "pull" by those who could beneficially apply the technology.

DOE Assessment and Actions

DOE acknowledges the aforementioned barriers and agrees with the opportunities identified by the Task Force.

Systems Approach. A systems management approach that includes systems thinking, systems engineering, and value management will be applied as technological innovations and advancements are explored and implemented. For example, EM will investigate technologies for the non-elutable sequestration or removal of contaminants (such as technetium-99) from waste materials and waste processing streams to minimize the generation of secondary waste and to avoid the cost and added risk associated with repetitive or additional waste processing.

Regulatory Framework. Regulatory considerations and requirements will continue to be an integral part of EM's decision-making process and execution strategy. This is especially important when significant changes to existing remedial systems or even wholesale replacements are considered to incorporate advancements in the state of the art or more ecologically friendly remedial solutions.

Engagement with Academia. DOE fully recognizes the need to leverage and harness the expertise, resources, and capabilities of universities, colleges, technical institutions, and research centers. DOE envisions academia to serve EM in three distinct capacities: (1) as an expert-based resource for conducting basic and applied scientific research and for providing engineering solutions; (2) as a pool of recognized subject matter experts to support technical peer reviews and independent technical assessments; and (3) to serve as incubators and pipelines for the future workforce.

DOE will continue to support and promote programs that engage the academic community such as the (Office of) Nuclear Energy University Program, the (Office of) Science Graduate Fellowship, and the Computational Science Graduate Fellowship. EM is actively benchmarking the DoD University Affiliated Research Centers Program. EM is seeking to establish formal collaborations with the University Affiliated Research Centers that support the Navy Department because of the common and cross-cutting nature of technology areas, including similar opportunities for technology and knowledge sharing.

EM will continue to support minority-serving institution programs and the DOE Fellows Program that have successfully provided students with unique opportunities to integrate classroom course work, applied research, and actual EM field work.

Engagement with Other Technologists.

Leveraging the Federal Investment. According to the Congressional Budget Office in its December 2013 report on federal investment, spending in the three investment categories— (1) physical capital, (2) research and development, and (3) education and training— totaled $531 billion in fiscal year (FY) 2012. Research and development accounted for one-quarter of that investment, or $139 billion, as shown in Figure 9. Considering that large investment of American taxpayer dollars in scientific and technological advancements, DOE will overtly seek collaborations with other federal agencies to support the EM mission. These agencies include, but are not limited to: the Office of Science and Technology Policy (OSTP) within the Executive Office of the President; the National Science Foundation (NSF); the Research Directorate within Office of the Assistant Secretary of Defense for Research & Engineering; the Defense Advanced Research Projects Agency; the Office of Naval Research; and the U.S. Army Engineer Research and Development Center.

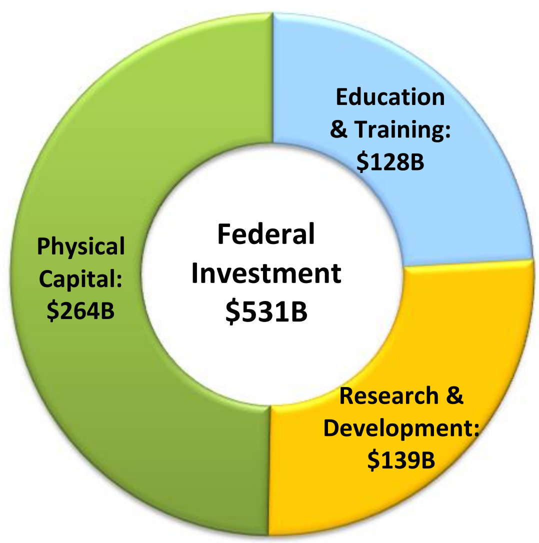

Figure 9. 2012 US Federal Investments

DOE will also capitalize on inter-agency collaborations such as the Federal Remediation Technologies Roundtable, which was established in 1990 to bring together top federal cleanup program managers and other remediation community representatives. Other member agencies in the Federal Remediation Technologies Roundtable are DoD, EPA, NASA, and Department of the Interior. Interagency collaborations provide opportunities to:

- Share information and learn about technology-related efforts of mutual interest;
- Discuss future directions of the national site remediation programs and their impact on the technology market;
- Interact with similar state and private industry technology development programs; and
- Form partnerships to pursue subjects of mutual interest.

Similarly, DOE will participate in federal science and technology initiatives such as the National Robotics Initiative, which is part of the President Obama's 2011 Advanced Manufacturing Partnership that was created to develop the next generation of robotics, to advance the capability and usability of such systems and artifacts, and to encourage existing and new communities to focus on innovative application areas. Current sponsoring agencies in the National Robotics Initiative include NSF, NASA, U.S. Department of Agriculture, and National Institutes of Health.

Other key science- and technology-driven programs that provide federal expertise and capabilities include the DoD Strategic Environmental Research and Development Program and the Environmental Security Technology Certification Program.

International Collaboration and Cooperation. A Statement of Intent between EM and the Nuclear Decommissioning Authority and the United Kingdom of Great Britain and Northern Ireland is a formal international agreement that has been in place since 2007. It facilitates the exchange of information and technology in various areas related to nuclear materials, waste, and fuel management. NE and the United Kingdom's National Nuclear Laboratory became signatories in 2013 and 2014, respectively. EM intends to continue this international collaboration, and collaborate with other countries (e.g., Canada, Argentine Republic, Ukraine, and Japan) with mutual interests. EM will also place special emphasis on continued collaboration with Japan and France because of their experience in environmental cleanup.

EM will continue to support International Atomic Energy Agency (IAEA) activities involving cross-cutting nuclear technologies such as nuclear facility decommissioning. Active participation on the International Decommissioning Network, which facilitates the sharing of practical decommissioning experience within the worldwide nuclear industry, provides the opportunity for knowledge growth and technology expansion. Similarly, participation on the IAEA's Joint Convention on the Safety of Spent Fuel Management and Safety of Radioactive Waste Management, provides insights on smarter and safer management of nuclear assets, radioactive materials, and radioactive waste.

