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Congressional Requesters

September 2019

ENVIRONMENTAL LIABILITIES

DOE Would Benefit from Incorporating Risk-Informed Decision-Making into Its Cleanup Policy

Accessible Version

GAO-19-339

GAO Highlights

Highlights of GAO-19-339, a report to congressional requesters

Why GAO Did This Study

As of 2018, the U.S. government faced an estimated $577 billion in environmental liabilities. DOE is responsible for more than 85 percent of these liabilities. DOE is charged with cleaning up contamination from nuclear weapons production and energy research dating back to World War II and the Cold War, which generated large quantities of liquid and solid radioactive waste and contaminated soil and water. Since the mid-1990s, GAO and others have recommended that DOE adopt a risk-informed approach to making cleanup decisions—that is, an approach that helps agencies consider trade-offs among risk, cost, and other factors in the face of uncertainty and diverse stakeholder perspectives.

GAO was asked to review DOE's environmental cleanup decision-making. This report examines (1) the extent to which DOE has a framework for making risk-informed cleanup decisions, and (2) essential elements of a framework for making risk-informed cleanup decisions. GAO conducted a literature review, interviewed DOE officials, and convened an experts' meeting through the National Academies regarding risk-informed decision-making.

What GAO Recommends

GAO is making two recommendations, including that DOE revise EM's 2017 cleanup policy to establish how EM should

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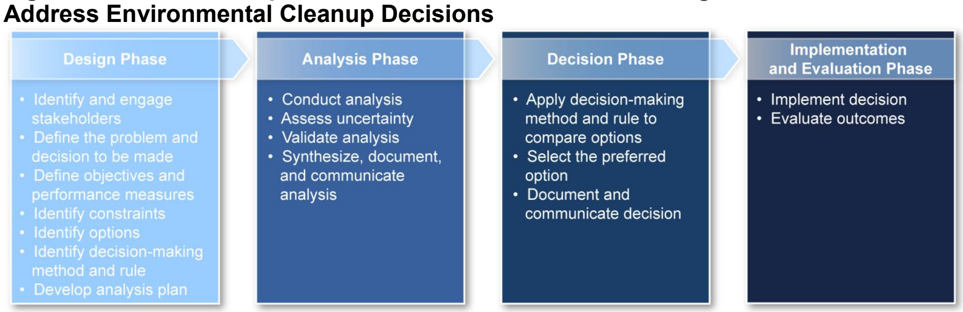
DOE Would Benefit from Incorporating Risk-Informed Decision-Making into Its Cleanup Policy

What GAO Found

The Department of Energy's (DOE) Office of Environmental Management (EM) follows certain laws—including the Comprehensive Environmental Response, Compensation, and Liability Act and the Resource Conservation and Recovery Act—agreements, federal guidance, and court decisions, which establish standards and procedures for DOE's cleanup of hazardous and radioactive waste. However, DOE does not have a framework for implementing these requirements and guidance to make cleanup decisions in a risk-informed manner. For example, DOE's 2017 cleanup policy, which governs the EM cleanup program, does not direct how EM should make environmental cleanup decisions, including how to make risk-informed cleanup decisions. For more than 20 years, several organizations—including the DOE Inspector General and GAO—have recommended that DOE adopt a risk-informed approach. By revising EM's 2017 cleanup policy to establish how EM should apply the essential elements of a risk-informed decision-making framework into its current decision-making requirements and guidance, DOE sites would be better able to implement consistent decision-making processes and ensure that resource allocation is risk informed to the extent practicable.

To assist agencies, such as DOE, in identifying and implementing the essential elements of risk-informed decision-making, GAO synthesized key concepts from relevant literature and input from experts who participated in GAO's meeting convened by the National Academies of Sciences, Engineering, and Medicine (National Academies). GAO subsequently developed a framework to be relevant to multiple types of cleanup decisions, from selecting a cleanup approach at a single site to prioritizing cleanup activities across sites. According to literature, entities implementing the framework should ensure that their decision-making process is participatory, logical, transparent, and traceable, and that it uses current scientific knowledge to produce technically credible results. The framework consists of four broad phases: (1) designing the decision-making process, (2) analyzing different options, (3) deciding which option is preferred, and (4) implementing and evaluating the preferred option. Each phase consists of several steps, such as identifying stakeholders, developing an analysis plan, and validating the analysis (see figure).

