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Report to the Committee on Science, Space, and Technology, House of Representatives

October 2021

NUCLEAR WASTE CLEANUP

DOE Needs to Better Coordinate and Prioritize Its Research and Development Efforts

Accessible Version

A Century of Non-Partisan Fact-Based Work

GAO-22-104490

GAO Hightlight

Highlights of GAO-22-104490, a report to the Committee on Science, Space, and Technology, House of Representatives

October 2021

NUCLEAR WASTE CLEANUP

DOE Needs to Better Coordinate and Prioritize Its Research and Development Efforts

Why GAO Did This Study

R&D has played an essential role in EM's efforts to clean up massive amounts of contamination from decades of nuclear weapons production and energy research. Such R&D has led to safer, more efficient, and more effective cleanup approaches. Prior studies have found that investments in R&D could reduce the future costs of EM's cleanup efforts, which have increased by nearly $250 billion in the last 10 years. However, funding designated for nuclear cleanup R&D has declined since 2000.

GAO was asked to review EM's R&D efforts. This report examines (1) how EM identifies cleanup-related R&D needs, (2) how and the extent to which EM coordinates R&D across the EM complex, and (3) the extent to which EM prioritizes cleanup-related R&D efforts. GAO reviewed DOE and EM documents and interviewed EM site and headquarters officials and national laboratory representatives. In addition, GAO compared EM's coordination of R&D to leading practices for collaboration and compared EM's efforts to prioritize R&D with GAO's risk-informed decision-making framework.

What GAO Recommends

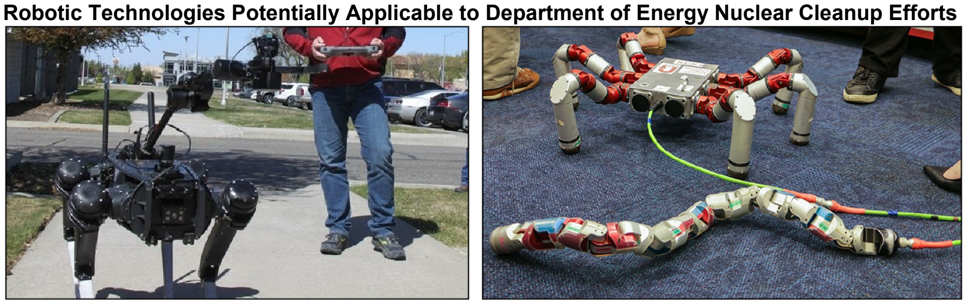
GAO is making four recommendations, including that DOE (1) develop a system to collect R&D information across the complex to enable monitoring and evaluation of outcomes and (2) develop a comprehensive approach to prioritizing R&D across the EM complex that follows a risk-informed decision-making framework. DOE concurred with the recommendations made in this report.

View GAO-22-104490. For more information, contact Nathan Anderson at (202) 512-3841 or andersonn@gao.gov.

What GAO Found

The Department of Energy's (DOE) Office of Environmental Management (EM) identifies cleanup-related research and development (R&D) needs across the EM complex—EM headquarters and sites and DOE's national laboratories—in various ways. For example, DOE officials and contractors at EM sites work closely with national laboratories to identify project-specific R&D needs, including those encountered during the course of cleanup activities, such as managing vapors in nuclear waste storage areas. EM headquarters may identify complex-wide needs (e.g., ways to improve worker safety, such as using robotics, see figure) or work with other DOE offices, including the Office of Nuclear Energy, to identify R&D needs that span DOE missions, such as spent nuclear fuel storage.

Robotic Technologies Potentially Applicable to Department of Energy Nuclear Cleanup Efforts



Source: U.S. Department of Energy (left) and photograph provided courtesy of Carnegie Mellon University (right). | GAO-22-104490

EM uses both formal and informal mechanisms to coordinate R&D across the EM complex, including the national laboratory network and working groups. EM's coordination of R&D efforts fully aligns with four of GAO's seven leading practices for collaboration, such as clarifying roles and responsibilities and including relevant participants. However, EM does not fully follow other leading practices, which affects its ability to evaluate the effectiveness of R&D efforts. For example, EM officials told GAO that it does not have a formal system to collect information on R&D activities across the complex, which would enable it to monitor and evaluate the activities' outcomes. Collecting such information could help EM determine whether to encourage or discourage investments in certain areas.

EM also does not take a comprehensive approach to prioritizing R&D. Individual EM sites and national laboratories have their own decision-making processes for prioritizing R&D, but these may not address long-term or complex-wide needs. GAO has found that risk-informed decision-making can help agencies weigh numerous factors and consider tradeoffs, and that doing so would help EM set cleanup priorities within and across its sites. By developing a comprehensive approach to prioritizing R&D that follows a risk-informed decision-making framework, EM would be better positioned to provide sites with guidance for R&D spending beyond their immediate operational needs and direct its limited R&D resources to its highest priorities.

Contents

Abbreviations

ARPA-E	Advanced Research Projects Agency-Energy
DOE	Department of Energy
EM	Office of Environmental Management
LDRD	Laboratory-Directed Research and Development
LM	Office of Legacy Management
National Academies	National Academies of Sciences, Engineering, and Medicine
NNLEMS	Network of National Laboratories for Environmental Management and Stewardship
R&D	research and development
SEAB	Secretary of Energy Advisory Board
UK	United Kingdom

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October 28, 2021

The Honorable Eddie Bernice Johnson
Chairwoman
The Honorable Frank Lucas
Ranking Member
Committee on Science, Space, and Technology
House of Representatives

Research and development (R&D) has played an essential role in federal efforts to clean up massive amounts of radioactive and hazardous contamination produced by more than 75 years of nuclear weapons production and energy research. Advances in R&D have enabled the Department of Energy's (DOE) Office of Environmental Management (EM) to carry out this cleanup using safer, more efficient, and more effective approaches. For example, EM has used robotics to more safely and efficiently detect radiation in the pipes of buildings on its sites, enabling safer and more effective cleanup of contaminated structures. The proportion of EM's budget designated for R&D has generally declined since 2000.[1] Nevertheless, EM's costs to clean up millions of gallons of radioactive waste, thousands of contaminated facilities, and large quantities of contaminated soil and water continue to grow—more than doubling over the last 10 years to over $400 billion—underscoring the need for continued investment in R&D.

Various studies have identified the importance of R&D for EM's cleanup mission. For example, a 2019 study by the National Academies of Sciences, Engineering, and Medicine (National Academies) found that attention to and investments in R&D could increase the efficiency and

[1]According to EM documents, EM's budget for headquarters-managed R&D decreased from about 5.5 percent of its total budget in the period between 1989 and 2002 to about .4 percent in fiscal year 2021. However, EM's environmental liability—the estimated costs of cleanup—grew from $163 billion in fiscal year 2011 to $406 billion in fiscal year 2020. In 2017, we designated the federal government's environmental liabilities as a high-risk area because of the large and expanding estimated costs of cleaning up areas where federal activities have contaminated the environment. DOE is responsible for the largest share of the federal government's liabilities. GAO, *High-Risk Series: Progress on Many High-Risk Areas, While Substantial Efforts Needed on Others*, GAO-17-317 (Washington, D.C.: Feb. 15, 2017). GAO's high-risk program identifies government operations with greater vulnerabilities to fraud, waste, abuse, and mismanagement or the need for transformation to address economy, efficiency, or effectiveness challenges.

reduce the future costs of EM's cleanup efforts, improve decision-making approaches, reduce risks, and increase stakeholder acceptance of new cleanup approaches.[2] In 2014, the Secretary of Energy Advisory Board (SEAB) stated that "without the development of new technology, it is not clear that the cleanup can be completed satisfactorily or at any reasonable cost."[3] These studies also, respectively, cited challenges in how EM coordinates and prioritizes cleanup-related R&D efforts throughout the EM complex, which comprises EM's 16 active cleanup sites and the national laboratories that conduct cleanup-related R&D.

You asked us to review EM's R&D efforts and opportunities to use new technologies to address risks, reduce costs, and reduce time needed for cleanup. This report examines (1) how EM identifies cleanup-related R&D needs, (2) how and the extent to which EM coordinates R&D across the EM complex, and (3) the extent to which EM prioritizes cleanup-related R&D efforts.

To address all three objectives, we reviewed documents from EM and other relevant DOE offices such as the Office of Science and the Office of Legacy Management. These documents include budget justifications and process and planning documents such as EM's strategic vision documents and *Technology Development Framework*. We also reviewed planning documents and studies from DOE's laboratories. In addition, we reviewed internal and external assessments of EM's technology development efforts, including EM's internal evaluations of site-specific R&D projects and reports from other relevant entities such as the National Academies and the SEAB. We also reviewed prior GAO reports on EM, more generally, that could be relevant to our analysis. We interviewed DOE officials representing EM leadership, EM's Technology Development Office, 12 of the 16 EM sites, and other relevant DOE offices, specifically the Office of Science, Office of Legacy Management, and the Advanced

[2]National Academies of Sciences, Engineering, and Medicine, *Independent Assessment of Science and Technology for the Department of Energy's Defense Environmental Cleanup Program* (Washington, D.C.: The National Academies Press, 2019).

[3]Secretary of Energy Advisory Board, Department of Energy, *Report of the Task Force on Technology Development for Environmental Management* (Washington, D.C.: 2014), accessed August 31, 2020, https://www.energy.gov/sites/prod/files/2015/01/f19/Report%20of%20the%20SEAB%20Task%20Force%20on%20Tech%20Dev%20for%20EM_FINAL.pdf.

Research Projects Agency-Energy (ARPA-E).[4] In addition, we took the following steps:

- To describe how EM identifies clean-up related R&D needs, we reviewed DOE and national laboratory documents and interviewed EM, site, and laboratory officials about how they identify and address R&D needs.
- To examine EM's coordination efforts, we reviewed EM documents and interviewed EM and site officials and laboratory representatives about mechanisms EM uses to coordinate cleanup R&D. We compared EM's coordination activities with leading practices we previously identified for interagency collaboration[5] and *Standards for Internal Control in the Federal Government*.[6]
- To examine the extent to which EM prioritizes cleanup-related R&D, we compared the information from our document reviews and interviews to GAO's risk-informed decision-making framework.[7]

Additional details on our scope and methodology are described in appendix 1.

We conducted this performance audit from September 2020 to October 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

[4]Four of EM's 16 sites—Brookhaven National Laboratory, the Separations Process Research Unit, the Moab Site, and the Energy Technology Engineering Center—decided not to participate, noting that they do not have a role in R&D.

[5]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sept. 27, 2012).

[6]GAO, *Standards for Internal Control in the Federal Government,* GAO-14-704G (Washington, D.C.: Sept. 10, 2014).

[7]GAO, *Environmental Liabilities: DOE Would Benefit from Incorporating Risk-Informed Decision-Making into Its Cleanup Policy,* GAO-19-339 (Washington, D.C.: Sept. 18, 2019).

Background

R&D Overview

EM does not define R&D, but DOE, for purposes of atomic energy development, defines it as "(1) theoretical analysis, exploration, or experimentation; or (2) the extension of investigative findings and theories of a scientific or technical nature into practical application for experimental and demonstration purposes, including the experimental production and testing of models, devices, equipment, materials, and processes." The Office of Management and Budget and other entities[8]—including GAO, SEAB, and the National Academies—typically describe R&D as comprising three categories.[9] Based on our review of reports from these entities, we describe the categories as basic, applied or incremental, and disruptive or high-impact.

- **Basic research**. Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts. Basic research may include activities with broad or general applications in mind, but generally excludes research directed towards a specific application or requirement. For example, research on the atomic- and molecular-scale chemistries of waste processing and ways to immobilize radioactive and hazardous contaminants in engineered and natural systems is considered basic research.
- **Applied research or incremental technology development**. Original investigation undertaken in order to acquire new knowledge and directed primarily toward a specific practical aim or objective. Applied research can include experimental development, including creative and systematic work, that draws on knowledge gained from research and practical experience and that is directed at producing

[8]See, for example, Office of Management and Budget Circular No. A–11 (2020), Section 84.

[9]Various entities may refer to R&D as "science and technology development" or "technology development"; throughout this report, we treat these terms as interchangeable with R&D. In general usage, "basic" and "applied" may be used to describe research undertaken for foundational knowledge and specific applications, respectively. In contrast, "incremental" and "disruptive" may be used to describe technologies or innovations rather than the underlying research itself. For the purposes of this report, we use "research and development" to describe the universe of activities that range from any kind of research to the development and demonstration of technologies.

new products or processes or improving existing products or processes.

- **Disruptive or high-impact technology development**. Includes projects that carry a higher risk of failure but that offer significant rewards in the long term. This entails R&D outside the day-to-day program that targets big challenges and holds the promise of breakthrough improvements.

DOE and EM Structure

A variety of DOE offices and laboratories, and EM sites, have a role in EM's R&D efforts (see fig. 1).

EM Technology Development Office. This office develops, manages, and operates EM's R&D program, which EM aims to manage as a single portfolio. The Technology Development Office is responsible for all EM R&D efforts, including those conducted at EM sites and at the national laboratories. The office reports to EM's Office of Field Operations, which provides leadership and develops mission strategies, policy, and guidance for site operations.

EM Laboratory Policy Office. This office oversees Savannah River National Laboratory and coordinates with the Network of National Laboratories for Environmental Management and Stewardship (NNLEMS). NNLEMS is a consortium of 11 laboratories that we describe in further detail below.