Engagement with Key Stakeholders. Stakeholder involvement and public participation as mandated by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (as amended), the Resource Conservation and Recovery Act of 1976, and the National Environmental Policy Act of 1969 (as amended) are key features of EM's decision-making process and will continue as new technologies and approaches are evaluated and implemented. Community outreach and other public participation activities will continue, such as: (1) environmental justice as directed by Presidential Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations"; (2) engagement with the EM Site-Specific Advisory Board and compliance the Federal Advisory Committee Act (FACA) of 1972; and (3) non–Federal Advisory Committee Act advocacy groups.

Contractor Incentives. As part of performance measurement baselines, which are detailed plans against which work is budgeted, managed, and executed, contractors perform assessments to qualitatively and quantitatively evaluate potential risks to meeting their contract (and project) deliverables. Although developing technology is one of the factors considered, it is often analyzed as an adverse impact because, in this context, "technology" implies "low maturity," which in turn translates to "high risk." New technologies are not often pursued because they are unproven, have little or no performance history, and require extensive proof-of-principle testing. Once new technologies are labeled as "high risk," there is little analysis on the opportunities (positive impacts) afforded by the development and implementation of technological advancements.

When baselines are established, focus is placed on the delivery of the technical scope on time and within cost. There is little to no incentive for contractors to deviate from executing against the baseline. Moreover, contractors are driven to deliver on their statement of work during their prescribed period of performance, which is typically five years. This short-term, scope-focused structure does not encourage technological innovation. Contractor performance is likely to be unfavorably rated if a technology is not successfully demonstrated or deployed.

DOE will identify strategies that promote and enable contractors to exploit new and emerging technologies, especially those that have the potential to be high mission impact. Incorporating performance incentives and flexibility for technological innovation in contracts will be explored. Sharing the financial benefits of incorporating innovations and implementing smarter solutions has already proven to be effective at motivating contractor performance, in particular for EM's closure of Rocky Flats Environmental Technology Site (formerly, Rocky Flats Plant) in 2005 and Fernald Feed Materials Production Center (commonly referred to simply as Fernald) in 2006.

Refer to Table 1 (beginning on page 19) for additional information and a crosswalk of the Task Force's recommendations and DOE responses.

Implementation Strategies

One of the more significant recommendation made by the Task Force is on the overall structure for which EM's technology portfolio should be organized.

Technology Portfolio. The Task Force recommends that the DOE implement "…a comprehensive program that includes incremental technology development, the pursuit of game-changing technology, and advancement of the scientific foundations for the EM work." In this construct, EM would have a technology portfolio including:

- A focus area on **incremental technologies** that strive to improve the efficiency and effectiveness of existing cleanup processes;
- A second focus area on **high-impact technologies** that are outside the day-to-day program, that target big challenges, and that hold the promise of breakthrough improvements; and,
- A third focus area on **fundamental research** that provides knowledge and capabilities that bear on the EM challenges.

DOE Assessment

DOE concurs with the recommended structure of EM's technology portfolio. DOE believes that it provides a foundation upon which EM's management scheme can feature a technology portfolio that addresses the technical complexities associated with EM's mission. This structure is consistent with that of other federal agencies whose research and development investment portfolio, as reported by CBO in its December 2013 federal investment report, includes:

- Basic research, which seeks to expand knowledge without regard to commercial application (i.e., **fundamental research**);
- Applied research, which attempts to link that understanding to some practical purpose (i.e., **incremental technologies**); and
- The development of new products and services (i.e., **high impact technologies**).

A critical first-step in re-aligning EM's technology portfolio is to define the scope and magnitude of EM's problem set so that opportunities for innovation can be identified and pursued. EM's technology portfolio will be shaped by its multi-faceted mission and the various technology needs and opportunities. The timing of the needs and opportunities will be influenced by the duration of EM's remaining mission, which is at least 50 more years and extends over two more workforce generations. Within this span, EM's mission focus and priorities will shift thus creating time horizons. As a result, EM's "living" technology portfolio demands diligence in keeping pace with the state-of-the-art.

DOE also believes that a fourth component of EM's technology portfolio that focuses on rapid response to unforeseen urgent operational events and emergencies when gaps in technologies and solutions are identified. Establishing this capability would facilitate the quick infusion of technologies to improve responses to unexpected events and improve recovery efforts.

EM's portfolio will encompass the entire technology life cycle (Figure 10) that includes:

- Research and development, which is focused on undiscovered, unrealized, or otherwise unproven innovation;
- Demonstration, which is proving a concept in an effort to identify potential applications, feasibility, performance for a new technology;
- Deployment, which is the initial field application of newly developed or matured technologies;
- Transfer, which is the exchange of mature technologies for widespread utilization by a broader pool of end-users;

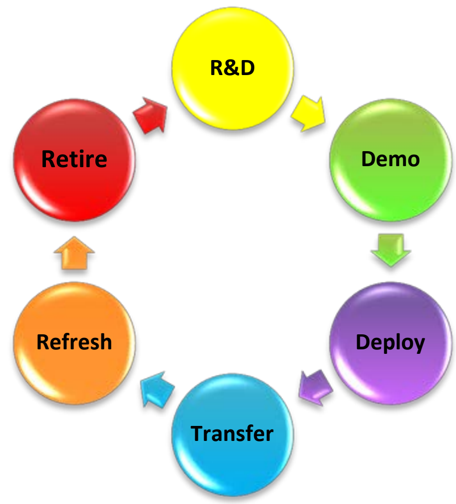

Figure 10. EM Technology Lifecycle

- Refreshment, which is the periodic upgrade or like replacement of existing technologies; and
- Retirement, which is the end-of-life for a particular technology that has become obsolete or is no longer needed.

DOE Actions in Incremental Technologies

DOE is now incorporating this portfolio structure into EM's technology management program. While initial steps have been taken to implement portions of the recommendations, the challenge remains to organize, connect, and fully fund the elements in a way that establishes an enduring flow of technical development and maturation as well as synergy across the overall program.