Figure: Phases and Steps of a Risk-Informed Decision-Making Framework to Address Environmental Cleanup Decisions



Source: GAO. | GAO-19-339

Data for Highlights Figure: Phases and Steps of a Risk-Informed Decision-Making Framework to Address Environmental Cleanup Decisions

Flow chart showing 4 phases.

1. Design Phase:

- Identify and engage stakeholders
- Define the problem and decision to be made
- Define objectives and performance measures
- Identify constraints
- Identify options
- Identify decision-making method and rule
- Develop analysis plan

2. Analysis Phase:

- Conduct analysis
- Assess uncertainty
- Validate analysis
- Synthesize, document, and communicate analysis

3. Decision Phase:

- Apply decision-making method and rule to compare options
- Select the preferred option
- Document and communicate decision

4. Implementation and Evaluation Phase:

- Implement decision
- Evaluate outcomes

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Abbreviations

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CRESP	Consortium for Risk Evaluation with Stakeholder Participation
DOE	Department of Energy
EM	Office of Environmental Management
EPA	Environmental Protection Agency
National Academies	National Academies of Sciences, Engineering, and Medicine
RCRA	Resource Conservation and Recovery Act

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Congressional Requesters

As of fiscal year 2018, the U.S. government faced an estimated $577 billion in environmental liabilities—the estimated cost to clean up areas where federal activities have contaminated the environment, including hazardous and radioactive waste resulting from nuclear weapon production.[1] The Department of Energy (DOE) is responsible for the largest share of reported federal environmental liabilities—about 86 percent in fiscal year 2018. DOE's liabilities include cleaning up contamination from nuclear weapons production and energy research dating back to World War II and the Cold War, which generated millions of gallons of liquid and solid radioactive waste, millions of cubic meters of solid radioactive waste, thousands of tons of spent nuclear fuel and special nuclear material, and large quantities of contaminated soil and water.[2]

The federal government's environmental liabilities have been growing for the past 20 years and are likely to continue to increase. In 2017, we designated the federal government's environmental liabilities as a high-risk area because of the large and increasing estimated costs of cleaning up these sites.[3] We found that because of the lack of complete information and the often inconsistent approach to making cleanup decisions, federal agencies cannot always address their environmental

[1]Department of Treasury, *FY18 Financial Report of the United States Government* (Washington, D.C., 2019). For the purpose of this report, environmental liabilities include both environmental and disposal liabilities.

[2]The Department of Defense is responsible for the second largest share of reported federal environmental liabilities—about 12 percent in fiscal year 2018—which includes cleanup responsibilities stemming from base realignment and closure activities and the disposal of weapon systems. The rest of the federal government makes up the remaining 2 percent of the liabilities, with agencies such as the National Aeronautics and Space Administration and the Departments of Transportation, Veterans Affairs, Agriculture, and the Interior holding liabilities that relate to their missions. For example, the Department of the Interior and the Department of Agriculture's environmental liabilities include cleanup of potentially contaminated abandoned mines.

[3]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.

liabilities in ways that balance the benefits of reducing risks to human health and the environment with the costs of achieving those reductions, and in doing so, achieve the greatest reduction in risk given limited resources. We also found that future progress in addressing the federal government's environmental liabilities depends, among other things, on how effectively federal departments and agencies set priorities. This will occur under increasingly restrictive budgets that underscore the importance of selecting cost-effective solutions.

Independent reviews conducted since the mid-1990s have found that DOE and other agencies would benefit from adopting a risk-informed approach to making cleanup decisions—that is, a decision-making approach that helps agencies consider trade-offs among risks to human health and the environment, cost, and other factors in the face of uncertainty and diverse stakeholder perspectives. In the context of this report, we define "risk" in terms of the probability and adverse consequences to human health or to the environment of exposure to an environmental hazard. These reviews have found that agencies could benefit from prioritizing federal funding in a way that better manages risks while considering limited resources. For example, the National Academies of Sciences, Engineering, and Medicine (National Academies) has reported for over a decade that DOE's cleanup strategy could benefit from a risk-informed framework for making cleanup decisions.[4] In addition, in 2015, a review organized by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) reported that DOE is not optimally using available resources to reduce risks to human health