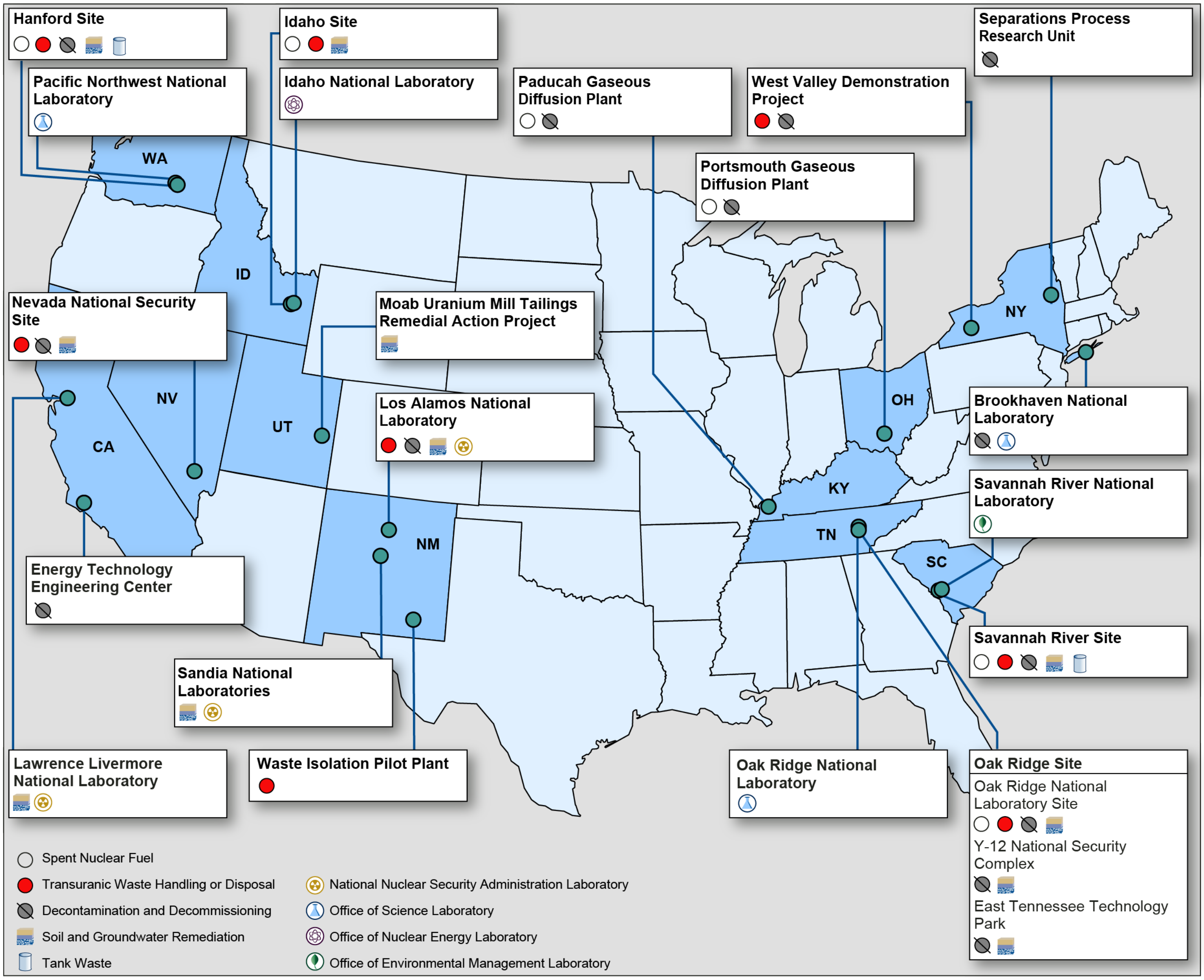
EM Office for Regulatory and Policy Affairs. This office provides technical and policy support in the planning and field execution of the cleanup mission as well as leadership in regulatory affairs. Within this office, EM's International Program works with program offices and EM sites to develop and implement strategies for interactions with the international community that support EM's cleanup mission.

EM sites. EM has 16 active cleanup sites, among which R&D needs and efforts vary.[10] At each site, EM oversees contractors that conduct the cleanup work.[11]

[10]EM has completed cleanup at 91 of its original 107 sites.

[11]DOE oversees its contractors' activities through headquarters offices and local federal field and site offices co-located at each contractor's location.

Figure 1: Map of the Department of Energy (DOE) Environmental Management Complex



Source: GAO analysis of DOE information and Map Resources (map). | GAO-22-104490

Accessible Data Table for Figure 1

Item	Symbol
Hanford Site	Spent Nuclear Fuel Transuranic Waste Disposition Deactivation and Decommissioning Soil and Groundwater Remediation Tank Waste
Nevada National Security Site	Transuranic Waste Disposition Soil and Groundwater Remediation
Lawrence Livermore National Laboratory	Soil and Groundwater Remediation National Nuclear Security Administration Laboratory
Waste Isolation Pilot Plant	Transuranic Waste Disposition
Oak Ridge National Laboratory Site	Deactivation and Decommissioning Soil and Groundwater Remediation Transuranic Waste Disposition Spent Nuclear Fuel
Y-12 National Security Complex	Deactivation and Decommissioning Soil and Groundwater Remediation
East Tennessee Technology Park	Deactivation and Decommissioning Soil and Groundwater Remediation
West Valley Demonstration Project	Deactivation and Decommissioning Transuranic Waste Disposition
Separations Process Research Unit	Deactivation and Decommissioning
Portsmouth	Spent Nuclear Fuel Deactivation and Decommissioning
Paducah	Spent Nuclear Fuel Deactivation and Decommissioning
Energy Technology Engineering Center	Deactivation and Decommissioning
Savannah River Site	Transuranic Waste Disposition Tank Waste Spent Nuclear Fuel Deactivation and Decommissioning Soil and Groundwater Remediation
Moab Uranium Mill Tailings Remedial Action Project	Soil and Groundwater Remediation
Pacific Northwest National Laboratory	Office of Science Laboratory
Sandia National Laboratories	Soil and Groundwater Remediation National Nuclear Security Administration Laboratory
Los Alamos National Laboratory	Transuranic Waste Disposition Soil and Groundwater Remediation Deactivation and Decommissioning National Nuclear Security Administration Laboratory
Idaho National Laboratory	Office of Nuclear Energy Laboratory

Oak Ridge National Laboratory	Office of Science Laboratory
Savannah River National Laboratory	Office of Environmental Management Laboratory
Brookhaven National Laboratory	Deactivation and Decommissioning Office of Science Laboratory
Idaho Site	Spent Nuclear Fuel Transuranic Waste Disposition Soil and Groundwater Remediation

Note: The Waste Isolation Pilot Plant is the only repository for the permanent disposal of transuranic waste. Other sites handle transuranic waste disposition by preparing such waste for disposal. Various sites also have on-site disposal areas such as near-surface landfills for other types of waste, such as low-level waste.

EM's cleanup sites include the following:

- The Hanford site in Washington State and the Savannah River Site in South Carolina include the majority of EM's radioactive contamination and radioactive tank waste, which is particularly costly and complicated to treat. The Hanford and Savannah River sites also have extensive soil and groundwater contamination and contaminated buildings that will require decontamination and decommissioning.[12] DOE estimates that cleanup activities will continue at the Hanford site for at least 50 more years and at the Savannah River Site for at least 40 more years.
- The Idaho National Laboratory has some radioactive tank waste and contamination generated from Cold War–era conventional weapons testing, government-owned research and defense reactors, spent nuclear fuel reprocessing, laboratory research, and defense missions at other DOE sites.
- The Oak Ridge site comprises cleanup efforts across three cleanup campuses—the East Tennessee Technology Park, Oak Ridge National Laboratory, and Y-12 National Security Complex.[13] The cleanup efforts include the decontamination and decommissioning of facilities and soil and groundwater remediation. This site is responsible for remediating significant mercury contamination.

[12]Decontamination and decommissioning refers to the process of placing a contaminated (nuclear, radiologically, or radioactive) facility into a stable and known condition and then closing and securing the facility consistent with established end states.

[13]East Tennessee Technology Park was the site of facilities that enriched uranium through gaseous diffusion technology; DOE completed demolition work there in October 2020. Oak Ridge National Laboratory and Y-12 National Security Complex are active DOE sites.

- The Portsmouth site in Ohio and the Paducah site in Kentucky conduct cleanup of gaseous diffusion plants that are contaminated from decades of uranium enrichment. Cleanup efforts include soil and groundwater remediation, as well as the decontamination and decommissioning of hundreds of facilities across each site.
- The Waste Isolation Pilot Plant is an underground repository located near Carlsbad, New Mexico, that is the only deep geological repository for the permanent disposal of a certain type of defense-generated nuclear waste, referred to as transuranic waste.[14] DOE's current planning assumes that the site will remain open to accept transuranic waste beyond 2050.[15]
- The West Valley Demonstration Project in New York State is the site of a commercial reprocessing facility that operated in the 1960s and 1970s and created various wastes that have remained on-site since the facility closed in 1976. As we found in January 2021, there is currently no viable disposal pathway for West Valley's transuranic and high-level wastes.[16]

National laboratories. DOE has 17 laboratories that conduct R&D and manage scientific facilities. Some DOE laboratories are co-located with EM cleanup sites; for example, Pacific Northwest National Laboratory, an Office of Science laboratory, is co-located with the Hanford site, and Savannah River National Laboratory, EM's lead laboratory, is co-located with the Savannah River Site.[17] Savannah River National Laboratory leads R&D on behalf of EM.

[14]Transuranic waste is waste contaminated by nuclear elements heavier than uranium, such as plutonium, and consists of contaminated tools, protective clothing and rags, soil, and other materials.

[15]U.S. Department of Energy, Office of Environmental Management, *EM Strategic Vision: 2021-2031* (Washington, D.C.: April 2021).

[16]GAO, *Nuclear Waste: Congressional Action Needed to Clarify a Disposal Option at West Valley Site in New York*, GAO-21-115 (Washington, D.C.: Jan. 13, 2021).

[17]DOE's national laboratories generally have a primary DOE entity as a client. For example, EM is the primary client for Savannah River National Laboratory. Other DOE laboratories that conduct cleanup-related R&D have as clients DOE's Office of Science, Office of Nuclear Energy, or National Nuclear Security Administration. Multi-program laboratories such as the Pacific Northwest National Laboratory may conduct large portions of their work for clients other than the primary DOE client. Lawrence Berkeley National Laboratory leads various R&D efforts on behalf of the Office of Legacy Management, including on climate resilience for soil and groundwater remediation.

NNLEMS. NNLEMS is a consortium of 11 DOE laboratories that conduct R&D related to nuclear cleanup and the long-term surveillance and maintenance of sites with contamination remaining after cleanup. This consortium supports EM and the Office of Legacy Management, advises DOE on cleanup-related policy decisions, and conducts strategic planning and peer review on behalf of EM.[18] The director of the Savannah River National Laboratory is co-chair of NNLEMS.

Throughout this report, “EM complex” refers to the EM offices described above, the 16 EM sites, NNLEMS, and the individual national laboratories that conduct EM-related R&D efforts (see fig. 2).

Three DOE offices outside of EM intersect with EM’s R&D efforts:

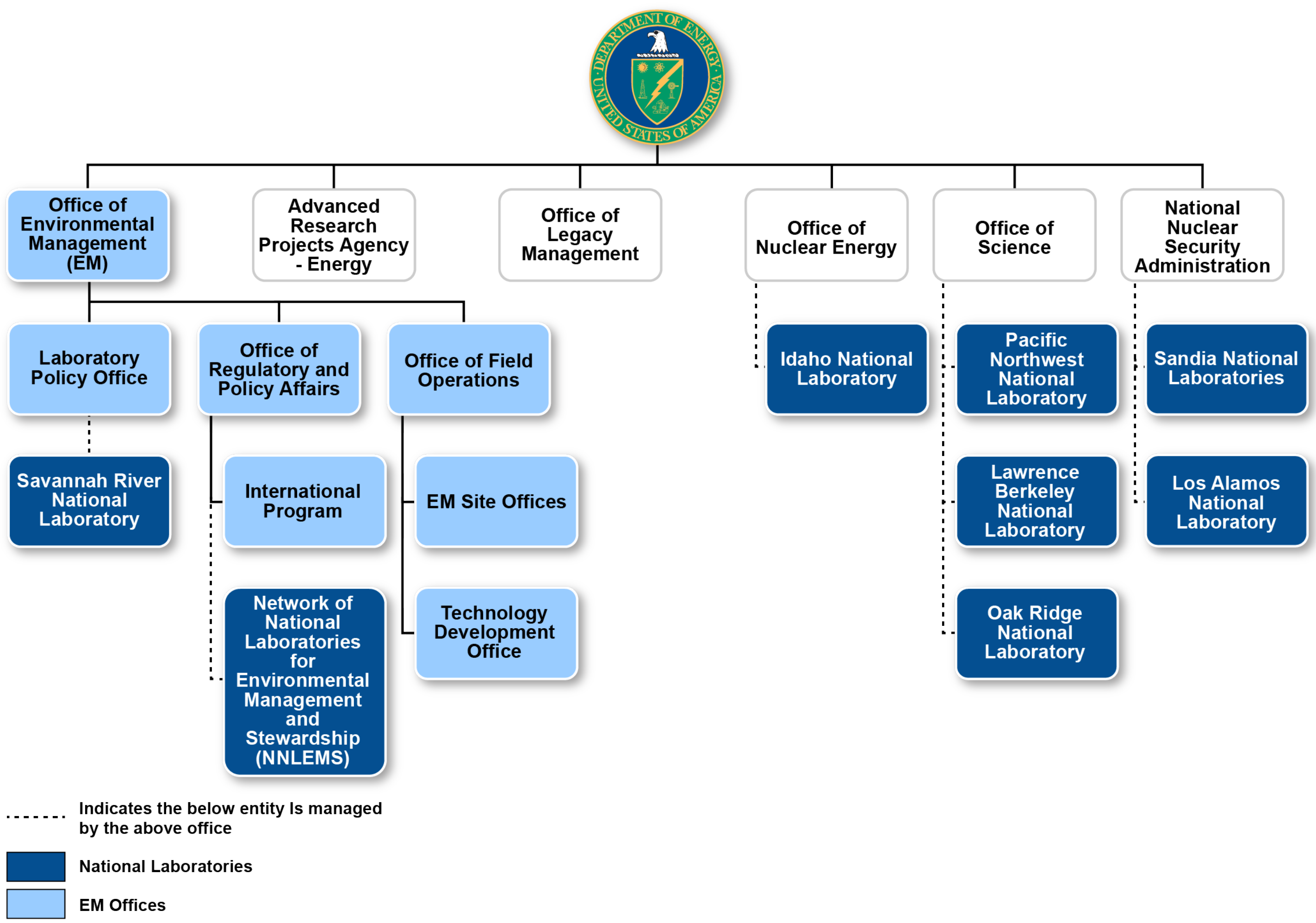
- **Office of Science**. This office’s mission is to sponsor basic research, and it is the nation’s single largest funding source for basic research in the physical sciences. The Office of Science also oversees 10 national laboratories, some of which are part of NNLEMS. The Office of Science historically has supported basic research needed to develop cleanup-related technologies and strategies.
- **Office of Legacy Management**. This office’s mission is long-term surveillance and maintenance of former nuclear waste sites that have completed cleanup. EM transfers sites to the Office of Legacy Management for long-term stewardship once cleanup is complete. This office’s R&D needs, related to long-term surveillance and maintenance, overlap with those of EM.
- **ARPA-E**. ARPA-E sponsors high-potential, high-impact energy technologies that are considered too early for private-sector investment. ARPA-E historically has not sponsored nuclear-cleanup related research, but the Energy Act of 2020,[19] enacted in fiscal year 2021, established a new goal for ARPA-E to develop nuclear cleanup-related technologies.[20]

[18]The network originally formed as a consortium of six core EM laboratories in 2017 and was called the EM National Laboratory Network. In 2021, it incorporated laboratories that conduct work for DOE’s Office of Legacy Management and became NNLEMS.

[19]Energy Act of 2020, Pub. L. No. 116-260, div. Z, tit. X, § 10001 (codified at 42 U.S.C. § 16538).

[20]Specifically, the Energy Act of 2020 made it a new goal of the program to “provide transformative solutions to improve the management, clean-up, and disposal of radioactive waste and spent nuclear fuel.” 42 U.S.C. § 16538(c)(1)(A)(iv).

Figure 2: Department of Energy (DOE) Organizational Structure for the Office of Environmental Management and Other DOE Offices with Responsibilities for Research and Development



Source: GAO analysis of DOE information. | GAO-22-104490

Funding

Various entities receive and expend funding for cleanup-related R&D efforts across the EM complex.

- **Technology Development Office**. The Technology Development Office has received between $25 million and $35 million in funding each fiscal year since fiscal year 2018. Of this amount, $15 million has typically been congressionally directed to specific initiatives.[21] The Technology Development Office may provide the remaining funds to sites to supplement their R&D efforts.[22]

- **Other EM offices**. According to EM officials, other EM headquarters offices, such as the Laboratory Policy Office, direct funding to certain laboratories within NNLEMS for R&D efforts.[23]
- **EM sites**. EM sites collectively direct at least another $80 million annually to national laboratories for site-specific operational R&D needs, according to EM officials. This includes R&D necessary to proceed with ongoing cleanup efforts, such as testing and demonstrating equipment to monitor contamination. EM officials also said that the sites directed an additional $180 million to these laboratories in fiscal year 2020, with an undetermined amount going to R&D expenditures.

EM Identifies Cleanup-Related R&D Needs through a Variety of Approaches

EM identifies cleanup-related R&D needs internally and through input from entities across DOE, including the sites themselves, national laboratories, and other DOE offices. Specifically, EM's sites identify needs in the course of their operations. In addition, the Technology Development Office identifies R&D needs—such as those relevant to multiple sites—or gaps in complex-wide R&D, including by collecting input from EM sites, national laboratories, and other DOE offices.

EM sites. EM officials and contractors at EM's sites identify project-specific needs, including needs that arise in the course of each site's cleanup operations. Sites often address such R&D needs by engaging

[21]Congressional direction is contained in legislative reports and explanatory statements and is not legally binding. However, DOE officials told us that they treat such report language as legally binding.

[22]DOE takes an additional 3.65 percent of the Technology Development appropriation for the Office of Science to use for DOE's Small Business Innovation Research and Small Business Technology Transfer programs. The Small Business Act requires DOE to spend a certain percentage of its R&D funds with small businesses through these programs.

[23]The Laboratory Policy Office contributed $2.8 million to NNLEMS participants in fiscal year 2020 and $1.7 million in fiscal year 2019, according to EM documents. EM officials told us that the Technology Development Office directed $10 million and the Laboratory Policy Office directed $6 million to certain laboratories within NNLEMS for R&D efforts in fiscal year 2020.

the national laboratories or adapting commercially available technologies. For example:

- Officials at the Oak Ridge site in Tennessee identified the need to remove mercury vapor from the air during facility deactivation and decommissioning activities. Site officials engaged Savannah River National Laboratory to develop technologies to reduce mercury vapor and debris in the building to limit worker exposure.
- At the West Valley Demonstration Project site in New York, officials identified the need for technology to reduce humidity levels within the site's nuclear waste storage tanks to prevent corrosion and oxidation of the storage tanks. The site adapted commercial drying systems commonly used in large sports arenas into a tank and vault drying system that uses HEPA filters to dehumidify the site's waste storage tanks.[24]
- Officials at the Hanford site's Office of River Protection in Washington State identified the need to manage tank farm vapors and other odors, which posed worker-safety risks. Officials worked with the site contractor to develop and test a commercially available technology used in the cleanup of the Fukushima-Daiichi plant in Japan.[25]
- Officials at the Portsmouth site in Ohio identified the need to measure uranium quantities within the piping in the site's buildings as part of deactivation and decommissioning activities. Officials at the site worked with Carnegie Mellon University to develop a robotics system to address this need.
- The sites may fund related R&D efforts from their overall budgets. The Technology Development Office also may fund R&D to address needs that sites identify. For example, when the Savannah River Site identified the need to investigate mercury release from the grout used to contain the site's radioactive waste, but did not have sufficient funding to pursue the associated R&D, the Technology Development Office funded research on the science underlying the release.

National laboratories. DOE's national laboratories work closely with EM sites to identify R&D needs and execute efforts to address those needs, including through NNLEMS. Scientists and other personnel from the

[24]The West Valley Demonstration Project is the site of a commercial reprocessing facility that operated in the 1960s and 1970s and created various wastes that remained on-site after the facility closed in 1976.

[25]On March 11, 2011, an earthquake and subsequent tsunami severely damaged the Fukushima-Daiichi nuclear power plant in Japan. Cleanup at the plant is ongoing.

national laboratories are integrated into EM site activities and can help identify R&D needs related to these activities. National laboratories may also use their own budgets to pursue research to address the needs they identify. For example:

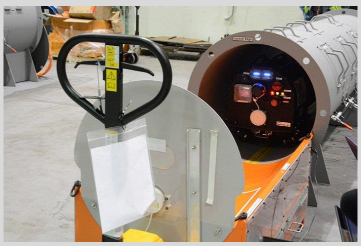
- Sandia National Laboratories works with EM's Carlsbad Field Office, which manages the Waste Isolation Pilot Plant, to identify R&D needs at the plant. In 2020, Sandia National Laboratories hosted workshops with site officials from the Carlsbad Field Office and the site contractor to identify and address R&D needs for Waste Isolation Pilot Plant operations. For example, the workshop explored potential R&D related to air quality, measuring salt movement, data management, robotics, power sources, and monitoring bolts that prevent falling rocks within the repository.
- The Savannah River National Laboratory, which is integrated with the Savannah River Site, initiated several technology development efforts through its Laboratory-Directed Research and Development (LDRD) program that EM was able to deploy.[26] For example, LDRD findings on the use of solvent-eating bacteria to treat groundwater contamination led to the deployment of a related technology at the Savannah River Site. Additionally, a LDRD project on modeling led to the deployment of a predictive modeling technology at the site's vitrification facility, which immobilizes waste into glass.
- Pacific Northwest National Laboratory identified the need to understand filter performance for tank operations and invested in basic research through its LDRD program. This research led to additional research on filters that could be used to remove certain substances from the Hanford site's tank waste to prepare it for treatment.[27]

[26]Laboratory-Directed Research and Development (LDRD) is R&D work laboratories perform on their own initiative. DOE is authorized to allocate up to 6 percent of the laboratories' budgets for such work at its national laboratories and must allocate at least 5 percent at its national security laboratories. LDRD funds cannot be directed to specific operational needs but may support R&D related to cleanup. 50 U.S.C. §§ 2791-2791a; DOE Order 413.2C *Laboratory Directed Research and Development* (October 2015). Technology Development officials told us that they do not include LDRD in their accounting of R&D funds expended throughout the complex.

[27]The filters could be used for the tank-side cesium removal system that will be built next to an underground tank and will filter waste directly from the tank to remove solids and cesium before the waste is treated.

Robotics for Nuclear Cleanup

The Department of Energy's Office of Environmental Management (EM) has promoted the development and demonstration of robotic technologies to improve worker safety and productivity. Robots can access areas restricted to workers due to size or contamination levels. For example, robots can measure radiation inside underground piping in former nuclear facilities. EM has collaborated with Carnegie Mellon University and the Portsmouth site on a robotics system to measure uranium within pipes of facilities to be deactivated and decommissioned.



Sites throughout the EM complex are conducting demonstrations of robotic technologies. For example, the Hanford site recently conducted a demonstration of a remote-controlled four-legged robot—a robotic "dog"—that workers could use to access difficult-to-reach areas without coming into contact with potentially hazardous materials.

The Portsmouth and Idaho sites have tested a robotic "snake" arm that can cut through metal and concrete materials in small and highly radioactive areas, including nuclear reactors and gaseous diffusion plants. It generates less waste and debris than other methods, according to EM officials. EM collaborated with the United Kingdom's (UK) Nuclear Decommissioning Authority and several UK companies to demonstrate the robot and laser system at Portsmouth. The Idaho Site is testing this system for transferring radioactive calcined waste, a byproduct of spent nuclear fuel reprocessing, to a new storage location.

Photo sources: DOE; Information Source: GAO analysis of DOE documents | GAO-22-104490

Other DOE offices. EM headquarters works with other DOE offices to identify complex-wide and site-specific R&D needs. For example,

- In 2015, DOE's Office of Science conducted a 4-day workshop that brought together scientists from other DOE offices, academia, the national laboratories, and industry to define basic research needs for the EM cleanup mission. The participants defined needs in measurement and characterization of waste streams, and in understanding the subsurface environment, among other things.[28] The workshop resulted in a report that identified priority research directions.
- DOE's Office of Nuclear Energy, together with its lead laboratory—Idaho National Laboratory—identified the need for research related to storage of a particular type of spent nuclear fuel. Specifically, some spent nuclear fuel was known to generate hydrogen, which could affect safe storage and pose challenges for EM as well. The Office of Nuclear Energy and Idaho National Laboratory worked with the Technology Development Office, the Savannah River National Laboratory, and the Savannah River Site to more precisely define the associated R&D needs. These offices have been conducting R&D to address this need—funded through a congressionally directed portion of the Technology Development Office's budget—since fiscal year 2015.

[28]The workshop was held July 8-11, 2015, and led to the publication of a report titled *Basic Research Needs for Environmental Management*, which summarizes the research directions identified in the workshop.

EM Uses Several Mechanisms to Coordinate R&D, but Its Efforts Do Not Fully Align with Some Leading Collaboration Practices

EM uses a variety of mechanisms to coordinate R&D, but its efforts do not fully align with certain leading collaboration practices. EM uses both formal and informal coordination mechanisms throughout the complex, including the national laboratory network and working groups. The agency also follows certain leading practices for collaboration—such as clarifying roles and responsibilities and including relevant participants. However, EM does not fully follow others, which affects its ability to identify, track, and evaluate the effectiveness of R&D efforts.

EM Uses Formal and Informal Mechanisms to Coordinate R&D throughout the EM Complex

EM uses formal and informal mechanisms to coordinate R&D throughout its complex, according to our review of documents and our interviews with DOE officials and representatives from the sites and national laboratories.

Formal mechanisms EM uses include technology exchanges, the national laboratory network, working groups, and specific initiatives. For example:

Technology exchanges with site managers, federal program managers, and technical staff. The Technology Development Office coordinates technology exchanges with site contractors through officials who serve as liaisons between the two entities. Site contractors provide on-site federal project managers with technology recommendations to address site needs. The managers use those recommendations to engage in technology exchanges with EM headquarters or others in the EM complex. For example, according to site officials we interviewed, the Hanford site’s Office of River Protection holds an annual meeting during which the site’s contractor reviews ongoing site projects and technology development efforts and assesses R&D efforts in the private sector and at the national laboratories. The site’s federal project managers use the recommendations from such reviews to engage in technology development exchanges with other EM sites, EM headquarters, the national laboratories, universities, and private-sector companies.