To ensure EM's continued success, it is necessary that a comprehensive reexamination of EM's approach to technology management be conducted, seeking out innovative opportunities. These opportunities include, but are not limited to, the following:

- Adapting technologies from other industries;

- Collaborating with other research institutions internal and external to DOE, foreign and domestic on research and technology development, demonstration and deployment; and

- Teaming with regulators and stakeholders.

For FY2015, some of the incremental technologies (currently structured as the EM Technology Development & Deployment program) that will be pursued are summarized below. These are primarily focused on addressing operational issues and improving existing processes and systems; FY2015 funding is approximately $12 million.

- **Technetium challenges**. This technology area is focused on identifying and developing strategies and technologies for the management, mitigation, and treatment of technetium that are problematic at the Hanford Site, the Savannah River Site, and the Oak Ridge Reservation.

- **Small business outreach**. This initiative involves targeted investments for promoting small business innovations through the use of EM facilities as "radioactive test beds" for technology demonstration and maturation. These test beds are somewhat analogous to Office of Science's "user facilities," which are federally sponsored research facilities that are made available for external use to advance scientific or technical knowledge. This initiative will, in part, be linked to DOE's Small Business Innovation Research and Small Business Technology Transfer programs. In FY2015, DOE plans to screen current awards for cross-cutting technologies and will develop EM-specific Technology Transfer Opportunity statements in support of the FY2016 Funding Opportunity Announcements.

- **Conceptual design of a universal waste disposal canister**. This initiative will begin in FY2015 and is integrated with Office of Nuclear Energy's Subsurface Technology and Engineering Research Development and Deployment Crosscutting Team.

- **Deployment of Advanced Simulation Capability for Environmental Management (ASCEM)**. This standardized, open-source, modeling platform for subsurface systems will be finalized for deployment in FY2016.

- **International collaboration**. This initiative leverages technologies, knowledge and resources in like mission areas from the United Kingdom of Great Britain and Northern Ireland, Japan, French Republic, and Canada.

DOE Actions in High Impact Technologies

In order to have a meaningful impact on the EM mission, it is necessary to identify the key areas that represent critical leverage points; those areas where investment in a fundamentally new or different approach could result in significant benefit to the EM program; these benefits include, in no particular order of priority:

- Reducing lifecycle costs;
- Accelerating lifecycle schedules;
- Mitigating mission uncertainties, vulnerabilities, and risks;
- Improving worker health and safety;
- Enhancing the protection of public health and safety and of the environment;
- Minimizing the generation of waste, including process-developed waste streams;
- Optimizing operational efficiency and performance; and
- Minimizing the cost of long-term, post-closure, and post-completion stewardship.

EM is initiating the key activities listed below:

- Engage the field element (site) offices, DOE national laboratories, site contractors, and regulators to help identify the critical leverage points.
- Engage nontraditional suppliers, new industries, and commercial experience to work through these leverage points and identify and prioritize the key opportunities.
- Assess potential returns and develop investment targets.

DOE Actions in Fundamental Research

Basic Research. A critical aspect of EM-related fundamental research is the engagement of DOE national laboratories and technology centers. These laboratories and centers, working with the sites and contractors, provide (1) the insights and perspectives that can help to identify the potential application and impact of new discoveries, and (2) the appropriate matrices, platforms, and test beds that provide an opportunity to evaluate these discoveries in the real world and, ultimately, facilitate the demonstration, development, and maturation of these discoveries into deployable technologies. In addition, the Laboratory Directed Research and Development programs at these DOE laboratories and centers can yield new developments that can be brought forward through fundamental research for potential application to EM challenges.

DOE Office of Science and EM are collaborating to establish an approach for conducting fundamental research in support of EM's unique challenges. A workshop, which will be sponsored by the Office of Science's Basic Energy Sciences Program, is being planned for summer 2015 to identify basic research needs for EM. It will focus on approaches to accelerate the rate and efficacy of nuclear waste processing and disposition.

Opportunities for fundamental research will also be pursued with universities, colleges, and other science and technology centers. Recognizing the research and development expertise, capabilities, and resources of other national and corporate laboratories that exist in other technically oriented federal agencies, EM will actively seek opportunities for mutually beneficial collaboration.

STEM Workforce Pipeline. The fundamental research component of EM's portfolio will not be exclusively focused on basic research. It will include initiatives to attract students into the academic disciplines of science, technology, engineering, and mathematics (STEM) with hopes they pursue advanced degrees related to EM's mission and ultimately become part of EM's future workforce. With a mission completion forecasted to be around 2065, EM will need at least two more workforce generations with highly technical knowledge, skills and abilities to complete the work.

EM will leverage DOE's own Minorities in Energy Initiative, which addresses the needs of underrepresented communities in the energy sector and aligns with the President's agenda for engaging more Americans in energy and STEM fields. This Initiative seeks to empower, equip, and prepare businesses, communities, schools, and individuals to partake in the technical, procurement, engagement, workforce, and energy literacy resources of DOE and the energy sector overall. Working with DOE's Office of Economic Impact and Diversity, EM will integrate cleanup-related opportunities.

Refer to Table 1 for additional information and a crosswalk of the Task Force's recommendations and DOE responses.

Funding

The Task Force recommends that "DOE increase its investments in science and technology for the EM cleanup program to about 3% of the annual EM budget." The funding targets for each major recommendation are:

- Incremental technology development at $30 to $50 million per year,
- High impact technology development at $75 to $100 million per year,
- Fundamental research at approximately $25 million per year, and
- EM University collaboration at approximately $10 million per year.

The corresponding total cost of the recommendations is in the range of $140 to $185 million per year. The Task Force believes that the investment in technologies "need not arise from new budget outlays, but should come in large part from the existing EM budget."

DOE Assessment

DOE agrees that EM's investment in science and technology must be increased at levels commensurate with the technical risks and opportunities of the EM mission. The categorization of the EM portfolio into incremental technologies, high impact technologies, and fundamental research offers a structure upon which EM can identify and prioritize technology needs. These investments must be made throughout the remaining lifecycle of EM mission to help ensure safe and successful completion.