[4]See, for example, National Research Council of the National Academies, Committee on Risk-Based Approaches for Disposition of Transuranic and High-Level Radioactive Waste, *Risk and Decisions About Disposition of Transuranic and High-Level Radioactive Waste* (Washington, D.C.: The National Academies Press, 2005). National Research Council of the National Academies, Committee on Improving Practices for Regulating and Managing Low-Activity Radioactive Waste, *Improving the Regulation and Management of Low-Activity Radioactive Waste*s (Washington, D.C.: The National Academies Press, 2006). National Research Council of the National Academies, Committee on Best Practices for Risk-Informed Remedy Selection, Closure and Post-Closure of Contaminated Sites, *Best Practices for Risk-Informed Decision Making Regarding Contaminated Sites: Summary of a Workshop Series* (Washington, D.C.: The National Academies Press, 2014).

and the environment.[5] The report called for a more systematic effort to assess and rank risks within and among sites, including through DOE's headquarters' guidance to sites, and to allocate federal taxpayer monies to manage the highest-priority risks through the most cost-effective means.

Leading decision-making, risk assessment, and risk management practices have been documented by numerous agencies, organizations, and academic entities, and these approaches share similar underlying themes. However, there is no one common or widely-accepted approach to making risk-informed decisions to address environmental cleanup responsibilities.

You asked us to review DOE's environmental cleanup decision-making in the context of risk-informed decision-making. This report (1) examines the extent to which DOE has a framework for making risk-informed cleanup decisions; and (2) identifies essential elements of a framework for making risk-informed cleanup decisions.

To examine the extent to which DOE has a framework for making risk-informed cleanup decisions, we reviewed key legal requirements, including the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 as amended (CERCLA) and the Resource Conservation and Recovery Act of 1976 as amended (RCRA). We also interviewed officials from DOE's Office of Environmental Management's (EM) Office of Regulatory Compliance regarding the extent to which DOE has a framework for risk-informed decision-making and the challenges, if any, that it faces in making risk-informed cleanup decisions.[6] We also analyzed DOE's orders and policies to determine what orders, policies, or guidance it has to make risk-informed cleanup decisions.

[5]Omnibus Risk Review Committee, *A Review of the Use of Risk-Informed Management in the Cleanup Program for Former Defense Nuclear Sites*, prepared for the U.S. Senate Committee on Appropriations and the U.S. House of Representatives Committee on Appropriations, August 2015. The explanatory statement accompanying the Consolidated Appropriations Act, 2014 directed DOE to retain a respected outside group to, among other things, undertake an analysis of how effectively DOE identifies, programs, and executes its plans to address risks to public health and safety from DOE's remaining environmental cleanup liabilities. EM requested that the Consortium for Risk Evaluation with Stakeholder Participation—an independent, multi-disciplinary consortium of universities led by Vanderbilt University—organize this review.

[6]EM manages most of DOE's cleanup activities for legacy defense waste and energy research.

To identify essential elements of a framework for making risk-informed cleanup decisions, we conducted a literature review of reports and studies on risk and decision-making in the context of environmental cleanup. We reviewed our prior reports on environmental cleanup, risk, and decision-making; reports from the National Academies; reports and studies from government agencies; and academic research. Specifically, we gathered information from our literature review about essential steps within a risk-informed decision-making process, including information about why each step is important and who should perform each step. Based on the results of our literature review, we developed a draft framework of essential elements for making risk-informed cleanup decisions. We worked with the National Academies to select 15 experts and convene a 2-day meeting with those experts. We asked the experts to discuss topic areas including (1) whether the draft framework was logical, reasonable, and a valid representation of risk-informed decision-making; and (2) the applicability of the draft framework to actual cleanup decisions. Throughout the 2-day meeting, we summarized key points and themes, and we recorded and transcribed the experts' meeting to ensure that we accurately captured the experts' statements. Following the experts' meeting, we analyzed the transcript to characterize the experts' responses and to identify major themes related to the framework. We then revised the draft framework to incorporate themes from the literature and the experts' views. Additional details on our objectives, scope, and methodology can be found in appendix I.