National laboratory network. The Technology Development and Laboratory Policy offices coordinate R&D efforts through NNLEMS and the Savannah River National Laboratory, EM's lead laboratory. When EM identifies R&D needs that the national laboratories can help address, NNLEMS coordinates efforts to address these needs, including by selecting a team of scientists from partner laboratories. For example, the network is conducting an independent review of crystalline silicotitanate technologies used by the Savannah River Site and other sites.[29] Savannah River National Laboratory defined the technical areas for which to seek experts, and other laboratories within the network—including the Sandia, Pacific Northwest, and Los Alamos National Laboratories—nominated scientists within those technical areas for the review team, according to laboratory officials.

Working groups. EM facilitates collaboration through EM-specific working groups and participates in department-wide working groups to share information with other offices and programs throughout the EM complex and throughout DOE. For example, the Energy Facility Contractors Group shares lessons learned and best practices in cleanup activities, including cleanup-related R&D. Information exchanges within working groups may also lead to technology transfers between entities. For example, officials from the Waste Isolation Pilot Plant participate in an international working group to share information related to disposal of nuclear waste in salt-based repositories.[30]

Specific initiatives. The Technology Development Office coordinates with other DOE offices on specific R&D initiatives and on overlapping program missions. For example, as previously noted, two sites—the Savannah River Site, managed by EM, and the Idaho National Laboratory site, managed by the Office of Nuclear Energy—face challenges with the long-term storage, transportation, processing, and disposal of DOE-owned and managed spent nuclear fuel. To address these challenges, the Technology Development Office coordinates with the Office of

[29]Crystalline silicotitanate ion exchangers are used to remove radioactive cesium and strontium from waste held in tanks.

[30]The Organization for Economic Co-operation and Development Nuclear Energy Agency has several international working groups specialized by topic that engage in information sharing and technology exchanges. For example, there is an Integration for the Safety Case group, which in turn has a Salt Club subgroup that focuses on salt-specific waste disposal issues.

Nuclear Energy on spent nuclear fuel research.[31] The Technology Development Office also coordinates with the Office of Legacy Management on R&D related to long-term management of former EM sites, since the Office of Legacy Management is responsible for the post-cleanup stewardship of former EM sites.

Furthermore, EM coordinates information sharing and collaborative R&D efforts with international entities through NNLEMS and headquarters programs such as EM's International Program. Through EM's International Program, for example, EM conducted a demonstration of a robot and laser system at the Portsmouth site that was developed in the United Kingdom (see sidebar for examples of robotics R&D at various EM sites). This system is intended to assist with cleanup tasks during the site's deactivation and decommissioning activities, such as cutting steel and concrete in a manner that minimizes additional waste and debris. In addition, national laboratories may collaborate on certain complex-wide R&D needs. For example, the Savannah River and Lawrence Berkley National Laboratories collaborate on the Advanced Long-Term Environmental Monitoring Systems project, which focuses on advancing artificial intelligence, machine learning, and sensor capabilities to test long-term groundwater monitoring technologies.

Informal mechanisms, such as leveraging relationships and information sharing, also can contribute to coordination on R&D efforts throughout the EM complex. For example:

Leveraging relationships. Several site officials and one laboratory representative told us that they leverage professional relationships, including relationships with individuals at other sites and laboratories, to share information and lessons learned.[32] Relationships among site officials and researchers at different laboratories can lead to informal technology transfers initiated by scientists between laboratories and sites with common cleanup needs. For example, one laboratory official said that because the EM complex includes laboratories managed by other

[31]Since fiscal year 2017, Congress has regularly directed EM to spend $4 million to $5 million of its technology development funds on the National Spent Nuclear Fuel Program to address issues related to the storage, transportation, processing, and disposal of DOE-owned and managed spent nuclear fuel. EM manages this program jointly with the Office of Nuclear Energy.

[32]We summarize the information gathered from officials and representatives in the report by using "some" to refer to two or three members of a group, "several" to refer to four or five members of a group, and "many" to refer to more than five members of a group.

DOE offices, a scientist developing a technology for the Office of Science or the National Nuclear Security Administration can bring that technology to EM's attention once it is available.

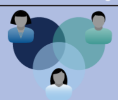
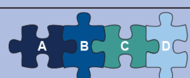
Information sharing. Many site officials also told us they share information informally at trade conferences and several told us they share information through trade publications and published journal articles. For example, site officials told us that the annual Waste Management Symposium provides a forum for site officials to share information on site challenges and technologies used.

EM Followed Most Leading Practices for Collaboration but Does Not Have a Common Definition of R&D, Consistently Track Spending, or Evaluate Outcomes

EM's coordination efforts on cleanup-related R&D across the EM complex fully aligned with four of the seven leading practices for interagency collaboration we previously identified but did not fully align with three practices. The seven leading practices for interagency collaboration, which we outlined in September 2012, are defining outcomes and monitoring progress for accountability, bridging organizational cultures, identifying leadership, clarifying roles and responsibilities, including relevant participants, identifying resources, and documenting agreement through written guidance and agreements.[33] Figure 3 describes these leading practices in more detail, and appendix II describes our full analysis in more detail.

[33]GAO-12-1022.

Figure 3: Leading Practices for Implementing Interagency Collaboration

Key features		Key considerations
	**Outcomes and accountability**	Have short-term and long-term outcomes been clearly defined? Is there a way to track and monitor progress toward the short-term and long-term outcomes?
	**Bridging organizational cultures**	Have participating agencies developed ways for operating across agency boundaries? Have participating agencies agreed on common terminology and definitions?
	**Leadership**	Has a lead agency or individual been identified? If leadership will be shared between one or more agencies, have roles and responsibilities been clearly identified and agreed upon? How will leadership be sustained over the long-term?
	**Clarity of roles and responsibilities**	Have participating agencies clarified the roles and responsibilities of the participants?
	**Participants**	Have all relevant participants been included? Do the participants have: full knowledge of the relevant resources in their agency, the ability to commit these resources, the ability to regularly attend activities of the collaborative mechanism, and the appropriate knowledge, skills, and abilities to contribute?
	**Resources**	How will the collaborative mechanism be funded? If interagency funding is needed, is it permitted? If interagency funding is needed and permitted, is there a means to track funds in a standardized manner? How will the collaborative mechanism be staffed? Have participating agencies developed online tools or other resources that facilitate joint interactions?
	**Written guidance and agreements**	If appropriate, have the participating agencies documented their agreement regarding how they will be collaborating?

Source: GAO. | GAO-22-104490

Accessible Data Table for Figure 3

Key features	Key consideration
Outcomes and accountability	Have short-term and long-term outcomes been clearly defined? Is there a way to track and monitor progress toward the short-term and long-term outcomes?
Bridging organizational cultures	Have participating agencies developed ways for operating across agency boundaries? Have participating agencies agreed on common terminology and definitions?
Leadership	Has a lead agency or individual been identified? If leadership will be shared between one or more agencies, have roles and responsibilities been clearly identified and agreed upon? How will leadership be sustained over the long-term?
Clarity of roles and responsibilities	Have participating agencies clarified the roles and responsibilities of the participants?
Participants	Have all relevant participants been included? Do the participants have: full knowledge of the relevant resources in their agency, the ability to commit these resources, the ability to regularly attend activities of the collaborative mechanism, and the appropriate knowledge, skills, and abilities to contribute?
Resources	How will the collaborative mechanism be funded? If interagency funding is needed, is it permitted? If interagency funding is needed and permitted, is there a means to track funds in a standardized manner? How will the collaborative mechanism be staffed? Have participating agencies developed online tools or other resources that facilitate joint interactions?
Written guidance and agreements	If appropriate, have the participating agencies documented their agreement regarding how they will be collaborating?

We reviewed EM's coordination efforts and found they fully aligned with four of the seven leading practices: identifying leadership, documenting agreement on collaboration, clarifying roles and responsibilities, and including relevant participants. For example:

- **Identifying leadership**. Various EM documents establish the Technology Development Office as the lead entity for R&D for the EM complex. Additionally, the NNLEMS charter identifies network leadership, including how it is to rotate among participating laboratories.
- **Documenting agreement**. EM has developed several documents to encourage and guide coordination. For example, the NNLEMS charter documents agreement among laboratories to coordinate on EM-related efforts and defines the roles and responsibilities of participants. In addition, the EM International Program *Strategic Plan*

outlines collaborative mechanisms among DOE offices for working with international entities on cleanup-related issues. EM also uses agreements with international entities, such as memorandums of understanding and statements of intent. For example, in 2020, DOE, the Nuclear Decommissioning Authority of Great Britain and Northern Ireland, and Atomic Energy of Canada Limited signed a statement of intent to share information on contracting approaches, aging infrastructure management, and stakeholder engagement strategies.[34]

We found that EM's efforts fully aligned with two additional leading practices and that coordinating entities experienced varying levels of engagement with these efforts. For example:

- **Clarifying roles and responsibilities**. EM, its sites, and the national laboratories understand their respective roles within the complex and in R&D activities, according to program documents and interviews with agency officials. For example, EM's *Technology Development Framework* defines the roles of several positions, such as the Technology Development Program Director, who is responsible for overall management and oversight of the Technology Development program. This framework also designates the Savannah River National Laboratory as the interface between the Technology Development Program Director and NNLEMS.

  The nuclear-related cleanup research roles for two DOE entities outside the EM complex, DOE's Office of Science and ARPA-E, are evolving and EM is working with these entities to more clearly understand and agree on their roles. Specifically, Office of Science officials said they generally no longer fund cleanup research, but EM believes that the Office of Science has a part in supporting cleanup-related basic research.[35] EM officials acknowledged that the Office of Science's reduced investment in cleanup-related basic research

[34]Atomic Energy Canada Limited is a quasi-governmental, or "federal Crown," corporation whose mandate is to "enable nuclear science and technology and to protect the environment by fulfilling the government of Canada's radioactive waste and decommissioning responsibilities."

[35]In response to a preliminary draft of our report, Office of Science officials noted that they continue to support certain ongoing initiatives relevant to cleanup-related research, such as the Basic Energy Sciences Energy Frontier Research Center program. Science officials stated that basic science relevant to environmental management continues as a priority topical area within this program. Representatives from one laboratory noted that they conduct basic research through this program on complex chemical phenomena to enable innovations in retrieving and processing high-level radioactive waste.

would leave a gap. They told us they would meet with the Office of Science to discuss opportunities to resolve this issue.

In addition, there is uncertainty about ARPA-E's role in and potential for developing cleanup-related technologies among ARPA-E, EM headquarters, the laboratories, and EM sites in the context of a new nuclear-cleanup related goal for ARPA-E established in the Energy Act of 2020. For example, several laboratory officials said ARPA-E could address long-term research needs and identify breakthrough research, but one laboratory official expressed concerns that ARPA-E's operating model of funding private-sector investment might not work for nuclear cleanup because of limited commercial opportunity for certain nuclear waste remediation technologies.[36] Technology Development officials said ARPA-E's potential role is supplementary to what the EM complex and other DOE offices contribute to cleanup R&D. In September 2021, ARPA-E officials said they had staff-level discussions with EM regarding potential future R&D opportunities but were not sponsoring research that impacts EM's mission.

- **Including relevant participants**. We found that EM regularly communicates with participants—including EM sites, national laboratories, and international entities—about available technologies and resources to assist in addressing cleanup challenges. For example, EM has taken steps to make federal project managers and site managers aware of NNLEMS as a resource. We found through our interviews with site officials that they were generally aware of its availability to them. This effort aligns with the leading practice of ensuring relevant participants are included in and have the appropriate knowledge and abilities to contribute to the collaborative effort.

  We found site officials varied in their use of NNLEMS. For example, officials from the Hanford site's Richland Operations Office, the Portsmouth site, and the Nevada National Security Site were aware of NNLEMS but had not formally interacted with the network because their R&D needs were limited and could be addressed without seeking assistance from the network. Richland Operations officials said they do not need the technology development resources provided by the network because they work directly with the Pacific Northwest

[36]Specifically, this official told us that ARPA-E's nonfederal cost-share requirements may be much more difficult to secure in certain nuclear cleanup technology topic areas, such as high-level waste processing. The ARPA-E model may be more effective in areas with broader commercial market opportunity, such as monitoring and sensor technology, this official said.

National Laboratory to address technology needs at the Hanford site. In addition, an official from one campus of the Oak Ridge site said they had no interaction with the network.[37] A Paducah site official said that although they were aware of the national laboratories as a resource for cleanup-related R&D, they were unaware of NNLEMS.[38]

EM's coordination efforts partially align with the remaining three leading practices for collaboration: bridging organizational cultures, identifying resources, and defining outcomes and monitoring progress for accountability. For example:

- **Bridging organizational cultures**. EM has taken some steps to bridge organizational cultures among entities in the EM complex, but it has not developed a common definition of R&D for stakeholders to use when sharing information about R&D efforts. The leading practice of bridging organizational cultures calls for collaborating agencies to have ways to operate across agency boundaries, such as by agreeing on common terminology and definitions. EM has established ways to operate across agency boundaries such as by leveraging working groups as a means to share information among contractors, the national laboratories, and different DOE offices. EM also has personnel in place, such as federal project managers and site liaisons, who advocate for site technology challenges and needs to EM headquarters.
- However, EM's coordination efforts do not fully align with this leading practice because EM has not developed or disseminated a common definition of R&D for EM R&D stakeholders to use. Our prior work has found that using common terminology and definitions allows federal agencies to better measure the scope and dimensions of their efforts.[39] We found in our interviews with officials throughout the EM complex that, in the absence of a common definition of R&D, EM R&D stakeholders—including EM headquarters and sites—interpreted R&D differently, such as with regard to technology demonstration, technology adaptation, and certain other activities. For example:

[37]As previously noted, the Oak Ridge site comprises three cleanup campuses.