DOE recognizes that technology is inherent throughout the lifecycle of EM's mission, and its budget allocations should reflect the importance of technology. During the initial years of the DOE cleanup program (generally, from 1989 to 2002), the focus was on the characterization of impacted soils water and the implementation of remedial response actions to gain control and contain the sources of contamination and contaminant releases. There was limited availability of cleanup technologies and associated tools (many of which were specialized), especially for radioactive contamination. There was also limited treatment, processing, and disposal technologies for the wide variety of nuclear waste, many of which were radioactive and chemically reactive. As such, DOE was driven to invest in technological innovation. Figure 11 shows the percentage of annual EM funding that was specifically allocated for technology development and demonstration; it averaged 5.49% during that period.

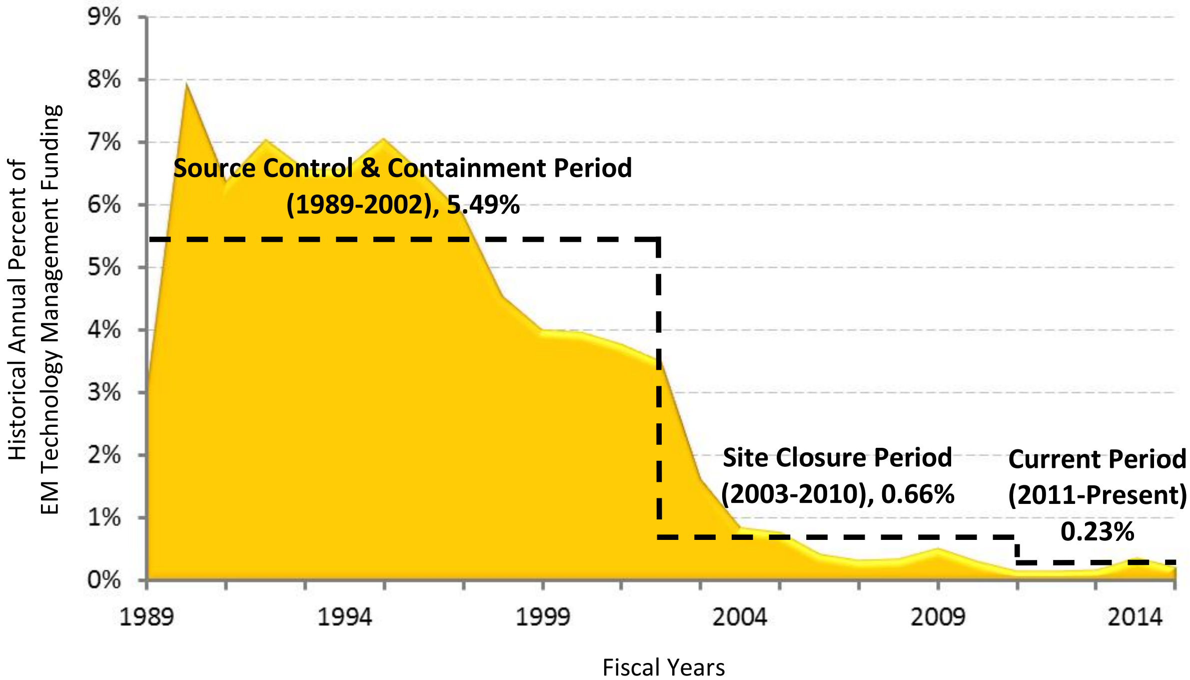

Figure 11. Historical EM Investment in Technology Development and Deployment

When the EM program placed emphasis on site closure (i.e., completing the original EM mission at a particular facility) and on footprint reduction (i.e., tactically completing EM mission activities within a particular facility in order to collapsing the acreage of EM operations) from about 2003 to 2010, the demand for technological innovations was not as great because proven solutions were readily available. During this period, the investment in technology innovation was reduced to an average of 0.66%, as shown in Figure 11. Most of the innovations realized during this period were the direct result of the creativity of cleanup contractors in their efforts to reduce cost and accelerate schedules.

In the current era of EM's mission, emphasis is on the dispositioning the radioactive liquid tank waste and high-level waste (i.e., nuclear waste created by the reprocessing of spent nuclear fuels) and the disposition of EM's problematic waste, including transuranic waste. At the Hanford Site alone, there is an estimated 206,791 cubic meters (about 55 million gallons) of waste in temporary storage among 177 underground tanks. This waste exists in four main waste phases: retained gas, salt cake (Figure 12), sludge (Figure 13), and supernatant (Figure 14). There are 46 radionuclides and 24 chemical constituents present in the Hanford tank waste making it one of the world's most complex waste streams. There is an additional 40 million gallons of high-level waste at the Savannah River Site and another 1 million gallons Idaho National Laboratory.

Figure 12. Saltcake

Figure 13. Sludge

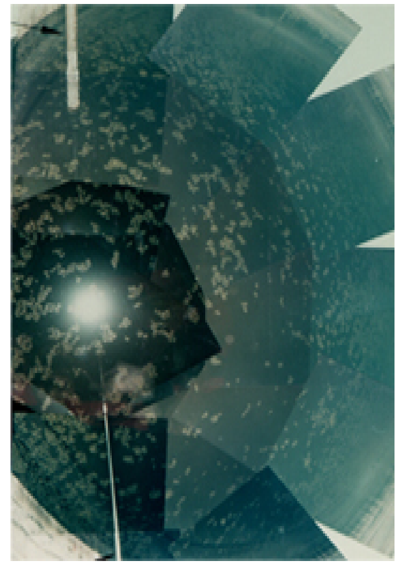

Figure 14. Supernatant

In FY2015, over one-third (35%) of the EM budget is for radioactive tank waste stabilization and disposition, which reflects EM's current highest priority mission area. Figure 15 is a breakdown of EM's FY2015 enacted budget. Technology development and deployment is funded at $13.8 million as part of Program Management, which accounts for 0.24% of the total EM budget.