We conducted this performance audit from July 2017 to September 2019 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.

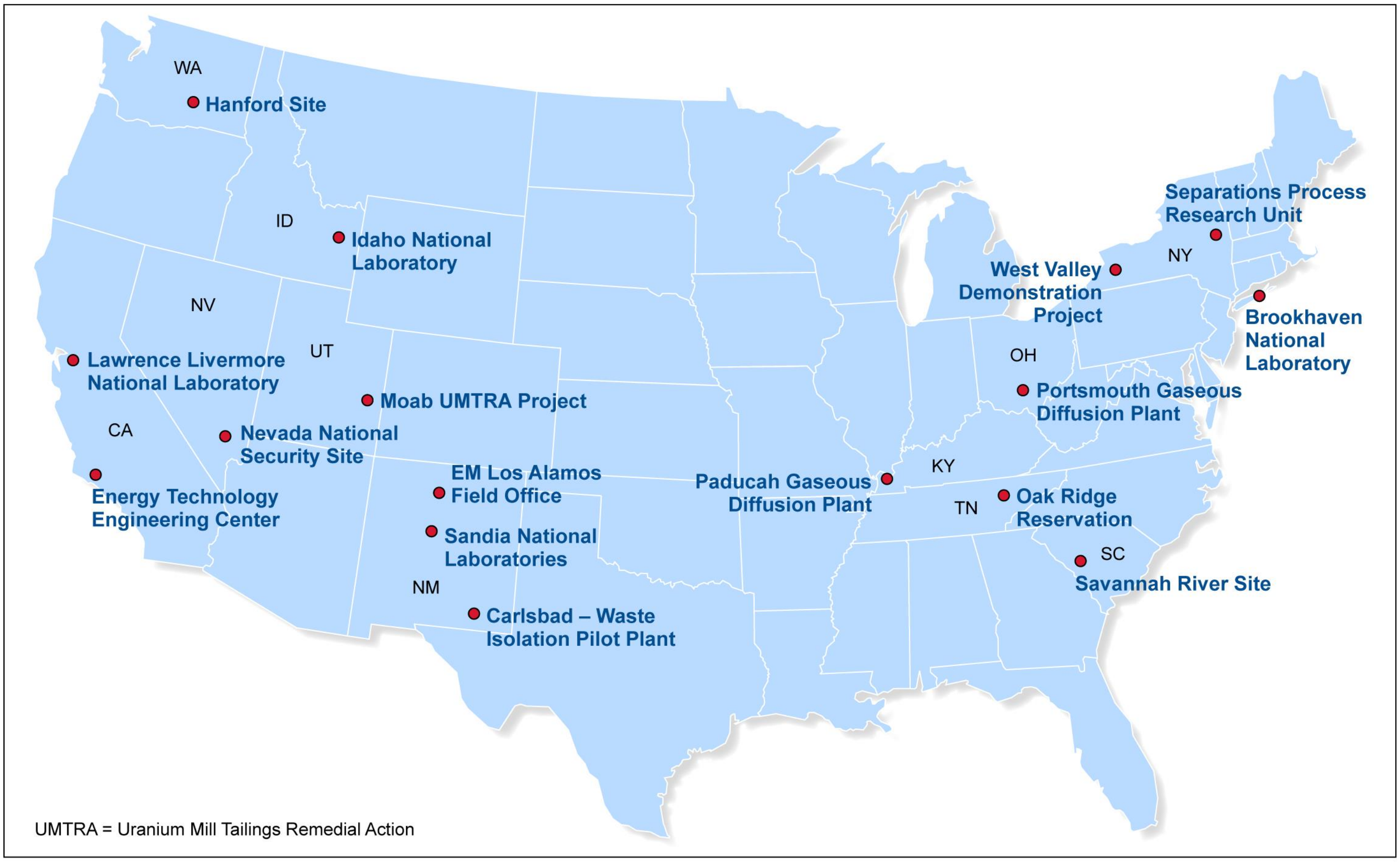
Background

Established in 1989, EM is responsible for the cleanup of legacy waste that resulted from the development and production of nuclear weapons and government-sponsored nuclear energy research dating back to World War II and the Cold War, including radioactive waste, spent nuclear fuel and nuclear material, and contaminated soil and water.[7] EM is also responsible for the disposition of certain types of waste, such as the waste stored in underground tanks at the Hanford Site in Washington State and the Savannah River Site in South Carolina. In addition, EM is responsible for the deactivation and decommissioning of excess facilities, such as the gaseous diffusion plants in Portsmouth, Ohio; Paducah, Kentucky; and Oak Ridge, Tennessee.