[38]EM officials said they sent the NNLEMS charter to site liaisons and field managers in advance of the 2020 NNLEMS review of headquarters-funded R&D activities at the sites but acknowledged that not all site officials might be aware of the network.

[39]GAO-12-1022

- **Technology demonstration**. A DOE memo we reviewed provided a working definition of technology development that included demonstration of new technology or equipment.[40] However, some site officials told us their technology demonstration activities did not constitute R&D efforts. For example, Hanford's Richland Operations Office conducted a demonstration of a remotely controlled robotic technology that would allow workers to access unreachable areas and reduce worker exposure to radiation.[41] It is unclear whether any EM documentation of cleanup-related R&D, such as its assessments of R&D efforts at certain sites, would have identified this as an R&D activity because this demonstration took place after EM's most recent site assessments in 2019. It is also unclear whether the site would report this demonstration to EM as R&D for future assessments because site officials—who told us they did not conduct R&D—may not consider it R&D.
- **Technology adaptation**. EM documentation includes the adaptation of commercially available technology in its description of technology development, but it is unclear whether EM collects information on such activities as part of its efforts to maintain awareness of complex-wide R&D activities. For example, the West Valley Demonstration Project site has adapted several commercial technologies, such as drying systems used in large sports arenas, to address site challenges. The site also worked with the University at Buffalo to adapt permeable treatment wall technologies to treat the site's groundwater contamination. We could not determine whether EM counted these activities in its overall tracking of R&D efforts throughout the complex, because these activities were not listed in any documentation of cleanup-related R&D efforts that EM provided. This documentation included assessments of R&D efforts at certain sites—which did not include the West Valley Demonstration Project site—and a 2020 NNLEMS review that EM commissioned of R&D activities funded by the Technology Development Office.
- **Other activities**. Officials within EM headquarters also had conflicting interpretations of what activities constituted R&D

[40]This memo, dated November 2020, accompanied the charter for a NNLEMS study of the Technology Development program.

[41]Unlike other robotic technologies tested around the complex, the technology demonstrated at the site had four legs, which allowed the robot to navigate the site's terrain that other robots, such as robots with wheels, were not able to navigate.

efforts. For example, senior EM officials told us that first-of-a-kind construction and laboratory-directed research and development constituted R&D. However, Technology Development officials said they did not track such activities as part of their oversight of EM's R&D program.

- In addition to leading practices for collaboration, federal standards for internal control call for using quality information—including information that is current and complete—to achieve objectives.[42] According to EM's *Technology Development Framework*, the main objective of the R&D program is to target technology development and address activities critical to EM needs, such as developing solutions that support EM's cleanup mission. However, without a common definition of R&D across the EM complex, sites may not document or report certain efforts as R&D to the Technology Development Office. As a result, EM may not have quality information from sites on their individual and collaborative R&D efforts in order to assess progress toward its R&D goals. Because the Technology Development Office has not developed or disseminated a common definition of R&D, it does not have assurance it is collecting the information it needs to systematically document R&D efforts across the complex and ensure its R&D stakeholders maximize their collaborative efforts.
- **Identifying resources**. EM has identified funding for certain collaborative mechanisms and provided personnel to ensure these mechanisms are sustained, but it does not systematically track funds spent on R&D across the EM complex. The leading practice of identifying resources calls for identifying the human, information technology, physical, and financial resources needed to initiate or sustain a collaborative effort. Regarding collaborative mechanisms, the Technology Development Office and the Office of River Protection at the Hanford site collaboratively funded the Test Bed Initiative, which demonstrated the use of an alternate treatment option for a portion of the site's tank waste. EM also designated a permanent liaison, who reports to senior EM leadership, coordinates resources for NNLEMS, and serves as a point of contact for EM offices and sites interfacing with the network. Moreover, according to EM officials, EM is developing online tools, such as an R&D dashboard, to help further facilitate coordination on R&D efforts.

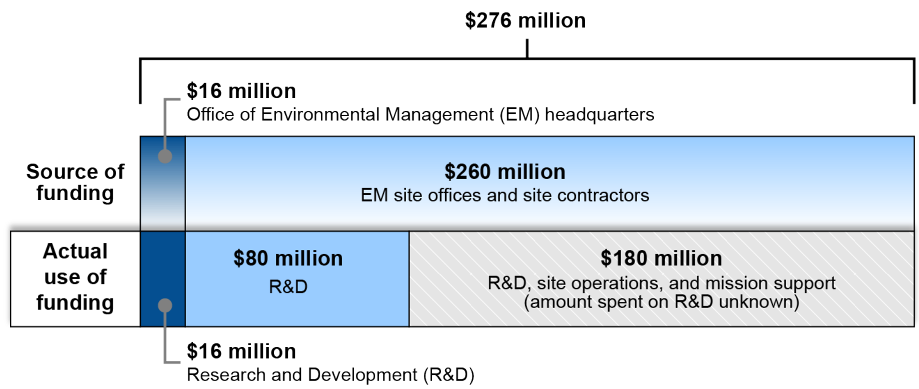
[42] GAO-14-704G. For example, agencies obtain relevant data from reliable internal and external sources in a timely manner based on the identified information requirements. Obtaining relevant data is related to the information being identified for use and having reliable sources means that the sources provide data free from error, bias, and misrepresentation.

- However, we found that EM's coordination efforts do not align with other attributes of this leading practice because EM does not systematically track funds spent on R&D across the EM complex. The leading practice of identifying resources calls for tracking interagency funding in a standardized manner for accountability, but EM does not have an internal system to systematically track R&D expenditures throughout the complex. Technology Development officials identify their office as the entity responsible for "maintaining awareness" of sites' R&D activities, but these officials did not specify what this involves. Although the Technology Development Office has established processes to track its own expenditures on R&D, Technology Development officials said they are not required to formally track site-funded R&D. It is also unclear whether EM's efforts to track R&D expenditures at its sites have captured all R&D activities across the entire EM complex. For example, Technology Development officials said that EM's 2019 site assessments covered the entire complex, but only the Hanford, Savannah River, Idaho National Laboratory, and Oak Ridge sites issued reports on their assessments. EM did not provide evidence that the assessments covered its other 12 sites.
- EM officials told us that in fiscal year 2019 they began collecting information on cleanup-related R&D funding that sites provided to NNLEMS laboratories and plan to do so annually.[43] While EM officials gave us a general breakdown of the approximately $276 million EM provided to six laboratories in NNLEMS in fiscal year 2020, they could not give us a detailed breakdown of these expenditures because they had not yet received all underlying data from the sites and laboratories (see fig. 4). As previously noted, Technology Development officials specified that $16 million came from EM headquarters and an additional $80 million came from the sites. However, Technology Development officials could not specify how much of the remaining $180 million went toward R&D efforts. They noted that some portion of the $180 million was used for overall site operations and administrative support. Because the Technology Development Office does not systematically track R&D funding throughout the complex, EM does not have information on the extent of its R&D investments and has limited assurance that its resources are aligned with R&D needs. By systematically tracking R&D expenditures throughout the complex, EM would have better assurance it is collecting complete information about R&D

[43]Prior to fiscal year 2020, NNLEMS was called the EM National Laboratory Network.

expenditures across the complex—information that it can use to identify the resources it needs to sustain collaborative R&D efforts.

Figure 4: Known and Possible Office of Environmental Management Research and Development (R&D) Funding to Certain Laboratories in Fiscal Year 2020



Source: GAO analysis of DOE information. | GAO-22-104490

- **Outcomes and accountability**. EM has taken steps to define outcomes for R&D and monitor and evaluate progress toward these outcomes at some individual sites, but it may not be comprehensively capturing R&D activities across the entire EM complex. The leading practice of outcomes and accountability entails clearly defining short-term and long-term goals and developing ways to monitor and evaluate progress toward these goals. Steps EM has taken to define outcomes include providing an overview of program goals and priorities and commissioning assessments of R&D activities undertaken at EM sites. For example, EM's annual strategic vision documents provide a high-level overview of program goals and priorities, such as addressing groundwater contamination at the Savannah River Site through technology deployment.[44] The strategic vision documents inform R&D-specific planning documents, such as EM's *Technology Development Framework*, and some sites' R&D planning efforts. To monitor progress, in 2019 EM commissioned assessments of R&D activities at certain EM sites. Additionally, in 2020, EM commissioned a NNLEMS review of how R&D activities that the Technology Development Office funded at EM sites aligned with overall EM priorities and how sites were using proven technologies. EM also collects information through regular and ad-hoc program and project reviews, according to EM officials.

[44]U.S. Department of Energy Office of Environmental Management, *EM Strategic Vision: 2021-2031* (Washington, D.C.: April 2021).

- However, we found that EM's monitoring and evaluation efforts do not fully align with this leading practice. As previously noted, Technology Development officials told us that their office is responsible for maintaining awareness of all EM-related R&D activities across the complex, regardless of the activity's funding source, in order to facilitate coordination and ensure efforts are not duplicated.[45] Technology Development officials told us they informally collect information on R&D projects in coordination with other EM offices and sites, project managers, and national laboratory personnel. They also said they began collecting information on R&D activities throughout the complex in 2019, when they began collecting information on funding, as described above. However, as of September 2021, the officials had not yet received the data that would enable them to provide us a detailed list of these activities or their outcomes. EM officials acknowledged that the agency still does not have an internal system to collect comprehensive information on R&D activities throughout the complex that would enable them to monitor and evaluate these activities' outcomes. Moreover, the agency's ongoing efforts to track outcomes do not cover the entire EM complex. For example, the NNLEMS review of R&D activities funded by the Technology Development Office did not include all 16 EM sites in its scope, according to documentation from this review.

  Without systematically and comprehensively collecting information on the results of complex-wide R&D efforts, including those funded by the Technology Development Office or individual site budgets, EM lacks the necessary information to systematically monitor and evaluate the effectiveness of its R&D investments and the value of its outcomes—information that could help it determine whether to encourage or discourage investments in certain areas. Collecting the information needed to monitor and evaluate outcomes could also help reduce potentially duplicative and overlapping R&D efforts.

[45]In addition, federal standards for internal control call for management to establish and operate monitoring activities. The monitoring principle of *Standards for Internal Control in the Federal Government* stipulates that management should establish and operate monitoring activities to monitor the internal control system and evaluate the results. GAO-14-704G. The Technology Development Office's tracking of R&D expenditures is part of its internal controls system for the program.

EM Does Not Have a Comprehensive Framework for Prioritizing R&D Efforts

EM's Technology Development Office has not taken a comprehensive approach to prioritizing R&D. In the absence of a comprehensive approach, individual EM sites and DOE laboratories have developed their own approaches for making R&D prioritization decisions, according to site and laboratory officials. These individual approaches to prioritizing R&D differ, including in the extent to which they consider complex-wide issues. For example, Office of River Protection officials at the Hanford site told us they prioritize R&D using various site-wide planning documents, including Hanford's Integrated Priority List and Hanford's 5-year plan.[46] On the other hand, Savannah River Site officials told us that individual programs at the site prioritize R&D efforts among their overall activities, rather than as a holistic R&D portfolio. Finally, an official from one of the three campuses at the Oak Ridge site told us that they develop a technology development plan with project managers from across the campus and prioritize projects internally. Of these three sites, only Hanford consults with the Technology Development Office in making prioritization decisions.

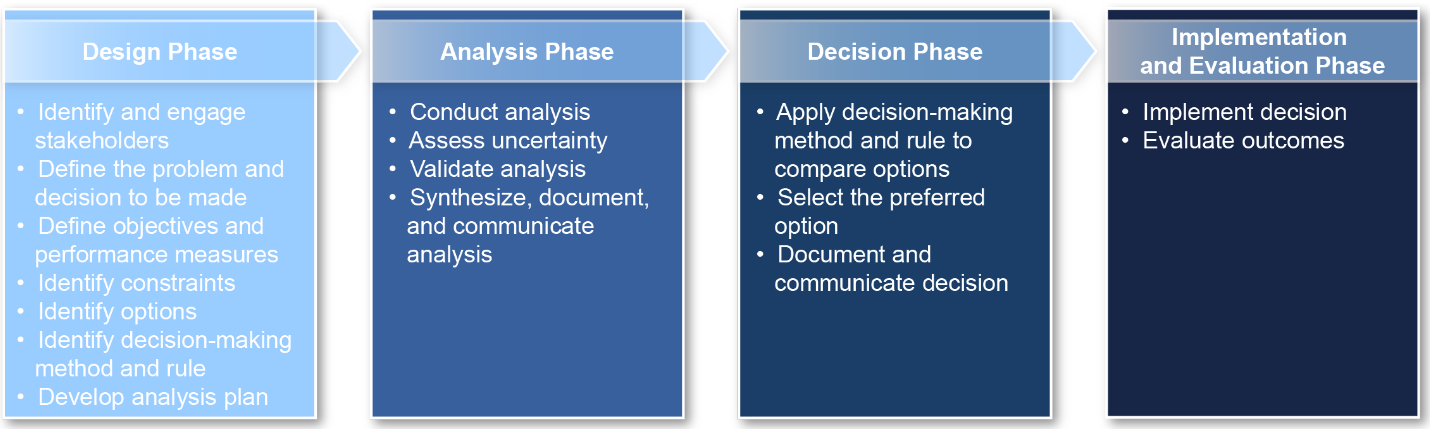
In our prior work on DOE cleanup efforts, we reported that setting national priorities and using a risk-informed decision-making framework could help EM save money and shorten cleanup time frames. In January 2019, we found that implementing a program-wide strategy to set national priorities, rather than prioritizing and funding cleanup activities by individual sites, would help EM better balance risks and costs across and within its sites, save tens of billions of dollars, and accelerate cleanup projects.[47] In September 2019, we found that by applying a risk-informed decision-making framework, EM would be better positioned to effectively set priorities within and across its sites and enhance its ability to direct its

[46]An Integrated Priority List is a management tool that ranks program activities according to their importance for meeting mission requirements and provides senior managers with an understanding of how various funding scenarios would affect program activities.