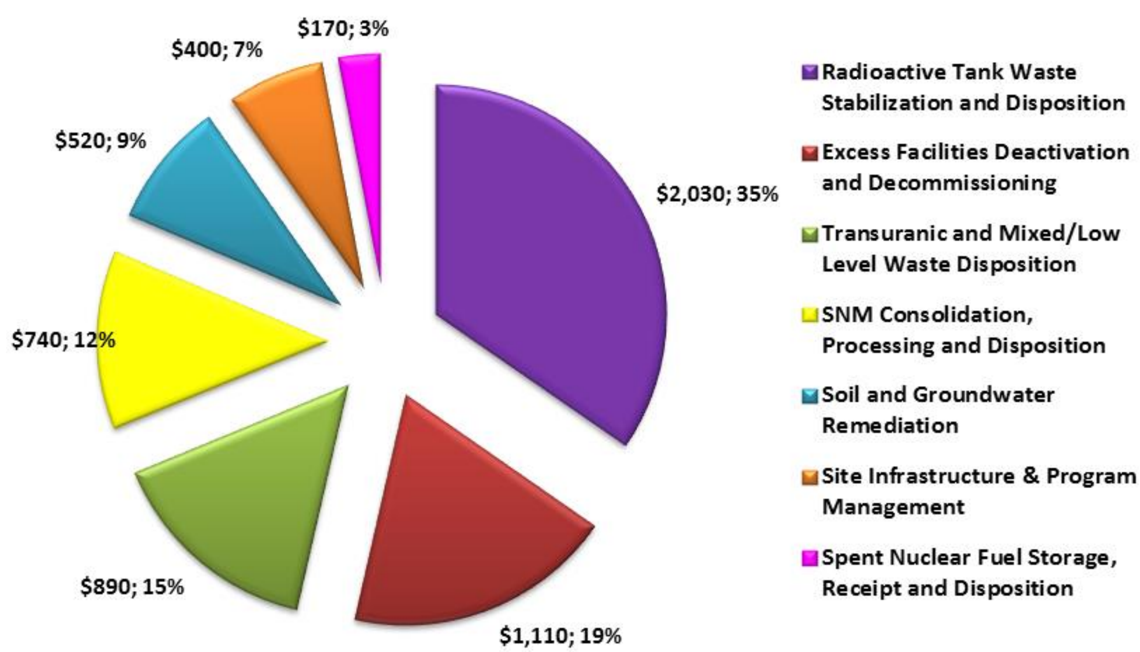

Figure 15. Distribution of FY2015 Budget ($5,681 Million) among EM Mission Areas

This level of funding for technology is not commensurate with the technical and regulatory uncertainties and risks associated with the work EM has to accomplish in the next several decades, particularly in the tank waste area. In addition, there are inherent risks associated with EM's aging infrastructure that need to be addressed beyond operational maintenance

Allocating 3% of EM's annual budget to technologies, as suggested by the Task Force, is appropriate and needed. Considering EM's average annual budget of $6 billion, the corresponding budget for technology management at 3% would be $180 million.

DOE Actions

The scope of EM's technology portfolio will be based on its mission gaps and the timing for when those gaps will need to be filled by technological innovations and solutions. Beginning in FY2016 and more earnestly in FY2017, DOE will gradually ramp-up (increase) its budget and funding for EM technology management activities. This ramp-up will be commensurate with mission need.

Refer to Table 1 for additional information and a crosswalk of the Task Force's recommendations and DOE responses.

Table 1. Crosswalk of Task Force Recommendations and DOE Responses

SEAB Recommendations	DOE Responses
General Recommendations	
DOE increase its investments in science and technology for the EM cleanup program to about 3% of the annual EM budget. The total cost range of the recommendations is $140–185 million per year.	DOE concurs. EM's investment in science and technology must be increased substantially especially considering the lifecycle cost estimate of over $235 billion in the next 50 years to accomplish the remaining mission scope, much of which is high risk. Considering EM's average annual budget of $6 billion, the corresponding budget for technology management at 3% would be $180 million. Beginning in FY2016 and more earnestly in FY2017, DOE will gradually ramp-up (increase) its budget and funding for EM technology management activities. This ramp-up will be commensurate with mission need.
EM investments should be focused on three strategic program elements: 1. An incremental technology development program focused on improving the efficiency and effectiveness of existing cleanup processes that is managed as a separate program element within EM and a dedicated budget; 2. A high-impact technology development program that pursues technologies that are outside the day-to-day program, target big challenges, and hold the promise of breakthrough improvements; and 3. A fundamental research program focused on developing new knowledge and capabilities that bear on the EM challenges with consideration for management by the DOE Office of Science in close coordination with EM.	DOE agrees that the strategic construct of a technology development program that is needed to address the many technical complexities associated with EM's mission must account for the current state of the art, the nature of EM's unique problem set, the relative timing on when solutions are needed, and the regulatory setting within which EM work is conducted. As such, EM's technology development program and its solution set must be tailored. There is a fourth program element that will be considered as the technology development program for EM is restructured. It is to establish the programmatic capability to respond to facility emergencies and unforeseen urgent operational events when gaps in technologies are identified. EM will examine opportunities to implement this type of element. DOE will incorporate features of all the suggested elements in EM's overall technology development program.
DOE create an EM university program to engage faculty, postdocs, and graduate students in the pursuit of the EM mission in order to provide a pipeline of new ideas, to access advances in engineering and science, and to provide a cadre of educated personnel for participation in the EM program in the decades ahead. This	DOE agrees that EM should establish a program that leverages and harnesses the expertise, resources, capabilities, and future universities, colleges, technical institutions, and research centers. The Nuclear Energy University Program has certainly been successful over the last several years, and EM will consider it as a benchmark. DOE envisions academia to serve EM in three distinct capacities: (1) as an expert-based resource for conducting basic and applied scientific research and for providing engineering solutions; (2) as a