In fiscal year 2019, EM's budget for this work was $7.2 billion, an increase of about $49 million from its fiscal year 2018 budget. EM has completed cleanup at 91 of the 107 sites for which it is responsible, but 16 sites remain, some of which are the most challenging to address (see fig. 1).

[7]In the fall of 1989, DOE established the Office of Environmental Restoration and Waste Management, which was later renamed the Office of Environmental Management.

Figure 1: Department of Energy (DOE) Office of Environmental Management (EM) Sites Where Cleanup Remains



Sources: GAO analysis of Department of Energy information; Map Resources (map). | GAO-19-339

Note: DOE has two field offices at the Hanford Site: the Office of River Protection and the Richland Operations Office.

EM's estimate of the cost to clean up these sites is growing. According to DOE's fiscal year 2018 financial statement, EM had an estimated environmental liability of $377 billion—out of DOE's overall $494 billion in environmental liability—which was about a 40 percent increase over EM's prior year estimate of $268 billion.[8] EM's environmental liability includes the costs of treating radioactive waste currently stored in underground tanks, decommissioning and tearing down contaminated facilities, and remediating soil and water contamination, among other things, according to agency documents. In January 2019, we reported that EM's estimated environmental liability may continue to grow, in part because the costs of some future work are not yet included in the estimated liability.[9]

Legal Requirements Governing Environmental Cleanup

Various federal laws, agreements, and court decisions require the federal government to clean up contamination or waste at federal sites and facilities, such as nuclear weapons production facilities and military installations. Key federal laws that govern DOE's cleanup of these sites include CERCLA and RCRA:

- **CERCLA.** CERCLA authorizes the federal government to respond to releases or threatened releases of hazardous substances.[10] Under CERCLA, the Environmental Protection Agency (EPA) has certain oversight authorities for cleaning up releases of hazardous substances on federal properties. DOE often enters into federal facility agreements with EPA and the relevant state regarding the cleanup of hazardous substances at DOE sites; we refer to these agreements as tri-party agreements.[11] Under CERCLA's National Contingency Plan—

[8]DOE's overall environmental liability in fiscal year 2017 was $384 billion. According to DOE officials, EM's environmental liabilities increased by $109 billion in part because EM assumed new work from other DOE organizations.

[9]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).

[10]42 U.S.C § 9604(a)(1).

[11]For DOE sites listed on the National Priorities List—EPA's list of the most seriously contaminated sites—section 120 of CERCLA requires DOE to enter into an agreement with EPA regarding the necessary cleanup actions at sites. 42 U.S.C. § 9620(e)(2). These agreements are known as federal facility agreements. As described below, sometimes DOE, EPA, and the relevant state enter into a tri-party agreement that covers DOE's CERCLA and RCRA obligations.

which establishes procedures needed to respond to releases and threatened releases of hazardous substances—DOE must consider nine criteria when selecting cleanup approaches at its sites. Specifically, there are two "threshold criteria" that all CERCLA cleanup remedies must meet to be considered for selection: they must (1) provide overall protection of human health and the environment, and (2) comply with "applicable or relevant and appropriate requirements," which may include federal or state standards for cleanup.[12] Five other selection criteria, used to analyze and compare alternative remedies that have met the threshold criteria, are called "primary balancing criteria:" long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost.[13] Finally, there are two final "modifying criteria" to be considered: state and community acceptance.[14] With respect to state acceptance, DOE must consider the state's position and key concerns related to the cleanup approaches and the state's comments on requirements that are applicable or relevant and appropriate into its selection of a cleanup approach.[15]