[47]GAO, *Department of Energy: Program-Wide Strategy and Better Reporting Needed to Address Growing Environmental Cleanup Liability,* GAO-19-28 (Washington, D.C.: Jan. 29, 2019).

limited resources to address those priorities.[48] The essential elements of the risk-informed decision-making framework, which we outlined in our September 2019 report, consist of 16 steps across four phases (see fig. 5). The first phase—the design phase—lays the groundwork for risk-informed decision-making throughout subsequent phases.[49] Organizations applying the framework should tailor the depth and extent of the phases and steps to the nature and significance of the decision being made.[50]

Figure 5: Phases and Steps in a Risk-Informed Decision-Making Framework



Source: GAO. | GAO-22-104490

The Technology Development Office has taken some steps toward applying risk-informed decision-making as outlined in the design phase, such as defining the problem, according to our review of the office's documents and our interviews with officials. Specifically, as described above, the Technology Development Office uses various mechanisms to

[48]GAO-19-339. Specifically, we recommended that DOE (1) revise its cleanup policy to establish how the EM program and DOE sites should apply the essential elements of a risk-informed decision-making framework into their decision-making, and (2) incorporate the essential elements of risk-informed decision-making into its program plan. DOE agreed with those recommendations. Although it had not implemented them as of September 2021, DOE noted in its response to our September 2019 report that the agency was working to develop a program-wide strategy to address risks in a more consistent manner to better align cleanup plans and activities with programmatic priorities and available budgets.

[49]The seven steps in the design phase are (1) identifying and engaging stakeholders, (2) defining the problem and decision to be made, (3) defining objectives and performance measures, (4) identifying constraints, (5) identifying options, (6) identifying a decision-making method and rule, and (7) developing an analysis plan.

[50]GAO-19-339.

identify R&D needs, such as through site managers and workshops. The office has also taken steps toward defining objectives and performance measures. For example, the *Technology Development Framework* describes the program's focus on solutions that support the EM cleanup mission through enhanced worker safety or that reduce risks, schedule, and/or costs of cleanup and have a significant effect on site closures. Technology Development officials told us that they apply performance measures to R&D projects that receive funding from their office.

However, the Technology Development Office has not taken other steps integral to a risk-informed decision-making approach for its own decisions or to guide site decisions. For example, the office has not identified a formal, systematic method to integrate information into a basis for making a decision, along with an associated decision rule that specifies which option should be considered "best" under that method.[51] Such formal decision-making methods provide a rigorous, transparent way to evaluate trade-offs among objectives.[52] The Technology Development Office and other DOE offices developed individual documents that inform or describe R&D priorities. These documents set forth priorities within individual functional areas, such as EM's mission elements (e.g., tank waste) or technology types (e.g., robotics); as previously noted, EM also participated in an Office of Science workshop to identify priorities for basic research. However, the Technology Development Office has not developed a rule or method for making decisions across these areas. For example, the priorities listed in the *Technology Development Framework*

[51]For example, one such method is "multiattribute utility theory," a type of multicriteria decision analysis for making decisions that have multiple, competing objectives. This method involves calculating a numerical score for each of the options under consideration as a way to evaluate their relative merit. To calculate a score, the performance of an option with respect to an individual objective is estimated, and then the individual estimates are summed or averaged into an overall score for that option. Objectives may be assigned weights as a way to express decision-maker or stakeholder preferences about the comparative importance of the objectives. For example, an option's performance with respect to reducing risks to human health may be weighted more heavily than its performance with respect to costs. The overall score for an option represents its expected utility, or value. For a risk-informed cleanup decision, decision rules that could be informed by such decision-making methods include selecting the option that minimizes either: (1) human health risks subject to constraints on cost and any other factors, or (2) cost subject to constraints on human health risks and any other factors. GAO-19-339.

[52]GAO-19-339.

cover nearly all the elements of EM's mission; accordingly, the document does not provide a framework for making selections among priorities.[53]

In addition, the Technology Development Office's prioritization process—including its Standard Operating Policies and Procedures for evaluating and approving funding proposals—provide guidance only for the small portion of R&D funding that the office controls.[54] As noted earlier, EM officials stated that they aim to manage the R&D program as a single portfolio, and that the Technology Development Office is responsible for all R&D efforts across EM. They also stated that the office is tasked with integration of R&D activities throughout the complex to facilitate coordination, prevent duplication of efforts, and ensure that R&D spending aligns with overall priorities. However, the Technology Development Office does not provide guidance on prioritizing R&D spending to the sites or laboratories, which spend the vast majority of R&D funds across the EM complex.

Throughout the course of our review, several officials told us that they face two key constraints, which may inform prioritization of R&D efforts: resource constraints and regulatory constraints. Risk-informed decision-making provides a framework for addressing both of these constraints, as we previously found.[55] Specifically:

[53]The *Technology Development Framework* identifies the following as priorities: Tank Waste Treatment, Soil and Groundwater Remediation, Facility Decontamination and Decommissioning, Spent Fuel and Nuclear Material Disposition, EM Spent Nuclear Fuel disposition and storage, and Program Enablers (such as sample collection, laboratory and in-situ analysis, robotics and remote systems, and artificial intelligence/machine learning). EM's strategic vision documents identify the same priorities (program enablers are referred to as "activities to maintain a safe, secure, and compliant posture"), as well as one additional priority area: disposition of transuranic and mixed low-level waste. Technology Development officials told us that this mission element was not an R&D priority.

[54]As noted earlier, EM could not provide a total for annual cleanup-related R&D expenditures throughout the complex. We identified a minimum of $110 million in such expenditures, between the $30 million expended by the Technology Development Office and the $80 million expended by the sites. Of the $30 million, the Technology Development Office decides how to spend about $15 million, and $15 million is congressionally directed. The Laboratory Policy Office also contributes $6 million to R&D expenditures, and the sites and laboratories may expend up to another $180 million.

[55]GAO-19-339.

Technology Needs at Nuclear Cleanup Sites: Detection and Monitoring

Officials from across the Department of Energy's Office of Environmental Management (EM) complex identified advancements in detection and monitoring as a key technology development need.

Non-destructive techniques. Officials from several sites cited a need for non-destructive techniques for measuring radiation levels within a structure or component (such as a building or pipe). Portsmouth officials said that workers often must cut open large components to measure radiation levels, making radiation detection a labor-intensive activity. Nevada National Security Site officials said that additional non-destructive technologies, such as larger x-ray devices, would enable them to detect and monitor waste inside a cargo or soft-sided container without destroying it or its inner linings.

Automated detection and monitoring. There is also a need for automated detection and monitoring technologies, such as drones, according to site officials. For example, Oak Ridge officials are considering the use of such technology for monitoring efforts related to bioremediation of water contaminated with mercury. Waste Isolation Pilot Plant officials said that drones could facilitate emergency response in the underground repository.

Long-term monitoring. Advancements are needed to make detection and monitoring technologies more effective in the long term, for example, in terms of resiliency to climatic events such as droughts, according to laboratory officials. One official said that research is needed to test the durability and resilience of currently deployed sensors for monitoring. Another official said that artificial intelligence is a priority technology need for managing the large amounts of data that result from long-term monitoring.

Remote monitoring. Site officials also discussed the need for advancements in remote monitoring technologies. For example, Waste Isolation Pilot Plant officials said the site needs technologies to remotely monitor the steel bolts holding up the repository's ceiling. Pacific Northwest National Laboratory officials said that advanced remote-monitoring technology would be useful for post-closure monitoring of former EM sites. According to Oak Ridge officials, remote-monitoring technologies would reduce worker exposure during site characterization and cleanup.

Source: GAO analysis of DOE information.| GAO-22-104490

- **Resource constraints**. Many EM, site, and laboratory officials that we interviewed told us that they face resource constraints, including limited budgets for R&D and restrictions on how some R&D funds can be spent. According to many of these officials, these constraints result in pressures to direct R&D resources toward efforts that address immediate operational needs rather than to forward-looking R&D efforts that could bring long-term efficiencies and gains for worker safety. Historically, the Technology Development Office has directed resources toward such forward-looking research, but Technology Development officials have said that setting aside even one percent of the program's funds for such investments would be a challenge in light of the office's current resource constraints. Prior studies of EM's R&D efforts have identified concerns about EM's level of investment in basic and breakthrough research in favor of incremental research. In addition, our prior work has found that effective management of R&D portfolios requires balancing investments between incremental R&D, which is tied to near-term products, and disruptive R&D, which is intended to deliver innovative technologies that can provide longer-term growth.[56] Risk-informed decision-making could provide a framework for managing constraints related to budgets and balancing such tradeoffs, such as by developing a decision-making method or rule that factors in budgetary considerations. For example, DOE's Office of Legacy Management has developed a risk-informed decision-making framework that includes a complexity factor to weigh sites' budgets in its overall calculation. This example illustrates how agencies can use a risk-informed decision-making framework to weigh factors such as potential cost savings and efficiency gains over time, which provides a basis for balancing long-term resource considerations with immediate-term constraints when making decisions.

- **Regulatory constraints**. Some EM site and laboratory officials told us that regulatory factors, such as concerns about regulator acceptance and delays in approval due to heavy regulator workload, have posed challenges to EM's ability to adopt certain technologies. For example, one official described a situation in which regulatory standards drove disproportionate spending toward R&D efforts that were unlikely to yield solutions.[57] Risk-informed decision-making provides a framework for managing such regulatory constraints. Specifically, the purpose of risk-informed decision-making is to consider trade-offs among risks to human health and the environment, cost, and other factors in the face of uncertainty and diverse stakeholder perspectives. Under the framework, decision-making should not be limited by regulatory or statutory constraints, such as federal or state cleanup requirements, because these constraints may not be fixed. For example, agencies should consider opportunities to negotiate or pursue waivers or changes to these types of constraints where appropriate, so that the decision-making process stays as open as possible to creative solutions.[58]

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[56]GAO, *Defense Science and Technology: Adopting Best Practices Can Improve Innovation Investments and Management,* GAO-17-499 (Washington, D.C.: June 29, 2017).

[57]Specifically, according to this official, there are no technologies currently available to restore groundwater to the standard in certain regulations, despite significant investment in related R&D. According to this official, more effective R&D investments would include critical assessments of existing approaches and predictive modeling of approaches under development.

[58]GAO-19-339

Risk-Informed Decision-Making for Research & Development: The Office of Legacy Management Approach

The Department of Energy's (DOE) Office of Legacy Management (LM) is charged with long-term environmental surveillance and maintenance at sites where active cleanup is complete to ensure the continued protection of human health and the environment.

In September 2019, LM began conducting an annual systematic risk screening process to better prioritize its resources. This aligns with recommendations we made to DOE's Office of Environmental Management in September 2019 related to risk-informed decision-making, which we have found positions agencies to more effectively set priorities.

LM's screening process evaluates key elements that help protect human health, influence how the sites are managed, and directly affect final outcomes. The process results in a Long-Term Stewardship index that allows LM to generally rank sites using categories. LM officials said that this index was the "cleanest" way to make comparisons across more than 100 different sites.

We observed that LM's risk-informed decision-making index fulfilled a key step in the design phase of the framework—identifying constraints—by developing an overview of the regulatory drivers for each LM site. LM also fulfilled another key step—identifying a decision-making method—by identifying four main risk categories: (1) human health risk, (2) stakeholder risk, (3) regulatory risk, and (4) institutional control risk, which includes administrative and legal controls. LM then developed a formula to calculate a ranking for each site in its index. The formula included a complexity factor to compare site budget against risk.

LM officials told us they use the index to ensure alignment between the highest ranking sites and LM's spending and to assess systemic trends across the program.

Source: GAO analysis of LM information and of GAO, *Environmental Liabilities: DOE Would Benefit from Incorporating Risk-Informed Decision-Making into Its Cleanup Policy*, GAO-19-339 (Washington, D.C.: Sept. 18, 2019 | GAO-22-104490.

During our review, Technology Development officials told us they had not developed a risk-informed decision-making framework because the office believed its current process for prioritization was appropriate, given the small proportion of overall R&D spending it has control over. They also told us that they believed this process was risk-informed, and that they were in the process of developing a program plan that would address prioritization in greater detail. However, based on the information these officials provided us, it is unclear when this plan will be complete, whether it will address only funding the office controls or complex-wide R&D investments, and whether it will incorporate risk-informed decision-making. Furthermore, in comments on a draft of this report, Technology Development officials stated that they were working on developing a risk-informed decision-making framework, but they did not provide any details about their approach such as any decision-making methods or rules they plan to use to weigh priorities and balance tradeoffs. By establishing a comprehensive risk-informed decision-making framework for R&D investments across the EM complex, EM would be better positioned to provide sites with guidance for R&D spending beyond their immediate operational needs and to direct its limited R&D resources to its highest priorities.