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program should be modeled on the DOE Office of Nuclear Energy University Program and budgeted at approximately $10 million per year.	pool of recognized subject matter experts to support technical peer reviews and independent technical assessments; and (3) to serve as incubators and pipelines for the future workforce.-
DOE engage all stakeholders—program offices, contractors, universities, national laboratories, regulators, concerned citizens, and political figures—in the consideration of new technologies in order to build a foundation for the acceptance of new approaches. There needs to be a common appreciation that new ways of doing business are necessary to catalyze success.	DOE acknowledges that proactive and forward-leaning outreach is needed to bolster efforts to revive and sustain the EM technology development program. DOE recognizes that these are untapped expertise and resources in various industry sectors well beyond DOE's current pool of contractors and national laboratories that could provide technological solutions, some of which are already commercially available and require minimal adaptation to EM's nuclear cleanup mission. DOE also recognizes that innovation is often born from technologist working in garages and basements of their own homes, in small businesses, and in start-up companies. DOE fully appreciates the importance of stakeholder involvement and public participation, especially in EM's environmental cleanup mission. Stakeholder and public acceptance of new technologies and technological approaches as they are introduced will be as important as when cleanup solutions are proposed.
SEAB Recommendations on Science and Technology Cleanup — Incremental Technologies	
EM should seek to pursue incremental changes in existing processes in order to improve their effectiveness, to speed up the cleanup, and to reduce cost.	DOE agrees that a viable EM technology development program must strive to continually improve the efficiency and effectiveness of its cleanup processes. In addition, EM believes that technology places a critical role in its ability to protect its workers, safely operate its many nuclear facilities and related infrastructure, protect and safeguard its assets, and ensure the safety and health of the public. As outlined in the earlier discussion of the incremental technology program, the FY2015 program has been refocused on key elements that are described in earlier sections of this document.
Because some of the cleanup challenges confronting DOE are not unique, EM should seek to engage with other agencies, such as DoD and NASA, in the pursuit of technology.	DOE agrees. EM is actively collaborating with the Strategic Environmental Research and Development Program, which is the DoD's environmental science and technology program, as well as with other federal agencies with related interests. EM is actively pursuing formal collaboration with Office of Naval Research and Naval Research Laboratory to leverage naval technologies and engineering solutions and capitalize on common research interests. EM is actively pursuing a partnership with the National Science Foundation and the Office of Science and Technology Policy (Executive Office of the President) in the National Robotics Initiative, which is an element of the President's Advanced Manufacturing Partnership launched in June 2011, focused on developing robots

SEAB Recommendations	DOE Responses
	that work with or beside people to extend or augment human capabilities, taking advantage of the different strengths of humans and robots. This could realize tremendous benefit when working in high radiation areas and handling highly radioactive materials.
There are also opportunities to harvest advances made elsewhere in DOE that would facilitate the EM mission.	DOE agrees. EM will look for opportunities to draw on and leverage Laboratory Directed Research and Development discoveries and advancements from the national laboratories. EM will continue to partner with Office of Nuclear Safety within the Office of Environment, Health, Safety and Security and actively participate in the Nuclear Safety Research and Development Program. EM is a contributing program participant in DOE's Subsurface Technology and Engineering Research Development and Deployment Crosscutting Team, which is pursuing next generation advances in subsurface technologies.
SEAB Recommendations on Science and Technology Cleanup — High-Impact Technologies	
There should be a substantial focused effort to pursue technologies that are outside the day-to-day program, that target big challenges, and that hold the promise of breakthrough performance.	DOE agrees that a component of the EM technology development program must actively seek breakthrough solutions, especially for EM's more problematic challenges, that afford the potential for high investment returns and effect meaningful reductions in EM's lifecycle cost and duration. This need will be addressed through the High-Impact Technology program described earlier. As this element will likely require a strategic approach over an extended time horizon, DOE agrees it must be managed separately from daily operations. DOE agrees that high-impact solutions will need to account for the various regulatory frameworks within which our sites operate.
The SEAB believes it is appropriate to pursue a program to pursue high-impact technology with ultimate funding on the order of $75 to 100 million per year if the initial results are promising. The SEAB suggests that the effort start at a smaller level ($10 to 15 million) to build the program and ideally to achieve some early success.	DOE agrees that for breakthrough technologies to be realized, a substantial investment is needed. EM must first identify the potential high-impact technologies and then develop funding requirements accordingly. EM will explore other opportunities to leverage funding from other sources to accomplish these technologies, in part or in whole. As outlined in earlier sections, DOE will be placing emphasis on high-impact technologies.
Participation in the program should be available to all who can contribute, and include the DOE national laboratories (who have been significant advocates of this approach), other federal laboratories (e.g., Naval	DOE will solicit the participation of a broad and diverse group of scientists, researchers, and technologists. A concerted effort will be made to seek involvement from other federal agencies and laboratories in order to leverage investments already made by the American taxpayer.

SEAB Recommendations	DOE Responses
Research Laboratory, National Institute of Standards and Technology), the universities, and contractors.	
There should be a rigorous process to select the projects to pursue, including a careful needs definition, open competition for proposals, and independent peer review.	DOE agrees that a robust technology development program would need to include the features suggested.
It is important to pursue technologies that do not threaten to create risk for the baseline technologies that are applied at the sites, but rather that promise less risk in their application.	DOE fully appreciates the regulatory and public acceptance of remedial technologies that have been fully vetted and are prescribed in regulatory decision documents such as Records of Decisions and hazardous waste operating permits. DOE considers advancements in the state of the art and the emergence of best available technologies during the periodic remedy reviews (typically five years) that are required by the EPA under Comprehensive Environmental Response, Compensation, and Liability Act and the Resource Conservation and Recovery Act. Value engineering studies are conducted to weigh the overall benefit of a new technological approach relative to the baseline remedy.
The SEAB suggests that the effort commence by way of a workshop involving the prospective participants to identify some specific challenges to be targeted.	DOE agrees. EM will host one or more High-Impact Technology workshop(s) to identify opportunities for game-changing innovations. EM technology need and opportunity statements for high-impact technologies will be developed with this information and in turn be used as the basis for research and acquisitions of high-impact technologies. More details on the focus on high-impact technology are provided in earlier sections of this document.
The process should also incorporate rigorous periodic reviews so that continued investment in approaches that do not hold promise is avoided.	DOE expects that rigorous periodic reviews will be performed as a matter of due diligence and due process.
The design of the program should recognize and build-in the reality that the pursuit of concepts developed through the program will have to be passed to the program offices for pilot efforts as well as full-scale demonstration.	DOE agrees for high-impact technologies to be fruitful, a lifecycle approach is needed through to implementation.
The possible homes for the program include EM, Advanced Research Projects Agency-Energy (a free-standing DOE entity), or the Office of Science. In the near term, the decision as to where to start the program should be guided by a judgment of	DOE will carefully assess and determine an organizational and management structure that serves in the best interest of EM as its technology development program is revived.