- **RCRA.** In 1976, RCRA was enacted to establish a framework for managing hazardous waste from its generation to final disposal. The act requires owners or operators—including federal agencies—of facilities that treat, store, or dispose of hazardous waste to obtain a permit for such activities. In 1984, Congress amended RCRA to, among other things, add a corrective action program to clean up contamination at facilities that treat, store, and dispose of hazardous waste and prohibit the land disposal of hazardous waste unless such disposal meets requirements established by EPA in regulation. Under RCRA's corrective action provisions, DOE must clean up contamination caused by hazardous waste at its sites by implementing remedial measures that protect human health and the

[12]Threshold criteria are the two most important criteria and consist of statutory requirements that must be satisfied by any potential remedy in order for it to be eligible for selection.

[13]Primary balancing criteria are used to identify major trade-offs between potential remedies and balance among them to select the preferred option.

[14]Modifying criteria may not be considered fully until after a formal public comment period is complete.

[15]For DOE sites listed on the National Priorities List, the cleanup approach must be jointly selected by DOE and EPA. If the agencies cannot agree on an approach, then EPA selects one.

environment. EPA's RCRA regulations establish detailed and often waste-specific requirements for the management and disposal of hazardous waste, including treatment standards for hazardous waste disposed of on land. Hazardous wastes may not be disposed of on land unless they are treated to substantially diminish the toxicity or substantially reduce the likelihood of migration of the waste so that threats to human health and the environment are minimized. Under RCRA, EPA may authorize a state to implement its own hazardous waste management program in lieu of the federal program, so long as the state program is at least as stringent. When states are authorized to implement RCRA, they can issue compliance orders to DOE regarding hazardous waste cleanup at DOE sites.[16] Unlike CERCLA's National Contingency Plan, there are no comprehensive cleanup regulations under RCRA. Instead, EPA and authorized states primarily use guidance to implement corrective actions and impose cleanup requirements at individual facilities through permits or compliance orders.

These requirements reflect the EPA regulatory requirements and, in authorized states, state statutory and regulatory requirements.

For almost all of its sites, DOE has entered into agreements with EPA and the relevant state. These agreements—known as tri-party agreements—integrate DOE's CERCLA response action obligations at the site with its RCRA corrective action obligations. These agreements can be amended if the parties agree and follow the amendment process specified in the agreement. In addition to these agreements, DOE sites may be subject to court orders or settlement agreements that end lawsuits or legal disputes, respectively. Court orders and settlement agreements can be amended if all the parties and, in the case of court orders, the judge agrees.

DOE Cleanup Decisions

DOE officials make decisions at a number of levels, including for individual cleanup projects, at individual sites, across sites, and at the policy level:

[16]Authorized states can issue compliance orders to DOE for violations of the state RCRA law, regulations, or permit at a DOE site that are not addressed in a tri-party agreement or settlement agreement for the site.

- For individual cleanup projects, DOE needs to make decisions about how to approach a specific cleanup activity. For example, in 2017, we reported on DOE's pending decision about how to treat a portion of waste—called low-activity waste—at its Hanford Site in Washington State.[17] Similarly, in 2017, we reported on DOE's need for a decision about whether to expand the Waste Isolation Pilot Plant disposal site in New Mexico.[18]
- At individual sites, as we reported in 2015, EM asks each site to create a prioritized list—called an Integrated Priority List—of facilities for disposition and other cleanup activities for the forthcoming fiscal year.[19] These site-level lists prioritize cleanup activities within a site based on a number of site-specific factors, including regulatory commitments, agreements with EPA and states, and risks to worker safety and the environment.
- DOE also makes decisions about how to prioritize funding across sites. DOE generally provides Congress with information on its future cleanup costs—which reflect the department's funding priorities across its sites—by submitting annual budget requests and associated reports. These budget requests are organized by site, and DOE appropriations are enacted or directed to be used at specific sites or on specific cleanup projects.
- Finally, DOE is in a position to make policy decisions that may affect numerous sites. For example, in October 2018, DOE published a request for public comment on its new interpretation of the definition of the statutory term ''high-level radioactive waste" found in the Atomic Energy Act of 1954 as amended and the Nuclear Waste Policy Act of

[17]GAO, *Nuclear Waste: Opportunities Exist to Reduce Risks and Costs by Evaluating Different Waste Treatment Approaches at Hanford*, GAO-17-306 (Washington, D.C.: May 3, 2017).