Conclusions

R&D plays an essential role in efforts by DOE's EM program to clean up contamination at 16 sites around the country remaining from 75 years of federal nuclear weapons production and energy research. Studies have found that investing in R&D may help EM identify safer, more effective, and cost-efficient cleanup approaches—especially needed because the federal government's environmental liability associated with cleaning up radioactive and hazardous waste is now over $400 billion and growing.

While EM's coordination efforts on cleanup-related R&D generally align with most leading practices for interagency collaboration, stakeholders across the complex operate on different understandings of what constitutes R&D, which has affected EM's ability to identify, track, and evaluate its R&D investments. Without a common definition of R&D for all EM stakeholders, sites may not be identifying and reporting to EM all R&D efforts taking place. By developing and disseminating a common definition of R&D, EM would have better assurance that it collects the quality information it needs to systematically track R&D efforts across the complex and to ensure that its R&D stakeholders are maximizing their collaborative efforts. Similarly, without a system to track R&D

expenditures across the complex, EM may have limited assurance that it is optimally aligning its resources with R&D needs. By systematically tracking expenditures throughout the complex, EM would have more assurance that it is collecting complete information about R&D expenditures and that it can identify the resources it needs to sustain collaborative efforts.

Further, without a mechanism or system to collect comprehensive data on R&D activities throughout the complex, EM is limited in its ability to monitor and evaluate the results of EM's R&D activities. By systematically collecting data on collaborative R&D efforts, including those funded by both the Technology Development Office and individual site budgets, EM would be better able to monitor and evaluate the outcomes of R&D efforts and would have better assurance that it is getting a positive return on its R&D investments. Doing so could also provide EM with valuable information on the characteristics of those R&D efforts that it may wish to encourage and those it may wish to discourage, and could enable EM to reduce potentially duplicative and overlapping R&D efforts.

Finally, according to EM officials, the Technology Development Office at headquarters has direct influence over a small portion of overall R&D funding—less than $15 million of at least $110 million and up to approximately $300 million in annual R&D funding. Nevertheless, this office has the ability to leverage a network of sites, laboratories, and stakeholders that have a collaborative structure in place, but without a comprehensive framework for prioritizing its R&D efforts, EM lacks assurance that it is directing its limited R&D resources to its highest priorities. We have reported that adopting a risk-informed decision-making framework can help agencies apply a defensible method for weighing numerous inputs, comparing options, and implementing decisions. By establishing a comprehensive approach to prioritizing R&D across the EM complex through a risk-informed decision-making framework, EM would be better positioned to provide sites with guidance for R&D spending beyond their immediate operational needs and would be better positioned to direct its limited R&D resources to its highest priorities.

Recommendations for Executive Action

We are making the following four recommendations to DOE:

- The Assistant Secretary for Environmental Management should develop and disseminate a common definition of R&D throughout the EM complex. (Recommendation 1)
- The Assistant Secretary for Environmental Management should systematically and comprehensively track R&D funding throughout the EM complex. (Recommendation 2)
- The Assistant Secretary for Environmental Management should deploy a system to collect comprehensive data on R&D efforts to enable EM to monitor and evaluate outcomes throughout the EM complex. (Recommendation 3)
- The Assistant Secretary for Environmental Management should develop a comprehensive approach to prioritizing R&D investments across the EM complex that follows a risk-informed decision-making framework. (Recommendation 4)

Agency Comments

We provided a draft of this report to DOE for review and comment. In its comments, reproduced in appendix III, DOE concurred with all four of our recommendations. DOE stated that it believes its actions thus far have satisfied two of our recommendations and that it is implementing and will continue to implement the other two recommendations. However, we believe further action is needed to address all four recommendations. Specifically:

- In response to our recommendation about developing and disseminating a common definition of R&D, DOE noted that EM has already implemented our recommendation and uses a “universally accepted” definition of R&D. However, we found that stakeholders throughout the EM complex varied in how they defined R&D, which contributed to the agency’s limitations in tracking and monitoring R&D throughout the complex. We continue to believe that disseminating a common definition throughout the complex will allow sites to more consistently document and report all relevant efforts as R&D to the Technology Development Office, which will in turn enable EM to more consistently collect information on and measure the effectiveness of complex-wide R&D efforts.
- In response to our two recommendations about tracking R&D funding and activities, EM officials noted that the dashboard they are developing would be available by the end of 2021 and would capture

all the technology and development activities managed by headquarters. However, DOE did not state whether the dashboard would capture the majority of EM's R&D activities—specifically, those managed by EM sites. As such, while the dashboard may provide a tool to facilitate coordination, it remains unclear to what extent it will enable systematic and comprehensive tracking of R&D funding and activities. DOE also noted that EM has started tracking funding to the national laboratories, which includes funding for R&D. However, as we found during the course of our review, EM was unable to collect these data at the level of detail needed to specify R&D funding and activities, and it remains unclear whether EM plans to do so. We continue to believe that systematically tracking R&D expenditures and activities throughout the complex would better enable EM to identify the resources it needs to sustain collaborative R&D efforts and to systematically monitor and evaluate the effectiveness of its R&D investments.

- Regarding our recommendation about using a risk-informed decision-making framework to prioritize R&D investments, DOE stated that EM is already implementing a comprehensive approach to prioritization and listed its overall cleanup prioritization criteria. However, these criteria are broad, and it remains unclear how EM plans to balance them, particularly within its limited R&D resources. We maintain that EM should develop a risk-informed decision-making framework to prioritize its R&D investments. Such a framework could provide a formal, systematic method to integrate information into a basis for making decisions about how to prioritize R&D funding, along with an associated decision rule that specifies which option should be considered "best" under that method. For example, DOE may use such a method to assign weights to the comparative importance of objectives, such as reducing risks to human health and cost effectiveness—two of the prioritization criteria DOE listed in its response. As we describe in our report, this framework serves as a tool to balance tradeoffs and manage constraints, such as those related to budgets and regulatory factors.

DOE also provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Energy, and other interested parties. In addition, this report is available at no charge on the GAO website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-3841 or andersonn@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix IV.

Nathan Anderson
Director, Natural Resources and Environment

Appendix I: Objectives, Scope, and Methodology

Our report examines (1) how the Department of Energy's (DOE) Office of Environmental Management (EM) identifies cleanup-related research and development (R&D) needs, (2) how and the extent to which EM coordinates R&D across the EM complex, and (3) the extent to which EM prioritizes cleanup-related R&D efforts.

To address all three objectives, we reviewed various DOE and external documents and interviewed officials. Specifically, we reviewed documents such as DOE's congressional budget justifications for EM from fiscal years 2011 to 2021, EM's strategic vision documents for 2020 and 2021, EM's *Technology Development Framework*, and EM site assessments of R&D efforts conducted within the past three years.[1] In addition, we reviewed technology assessments and other studies from DOE's national laboratories, such as a Savannah River National Laboratory study on groundwater monitoring wells at cleanup sites and an Idaho National Laboratory report on technical considerations for extended storage of aluminum-clad spent nuclear fuel. We reviewed legislation related to EM's R&D efforts, such as annual appropriations legislation from fiscal years 2011 to 2021. We also reviewed reports from the National Academies of Sciences, Engineering, and Medicine and the Secretary of Energy Advisory Board.[2]

[1]U.S. Department of Energy, Office of Environmental Management, *EM Vision 2020-2030: A Time of Transition and Transformation* (Washington, D.C.: March 2020); U.S. Department of Energy, Office of Environmental Management, *EM Strategic Vision: 2021-2031* (Washington, D.C.: April 2021); and U.S. Department of Energy, Office of Environmental Management, *Technology Development Framework* (Washington, D.C.: January 2021).

[2]National Academies of Sciences, Engineering, and Medicine, *Independent Assessment of Science and Technology for the Department of Energy's Defense Environmental Cleanup Program* (Washington, D.C.: The National Academies Press, 2019); Secretary of Energy Advisory Board, Department of Energy, *Report of the Task Force on Technology Development for Environmental Management* (Washington, D.C.: 2014), accessed August 30, 2020, https://www.energy.gov/sites/prod/files/2015/01/f19/Report%20of%20the%20SEAB%20Task%20Force%20on%20Tech%20Dev%20for%20EM_FINAL.pdf. Our literature search did not identify additional relevant reports.

We interviewed DOE officials representing EM leadership, EM's Technology Development Office, and other relevant DOE offices, including the Office of Science, Office of Legacy Management, and the Advanced Research Projects Agency-Energy (ARPA-E). We also interviewed officials representing 12 of EM's 16 active cleanup sites. We did not interview officials from the other four sites—Brookhaven National Laboratory, the Separations Process Research Unit, the Moab Uranium Mill Tailings Remedial Action site, and the Energy Technology Engineering Center—because they decided not to participate, stating that they did not have a role in cleanup-related R&D. Where appropriate, we summarized the information gathered from officials and representatives in the report by using "some" to refer to two or three members of a group, "several" to refer to four or five members of a group, and "many" to refer to more than five members of a group.

To examine how EM identifies clean-up related R&D needs, we reviewed DOE and national laboratory documents and interviewed EM, site, and laboratory officials about how they identify and address R&D needs. For example, we reviewed a 2016 Office of Science report, *Basic Research Needs for Environmental Management*, which summarizes research needs identified in an Office of Science workshop on basic research for cleanup technology. We also reviewed a Sandia National Laboratories report summarizing a 2020 workshop in which participants discussed R&D needs for the Waste Isolation Pilot Plant.[3] We also reviewed DOE laboratories' annual reports on laboratory-directed research and development from 2017 to 2020.

To evaluate the extent to which EM coordinates R&D collaboration across the EM complex, we reviewed EM and other DOE documents and interviewed officials from EM and other relevant DOE offices, as well as representatives from the national laboratories. We defined the EM complex as containing EM's 16 sites and DOE national laboratories that participate in cleanup-related R&D. We also reviewed documents and interviewed officials representing other DOE offices with a role or potential role in cleanup-related R&D, such as the Office of Science, Office of Legacy Management, and ARPA-E. We reviewed documents including the following:

[3]Sandia National Laboratories, "Alleviate Operational Challenges at WIPP Workshop," SAND2020-14327 (Albuquerque, NM: December 2020).

- EM's *Network of National Laboratories for Environmental Management and Stewardship (NNLEMS) Charter*, which describes the purpose, roles, and responsibilities of the laboratories and of agency officials in the network;[4]
- EM's International Program strategic plan, which outlines strategic objectives for international collaboration;[5] and
- other EM planning documents, such as its *National Laboratory Governance Framework*, Innovation and Technology framework, and robotics roadmap.[6]

We also reviewed the Energy Act of 2020, which established a new goal for ARPA-E to develop nuclear cleanup-related technologies.[7] In addition, we interviewed EM and national laboratory officials who oversee and conduct research throughout the EM complex about EM's coordination practices.

To examine the extent to which EM coordinates R&D across the EM complex, we assessed the information from the aforementioned document reviews and interviews and compared EM's coordination efforts to seven leading practices we have previously found to enhance and sustain collaborative efforts: (1) establishing clear leadership; (2) documenting collaboration through written guidance and agreements; (3) clarifying the roles and responsibilities of each agency; (4) including relevant participants; (5) bridging organizational cultures; (6) identifying and leveraging resources; and (7) defining outcomes and achieving

[4]U.S. Department of Energy Office of Environmental Management, *Network of National Laboratories for Environmental Management and Stewardship (NNLEMS) Charter* (Washington, D.C.: 2021).

[5]U.S. Department of Energy Office of Environmental Management, International Program *Moving Forward: Strategic Plan 2015-2020 Building Upon Strong International Partnerships* (Washington, D.C.: June 2016).

[6]U.S. Department of Energy Office of Environmental Management, *National Laboratory Governance Framework* (Washington, D.C.: October 2016); U.S. Department of Energy Office of Environmental Management, *Innovation and Technology: Charting the Path for Fiscal Years 2017 to 2021* (Washington, D.C.: December 2016); and U.S. Department of Energy Office of Environmental Management, *Research and Technologies Roadmap: Robotics and Remote Systems for Nuclear Cleanup* (Washington, D.C.: 2018).

[7]Energy Act of 2020, Pub. L. No. 116-260, div. Z, tit. X, § 10001 (codified at 42 U.S.C. § 16538).

accountability.[8] The seven leading practices comprise 23 key issues to consider.

To assess EM's coordination efforts compared with these leading practices, we first determined which key issues were applicable to EM's R&D coordination efforts. We determined that certain issues were not applicable. For example, we determined that one key issue within the outcomes and accountability leading practice—whether participating agencies had the means to recognize and reward accomplishments related to collaboration—did not apply to EM's R&D efforts because the nature of R&D collaboration in the EM complex is not conducive to measuring individual performance or to recognizing or rewarding collaboration-related accomplishments. We ultimately determined that 15 of the 23 key issues related to the seven practices applied to EM.

Based on our assessment of the applicable key issues under each leading practice, we rated EM's efforts as (1) fully aligned, (2) partially aligned, or (3) not aligned with each of the seven leading practices. We determined that EM's efforts fully aligned with a leading practice if all of EM's coordination efforts fully aligned with the key issues under the leading practice. We determined that EM's efforts partially aligned with a leading practice if at least half of EM's efforts only partially aligned or did not align with the applicable leading practices. We determined that EM's efforts did not align with the leading practice if EM's efforts did not align with any of the applicable key issues under consideration. To make the determinations, two analysts independently assessed the evidence and came to an agreement on their ratings. In cases when the first two analysts disagreed, a third analyst weighed in on how EM's efforts aligned with the leading practices and came to a final determination of the rating. There was full agreement on all ratings at the conclusion of our analysis.