SEAB Recommendations	DOE Responses
where the program could best be nurtured in its early years in a difficult funding environment.	
The program leadership should include technical experts (i.e., PhDs) in relevant science and engineering fields, experience in the management of technology, and field experience.	DOE agrees that technically competent and qualified leadership throughout the technology development program, federal and contractor alike, is needed.
Game-changing concepts for EM include: - In-situ treatment and stabilization; - New approaches to subsurface assessment and monitoring; and - Reduced complexity in waste treatment and waste form processes.	DOE agrees with the suggested game-changing concepts and will seek to identify other critical leverage points and concepts within the EM mission where drastic mission improvements and advancement could be realized.
SEAB Recommendations on Science and Technology Cleanup — Fundamental Research	
EM should seek to harvest science that bears on its task from the existing programs of the Office of Science.	DOE fully acknowledges the need to invest in research that focuses on fundamental research. Such research will help, for example, gain a better understanding of the rudimentary phenomena that influence the behaviors and interactions of EM's full scope of radio-chemical contaminants in the natural environment. Fundamental research will also help EM better understand the long-term durability and survivability of the various radioactive waste forms. As described elsewhere in this document, EM is in active discussions with the Office of Science on the creation of a fundamental research program that bears on EM mission needs.
Workshops involving potential participants should be held at an early stage to lay the groundwork for an EM-related fundamental research program.	DOE agrees. EM will work with the Office of Science to host a Basic Needs Research workshop to identify areas where fundamental research is needed. EM technology need and opportunity statements for fundamental research will be developed with this information and in turn be used as the basis for research.
The program, like other efforts pursued by the Office of Science, should be subject to stringent independent peer review.	DOE recognizes the value outward solicitations for critical review and feedback from professional cohorts. By its design, a peer review functions as a form of self-regulation within a professional community and helps to provide credibility to the work.

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Suggested potential areas for scientific pursuit include: - Rapid characterization of chemical and radioactive species (in process and in-situ); - Chemical sciences for advanced chemical separations and alternative waste forms; - Fate and transport in geologic media; - Advanced computing and information systems; and - Regulatory-related research.	DOE agrees with the suggested research areas. A workshop with the Office of Science is being planned to develop the focus areas for fundamental research.
SEAB Recommendations on University Engagement	
There also should be a focused effort to involve universities... because the EM program will proceed for decades, and there is a need to maintain a close connection with universities in order to provide a pipeline of fresh ideas, to access advances in engineering and science, and, most importantly, to provide highly educated personnel for participation in the EM program in the decades ahead.	DOE agrees that EM should establish a program that leverages and harnesses the expertise, resources, and capabilities of universities, colleges, technical institutions, and research centers. The basic program elements are in place, and further developments are being evaluated.
The Nuclear Energy University Program provides a good model for executing a university program that is directed at EM needs. - $10 million/year would be an appropriate target funding level. - The program might support individual research projects at $200-300K/year, with forward funding of 3-year awards and an option for an extension of 2 years. - Doctoral and post-doctoral fellowships might appropriately be part of the program.	The Nuclear Energy University Program has realized much success over the last several years, and EM will benchmark this program. EM is also actively benchmarking the DoD University Affiliated Research Centers Program, particularly those University Affiliated Research Centers that support the Navy Department because of mission need similarities and opportunities for technology and knowledge sharing. By statutory definition, a University Affiliated Research Center is an organization that: - Is a research organization within a university or college; - Provides or maintains DoD essential engineering, research, and/or development capabilities defined as core; - Receives sole source (non-competitive) contract funding from DoD under Congressional authority; - On average, it receives in excess of $6M annually from DoD of such sole source funds; and - Maintains a long-term strategic relationship with DoD. The University Affiliated Research Center program appears to afford many of the key features desired for a long-term sustainable partnership with universities.

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EM might consider other efforts to build the skilled workforce it will need on into the future such as: - Engage undergraduates in EM projects over the summer (with an eye to possible future employment) - Pursue workshops involving academia and industry concerning EM challenges and solutions, and - Promote programs to encourage current employees to pursue advanced degrees.	DOE agrees that succession planning and attracting new talent is essential to EM's mission long-term sustainability, particularly as the scope of remaining work spans three work force generations. Through a cooperative agreement with Florida International University as a minority-serving institution, EM established the DOE-Florida International University Science and Technology Workforce Development Program designed to create a pipeline of minority engineers specifically trained and mentored to enter the EM workforce in technical areas of need. Students selected as DOE Fellows perform research at Florida International University and at a DOE site. Upon graduation and completion of this fellowship, the students apply to Federal Internship programs such as Student Career Experience Program or apply for employment with EM contractors. EM has refocused its Minority Serving Institution program to increase the engagement with EM mission needs. EM recently created the EM Traineeship Program supporting postdoctoral appointments at DOE laboratories for practical, hands-on experience supporting a broad range of subsurface remediation projects. EM is also benchmarking the Scholarship for Service Program, which is administered by the Office of Personnel Management and funded through academic scholarship grants awarded by the National Science Foundation.
SEAB Recommendations on Funding	
The cost range of the SEAB's recommendations $140-185M/year with the following breakdown: - Incremental TD: $30-50M/year - High Impact TD: $75-100M/year - Fundamental Research: $25M/year - EM University Program: $10M/year	DOE concurs. EM's investment in science and technology must be increased substantially, especially considering the lifecycle cost estimate of over $235 billion in the next 50 years to accomplish the remaining mission scope, much of which is high risk. EM's annual budget has historically been between $5 and 6 billion. The funding range suggested by the Task Force corresponds to 2.8% to 3.1% of EM's annual budget. In comparison, that percentage is 0.24% for FY2015 ($13.8M out of $5.861B).