[18]GAO, *Plutonium Disposition: Proposed Dilute and Dispose Approach Highlights Need for More Work at the Waste Isolation Pilot Plant*, GAO-17-390 (Washington, D.C.: Sept. 5, 2017). We made four recommendations, including that DOE develop a long-term plan for disposing of DOE's transuranic waste that includes the need for excavating additional disposal space at Waste Isolation Pilot Plant and an integrated schedule that describes how DOE will complete the regulatory approval process and construction of new space before existing space at the plant is full. DOE concurred with the report's recommendations.

[19]GAO, *DOE Facilities: Better Prioritization and Life Cycle Cost Analysis Would Improve Disposition Planning*, GAO-15-272 (Washington, D.C.: Mar. 19, 2015).

1982 as amended.[20] DOE says this new interpretation is more fully based on radiological characteristics that determine risk and, as such, is the first step in a process of potentially opening new disposal pathways for certain types of radioactive waste.

Prior Recommendations on Risk-Informed Decision-Making

Since the mid-1990s, we and others have recommended that EM develop national priorities to consider risks and costs across and within its sites, as well as to adopt risk-informed approaches to decision-making, including the following:

- In March 1995, we reported that DOE's practice of negotiating agreements for individual sites without considering other agreements or available resources did not ensure that limited resources would be allocated in ways that could reduce the greatest environmental risks.[21] At that time, we recommended that EM develop national cleanup priorities for contaminated sites using data gathered during DOE's ongoing risk evaluation as a starting point and found that by doing so, DOE could better direct its resources to address those priorities while selecting effective and affordable cleanup remedies. While DOE took interim steps to develop a national strategy, DOE did not fully implement that recommendation.
- In 2005, the National Academies endorsed a risk-informed approach—which they defined as a formal, well-defined process that incorporates stakeholder participation for evaluating risks and other impacts—to dispositioning three specific waste types and recommended that DOE adopt a six-step process for making risk-informed decisions regarding these three waste types.[22] According to the National Academies, a formal, well-defined decision-making process would help avoid an ad hoc process that could lead to

[20]In June 2019, DOE published a supplemental notice that revised this proposed interpretation and provided additional information about it. 84 Fed. Reg. 26835 (June 10, 2019).

[21]GAO, *Department of Energy: National Priorities Needed for Meeting Environmental Agreements*, GAO/RCED-95-1 (Washington, D.C.: Mar. 3, 1995).

[22]The three waste types reviewed by the National Academies committee were: (1) high-level waste remaining in tanks; (2) low-activity products from the treatment of high-level waste; and (3) buried transuranic waste. National Research Council of the National Academies, *Risk and Decisions About Disposition of Transuranic and High-Level Radioactive Waste*.

inconsistent or poorly thought-out decisions that are not in the public interest. The National Academies also noted that using a risk-informed approach is compatible with the CERCLA process.

- In 2011, DOE's Office of Inspector General noted that DOE's practice of determining cleanup priorities at individual sites was driving costs and that the department should instead consider addressing environmental concerns on a national, complex-wide risk basis. The Inspector General recommended that EM address its environmental responsibilities on a national, complex-wide basis and direct resources to high-risk activities that threaten human health and safety or the environment.[23]
- In 2015, a report resulting from the independent review organized by CRESP recommended that DOE develop an approach to compare priorities across the complex based on risk and direct resources to better address higher-risk activities.[24] According to the 2015 report, DOE needed a more systematic approach to assess and rank risks within and among EM sites, including developing headquarters-level guidance and strategies to allocate funds targeting the highest-priority risks. Specifically, the report recommends that DOE headquarters, with advice from an interagency task force, should provide more detailed guidance to DOE sites to inform site priority-setting and budgeting. The report also recommends that DOE headquarters should work with the sites to ensure that headquarters guidance is implemented consistently at all sites and that prioritization and budgeting are fully risk-informed.
- In January 2019, we found that EM relies primarily on its sites to select cleanup remedies; however, EM sites generally do not consider other sites' risks and priorities or the financial resources available for cleanup nationwide.[25] We concluded that until DOE develops a program-wide cleanup strategy that sets national priorities and describes how DOE will direct available resources to address the greatest human health and environmental risks within and across sites, EM cannot be assured that it is effectively setting priorities within and across sites. We recommended, among other things, that DOE develop a program-wide strategy that outlines how DOE will

[23]Department of Energy, Office of Inspector General, *Special Report*: *Management Challenges at the Department of Energy*, DOE/IG-0858 (Washington, D.C.: November 2011).