Finally, we compared EM's coordination on R&D to the *Standards for Internal Control in the Federal Government*, specifically to (1) the monitoring principle that management should establish and operate monitoring activities to monitor the internal control system, and (2) the attribute that agencies obtain relevant data from reliable internal and

[8]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms,* GAO-12-1022 (Washington, D.C.: Sept. 27, 2012).

external sources in a timely manner based on the identified information requirements.[9]

To examine the extent to which EM prioritizes cleanup-related R&D, we compared information from our document reviews and interviews to GAO's risk-informed decision-making framework. Specifically, to assess how EM's prioritization process for R&D aligned with essential elements of risk-informed decision-making, we reviewed EM documents, including EM's Standing Operating Policies and Procedures titled "EM Technology Development Office Task Change Request/Technical Task Plan Proposal Submittal and Approval Process." We also interviewed Technology Development officials, other EM officials, and laboratory representatives and site officials such as project and program managers who were involved in decision-making for prioritizing program-wide or site-specific R&D efforts.

The essential elements of GAO's risk-informed decision-making framework consist of the 16 steps, across four phases, for decision-making when considering trade-offs among risk, cost, and other factors in the face of uncertainty and diverse stakeholder perspectives.[10] In addition to our document reviews and interviews, we requested that the Technology Development Office provide responses to questions corresponding to the steps in each phase. To assess the extent to which EM's R&D prioritization efforts aligned with the framework, we compared information from our document review and interviews, and from EM's responses to this questionnaire, with the 16 steps of the framework.

We conducted this performance audit from September 2020 to October 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe

[9]GAO, *Standards for Internal Control in the Federal Government,* GAO-14-704G (Washington, D.C.: Sept. 10, 2014).

[10]GAO, *Environmental Liabilities: DOE Would Benefit from Incorporating Risk-Informed Decision-Making into Its Cleanup Policy*, GAO-19-339 (Washington, D.C.: Sept. 18, 2019). To assist agencies in identifying and implementing essential elements of risk-informed decision-making, we synthesized key concepts from relevant literature and input from experts who participated in a May 2018 meeting convened by the National Academies of Sciences, Engineering, and Medicine. The framework was developed in the context of environmental cleanup at Department of Energy sites, but the framework itself can be applied to other types of decisions.

that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Review of the Office of Environmental Management's Coordination Efforts for Research and Development

To assess the Office of Environmental Management's (EM) coordination efforts on cleanup-related Research and Development (R&D), we compared these efforts to seven leading practices to help enhance and sustain interagency collaboration that we identified in prior work:[1] (1) establishing clear leadership; (2) documenting collaboration through written guidance and agreements; (3) clarifying roles and responsibilities of each agency; (4) including relevant participants; (5) bridging organizational cultures; (6) identifying and leveraging resources; and (7) defining outcomes and achieving accountability. These leading practices comprise 23 key issues to consider. To determine how EM's coordination efforts aligned with the seven leading collaboration practices, we reviewed EM documents and interviewed EM, laboratory, and site officials, and compared the information from these reviews and documents with the key issues. We conducted the assessment in three steps: (1) we determined which key issues under the leading practices were applicable to EM's R&D coordination efforts, (2) we assessed whether EM's efforts fully aligned, partially aligned, or did not align with the applicable key issues, and (3) we aggregated the ratings on the applicable key issues to determine whether EM fully aligned, partially aligned, or did not align with each of the seven leading practices.[2]

We found that EM's coordination efforts fully align with four of the seven leading practices and partially align with three of the seven leading practices: (1) bridging organizational cultures; (2) identifying and

[1]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms,* GAO-12-1022 (Washington, D.C.: Sept. 27, 2012).

[2]Fifteen of the 23 issues to consider when implementing these leading practices were applicable to EM's R&D coordination efforts. While we have generally found that addressing as many of the key issues under the seven leading practices as possible leads to more effective implementation of collaborative mechanisms, there are a wide range of situations and circumstances for coordination. Consequently, in some cases, addressing a few selected issues may be sufficient for effective collaboration.

leveraging resources; (3) defining outcomes and achieving accountability. Table 1 describes how we assessed EM on each of the seven leading practices based on the key issues to consider for each of these practices.

Table 1: Extent to which the Office of Environmental Management's Coordination Efforts on Research and Development Align with Leading Practices

	Fully Aligned	Partially Aligned	Not Aligned	Not Applicable
Leadership	**X**			
Has a lead agency or individual been identified?	X			
If leadership will be shared between one or more agencies, have roles and responsibilities been clearly identified and agreed upon?	X			
How will leadership be sustained over the long-term?	X			
Written Guidance and Agreements	**X**			
If appropriate, have the participating agencies documented their agreement regarding how they will be collaborating?	X			
Have participating agencies developed ways to continually update or monitor written agreements?				X
Clarity of Roles and Responsibilities	**X**			
Have participating agencies clarified the roles and responsibilities of the participants?	X			
Have participating agencies articulated and agreed to a process for making and enforcing decisions?				X
Participants	**X**			
Have all relevant participants been included?	X			
Do the participants have: full knowledge of the relevant resources in their agency, the ability to commit these resources, the ability to regularly attend activities of the collaborative mechanism, and the appropriate knowledge, skills, and abilities to contribute?	X			
Bridging Organizational Cultures		**X**		
What are the missions and organizational cultures of the participating agencies?				X
Have participating agencies developed ways for operating across agency boundaries?	X			
Have participating agencies agreed on common terminology and definitions?			X	
Resources		**X**		
How will the collaborative mechanism be funded? If interagency funding is needed, is it permitted?	X			
If interagency funding is needed and permitted, is there a means to track funds in a standardized manner?			X	
How will the collaborative mechanism be staffed?	X			
Are there incentives available to encourage staff or agencies to participate?				X
If relevant, do agencies have compatible technological systems?				X

	Fully Aligned	Partially Aligned	Not Aligned	Not Applicable
Have participating agencies developed online tools or other resources that facilitate joint interactions?		X		
Outcomes and Accountability		**X**		
Have short-term and long-term outcomes been clearly defined?	X			
Is there a way to track and monitor progress toward the short-term and long-term outcomes?		X		
Do participating agencies have collaboration-related competencies or performance standards against which individual performance can be evaluated?				X
Do participating agencies have the means to recognize and reward accomplishments related to collaboration?				X

Source: GAO analysis of Department of Energy information. | GAO-22-104490.

Appendix III: Comments from the Department of Energy

Department of Energy
Washington, DC 20585
October 18, 2021

Mr. Nathan Anderson
Director
Natural Resources and Environment
U.S. Government Accountability Office
Washington, D.C. 20548

Dear Mr. Anderson,

This letter provides the Department of Energy (DOE) response to the U.S. Government Accountability Office (GAO) draft report, GAO-22-104490, *Nuclear Waste Cleanup Research & Development*.

DOE concurs with the recommendations in the GAO draft report, which are intended to help ensure that Environmental Management (EM) is using a comprehensive approach to prioritizing research and development (R&D) activities across the EM complex while positioning EM to prioritize limited R&D resources. The actions necessary to address the GAO recommendations are already being taken. DOE continues to identify and evaluate opportunities across the complex to implement new R&D developments to accelerate timelines, reduce risk, and reduce life-cycle costs through more efficient and innovative approaches. Specific responses to the GAO recommendations, as well as technical comments, are enclosed.

DOE is committed to achieving the desired outcome of directing available resources to best address human health, research and development, and environmental risks associated with cleanup at EM sites.

Thank you for the opportunity to provide the DOE perspective on the draft GAO-22-104490 report. If you have any questions, please contact me or Ms. Nicole Nelson-Jean, Associate Principal Deputy Assistant Secretary for Field Operations, at (202) 586-1426.

Sincerely,

William I. White
Acting Assistant Secretary
for Environmental Management

Enclosures

Enclosure 1

Management Response

GAO Draft Report, GAO-22-104490 *Nuclear Waste Cleanup Research & Development*.

Recommendation 1: The Assistant Secretary for Environmental Management (EM) should disseminate a common definition of R&D throughout the EM complex.

Management Response: Concur.

EM currently utilizes a universally accepted research and development (R&D) definition for the program and the agency. Specifically, on November 12, 2020, the Associate Principal Deputy Assistant Secretary for Field Operations (EM-3, Nicole Nelson-Jean), issued guidance entitled, *Technology Development Activities at Environmental Management Field Sites*, which sets forth the definition of technology development, including research and development. EM, also defines technology development on a scale through the Technology Readiness Level.

Estimated Completion Date: Completed.

Recommendation 2: The Acting Assistant Secretary for Environmental Management should systematically and comprehensively track all R&D funding throughout the EM complex.

Management Response: Concur.

EM tracks all funds, including those spent on R&D. While the funds are tracked primarily at the site and laboratory level, EM is currently developing an R&D dashboard that will make the use of R&D more transparent across the complex. The dashboard will capture all the technology and development activities managed by Headquarters and will display relevant data about projects, budget, status, and performance. The goal is to provide more visibility to technology development for Department of Energy (DOE) senior management. The dashboard is being established by the Office of Technology Development, and is expected to be completed, for Headquarters sponsored projects, by the end of the calendar year 2021. The Laboratory Policy Office started tracking EM funding to National Laboratories for both R&D and non-R&D activities in FY 2020 and will continue to collect the data on an annual basis.

Estimated Completion Date: December 31,2021.

Recommendation 3: The Acting Assistant Secretary for Environmental Management should deploy a system to collect comprehensive data on R&D efforts to enable EM to monitor and evaluate results throughout the EM complex.

Management Response: Concur.

EM has taken strides to define outcomes, including providing an overview of program goals and priorities and commissioning assessments of R&D activities undertaken at EM sites. For example, EM's Strategic Vision provides a high-level overview of program goals and priorities,

1

Enclosure 1

such as addressing groundwater contamination at the Savannah River Site through technology deployment.[1] The Strategic Vision informs R&D specific planning documents, such as EM's Technology Development Framework, and cites R&D planning efforts.

In addition, the dashboard, as discussed under recommendation 2 will provide the desired R&D transparency across the EM complex and enable EM to monitor and evaluate results.

Estimated Completion Date: December 31, 2021.

Recommendation 4: The Acting Assistant Secretary for Environmental Management should develop a comprehensive approach to prioritizing R&D investments across the EM complex using a risk-informed decision-making framework.

Management Response: Concur.

EM takes a comprehensive approach to prioritizing all clean-up work across the complex to include R&D needed to execute clean-up as described below.

First and foremost, EM seeks to address any issues posing an immediate risk to human health or the environment. Taking many variables into account, EM's clean-up priorities are as follows:

- Activities to maintain a safe, secure, and compliant status.
- Radioactive tank waste stabilization, treatment, and disposal.
- Spent (used) nuclear fuel storage, receipt, and disposition.
- Nuclear material consolidation, stabilization, and disposition.
- TRU waste and mixed low-level waste disposition.
- Soil and groundwater remediation.
- Excess facilities deactivation and decommissioning.

Accomplishing EM's cleanup missions often depends on completing lower-priority activities first. Specifically, once maintenance of minimum safe conditions and base operations is assured, remaining cleanup priorities are established. This includes continual evaluation of R&D opportunities for innovative cleanup options, using established cleanup prioritization criteria:

- Risk reduction, including public and worker safety, environmental, and technical risks.
- Cost effectiveness savings opportunities and return on investment, affordability and ability to sustain higher funding levels for new higher cost activities.
- Regulatory drivers and other high consequence or interests, such as workforce impacts.
- Readiness to schedule and execute activity (e.g., ensuring that regulatory requirements are met, required contracts are in place).
- Site or Area closure opportunity or completion of a major cleanup activity.

[1] U.S. Department of Energy Office of Environmental Management, *EM's Strategic Vision: 2021-2031* (Washington, D.C.: June 2021).

2

Enclosure 1

In alignment with the EM programmatic priorities, recent Network of National Laboratories for Environmental Management and Stewardship (NNLEMS) work in evaluating R&D needs and developing technical targets has provided useful information for prioritizing investments in technology development across the EM complex. EM will effectively utilize the NNLEMS to advance the effectiveness of the scientific and technical expertise in the DOE National Laboratory Complex toward meeting the objectives of EM's legacy nuclear waste clean-up mission.

Estimated Completion Date: Complete.

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Agency Comment Letter

Text of Appendix III: Comments from the Department of Energy

Page 1

Department of Energy
Washington, DC 20585
October 18, 2021

Mr. Nathan Anderson Director
Natural Resources and Environment
U.S. Government Accountability Office
Washington, D.C. 20548

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Estimated Completion Date: Complete.

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

Nathan Anderson, Director, Natural Resources and the Environment, (202) 512-3841 or andersonn@gao.gov

Staff Acknowledgments

In addition to the individual named above, Amanda K. Kolling, Assistant Director; Alisa Beyninson, Analyst-In-Charge; Antoinette Capaccio, Tara Congdon, and Jasmine Latiolais made key contributions to this report. Also contributing to this report were Christopher R. Durbin, Charlotte E. Hinkle, Cindy Gilbert, Sara Sullivan, Evonne Tang, and Sarah Veale.

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