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The usage of incentivized contracts—that is, sharing the savings arising from new technology with the contractors—may facilitate the application of new technology in ways that reduce the budget impact. Incentives might be considered in order to encourage the application of new technologies; contractors might be allowed to reap some of the savings and be protected from some of the risks that derive from the implementation of new technology. (From SEAB recommendations on management.)	DOE agrees that performance incentives may motivate contractors to seek technological innovations. Currently, EM contractors are focused on product delivery and facility operations with little or no work statements for research and development. Also, contractors are limited to their period of performance (typically five years) and will only seek innovations that are within their term and realize near-term fee earnings. These considerations challenge EM's long-term research and development needs. Nonetheless, EM will evaluate its contracts, particularly those where high-value technological advancements could be realized, for incentive structures that reward innovation.
SEAB Recommendations on Management	
A systems management approach is needed broadest sense of the term	DOE agrees with the need for a management approach that fully appreciates and emphasizes the interdependency and interrelationship among the various elements of EM's mission, including the infusion of new technologies and solutions. No component of EM's program will be compromised for the gain of another. This includes the unwarranted generation of additional waste, subjecting waste, contamination, and radioactive materials to repetitive handling or additional processing, and increased occupational exposure to ionizing radiation.
In order for technology development to be effective, it must fit into a policy and regulatory regime.	DOE agrees that systems management and systems integration includes considerations for public policy and regulatory mandates. To that end, technology infusion will comport with that framework.
Other relevant stakeholders must be engaged in the technology decision-making at an early stage. The scope of engagement must even extend beyond regulators, program offices, and the contractors. The relevant stakeholders in this context also include citizen groups, and often others, such as governors and other political figures interested in the affected sites. DOE needs to be sophisticated in its communications and completely candid. The technology program should establish realistic expectations and make sure that the stakeholders understand not only the benefits of new approaches, but also the costs.	EM has a very active public participation and stakeholder element to its conduct of business as advocated by the EPA in its guidance for implementing cleanup under the Comprehensive Environmental Response, Compensation, and Liability Act. Requirements in the National Contingency Plan set minimum standards for informing and involving the public in cleanup actions. DOE recognizes, however, that activities above and beyond the National Contingency Plan requirements are often necessary to successfully involve communities. As suggested, EM will engage its stakeholders and the public early and on technologies that affect cleanup decisions and overall program implementation.

SEAB Recommendations	DOE Responses
EM Initiatives and Other Considerations	
Advocating small business innovation and technology transfer	EM will encourage and advocate for small business technologists to apply for DOE's Small Business Innovative Research (SBIR) and Small Business Technology Transfer (SBTT) grants in the Nuclear Security topical area where environmental management and nuclear nonproliferation technologies are captured. SBIR/STTR programs in many federal agencies provide the nation's largest source of early stage, high risk research and development funding for small business. In DOE's SBIR/SBIT Program, EM will identify and prepare Technology Transfer Opportunities and participate in SBIR calls for FY2016 Funding Opportunity Announcements. Another small business advocacy program that EM will benchmark is the DoD's United States Special Operations Command Office of Small Business Programs, which is designated to advocate on behalf of small businesses ensuring equal opportunities to conduct business with the Command. DoD and United States Special Operations Command continually strive to increase the number of contract awards to small businesses, service-disabled veteran-owned small businesses, woman owned small businesses, small disadvantaged businesses, and historically underutilized business zones.
Creating an enabling environment	DOE agrees. To this end, EM is working with the SBIR/STTR program to greatly increase the engagement and involvement of small business innovators in the program and to make available "radioactive test beds" where researchers and technologists will have access to actual radioactive materials, radioactive wastes, and radiation areas to conduct research and demonstrate technologies. EM will target researchers and technologists who have not historically performed work for DOE in an effort to facilitate the transfer of new technologies. The concept of radioactive test beds is somewhat analogous to Office of Science's "user facilities," which are federally sponsored research facilities that are made available for external use to advance scientific or technical knowledge.
International collaboration	EM will evaluate ongoing and potential new programs with international partners for opportunities to explore and evaluate new technologies and approaches to the cleanup mission. EM has an active portfolio of international collaborations and shared research as highlighted below. • Canada – Canada Nuclear Laboratory (formerly Atomic Energy of Canada Limited) o Statement of Intent in the field of radioactive waste management, decommissioning and environmental restoration signed February 2013 • People's Republic of China – State Development Planning

SEAB Recommendations	DOE Responses
	Commission of the People's Republic of China o Agreement on cooperation concerning Peaceful Uses of Nuclear Technologies signed June 1998 • French Republic – National Radioactive Waste Management Agency o Memorandum of Understanding concerning cooperation in the field of radioactive waste management that allows for exchange of information on geological repository issues signed November 2012 • Federal Republic of Germany – Ministry of Economics and Technology o Memorandum of Understanding for cooperation in the field of geologic disposal of radioactive wastes signed September 2011 • Hungary – Public Agency for Radioactive Waste Management o Memorandum of Understanding for Information Exchange Relating to Operation of Modular Vault Systems for Storage of Spent Nuclear Fuel signed December 2009 • Japan – Ministry of Energy, Trade, and Industry, Ministry of Environment o Bilateral Commission for Cooperation on Nuclear nonproliferation, security and civil nuclear power, expanded to include nuclear safety, emergency response and environmental management, as response to the accident at Fukushima Dai-ichi signed April 2012 • Kingdom of Spain – National Company of Radioactive Waste of Spain o Memorandum of Understanding Concerning Cooperation in the Field of Used Nuclear Fuel and Radioactive Waste Management signed March 2014 • United Kingdom of Great Britain and Northern Ireland – Nuclear Decommissioning Authority and National Nuclear Laboratory o Statement of Intent for Exchange of Information Concerning Management of Radioactive Waste renewed February 2012 • United Kingdom of Great Britain and Northern Ireland – Office for Nuclear Regulation o Arrangement for the Exchange of Information and Cooperation in the Area of Nuclear Safety Matters signed March 2014