[24]Omnibus Risk Review Committee, *A Review of the Use of Risk-Informed Management in the Cleanup Program for Former Defense Nuclear Sites.*

[25]GAO-19-28.

direct available resources to address human health and environmental risks within and across sites. DOE agreed with our recommendations.

DOE Has Requirements for Making Cleanup Decisions, but It Does Not Have a Framework for Ensuring Its Decisions are Risk-Informed

DOE is required to follow certain laws, agreements, federal guidelines, and court decisions (e.g., CERCLA, RCRA, and tri-party agreements with EPA and states) that establish standards, procedures, or requirements for DOE's cleanup mission, but the department does not have a framework for implementing these requirements and guidance to make cleanup decisions in a risk-informed manner.[26] In addition to laws and agreements with EPA and states, DOE has internal policies and guidance EM may follow when making different types of cleanup decisions that do not present a risk-informed framework. For example, we reviewed the following DOE internal policies and guidance, and none of them establish how to make risk-informed cleanup decisions:

- In 2017, DOE issued a cleanup policy—*Requirements for Management of the Office of Environmental Management's Cleanup Program*—[27] that governs the EM program and its operations activities.[28] This policy establishes, among other things, who within EM may authorize cleanup decisions but does not direct how EM

[26]Federal guidelines include, for example, Circular A-94. Office of Management and Budget, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Program*, OMB Circular No. A-94.

[27]Department of Energy, *Requirements for Management of the Office of Environmental Management's Cleanup Program*, (Washington, D.C.: July 20, 2017).

[28]According to EM policy, operations activities are reoccurring facility or environmental operations as well as activities that are project-like, with defined start and end dates. Department of Energy, Office of Environmental Management, *Policy and Protocol for Office of Environmental Management Operations Activities Protocol* (Washington, D.C.: Feb. 28, 2012).

should make environmental cleanup decisions, including how EM should make risk-informed cleanup decisions.[29]

- DOE's *Analysis of Alternatives Guide*, Guide 413.3-22, provides information on conducting analysis of alternatives for capital asset projects and programs.[30] According to DOE's guide, analysis of alternatives are an analytical comparison of the operational effectiveness, suitability, risk, and life cycle cost (or total ownership cost, if applicable) of alternatives that satisfy validated capability needs. The guide applies only to capital asset programs and projects, not to other types of environmental cleanup decisions, and it does not establish a framework for how DOE or its component agencies should make risk-informed cleanup decisions.
- DOE's *Risk Management Guide*, Guide 413.3-7A, provides non-mandatory risk management approaches for implementing the requirements of DOE Order 413.3B—which establishes program and project management direction for the acquisition of capital assets. According to the guide, it provides a "suggested framework for identifying and managing key technical, schedule, and cost risks." However, the guide primarily focuses on broader project and organizational risks, rather than risks to human health and the environment.[31] The guide does not establish a framework for DOE or its component agencies to make risk-informed cleanup decisions.
- DOE and EPA's *Principles of Environmental Restoration*, which is a 1999 guide that establishes four principles for streamlining the remedy selection process and enhancing cleanup decisions. The four principles are: (1) using a core team approach,[32] (2) identifying and defining problems, (3) identifying likely response actions, and (4)

[29]The 2017 cleanup policy notes that "the cleanup strategy for the contaminated sites is generally sequenced based on the extent of the environmental risk the site poses and any prior regulatory commitments," but the policy does not provide any additional details about how decisions should be made, how environmental risks are defined, or to what extent decisions regarding sequencing should be risk-informed.

[30]According to DOE Order 413.3B, a capital asset project is a project with defined start and end points required in the acquisition of capital assets. Department of Energy, *Program and Project Management for the Acquisition of Capital Assets*, DOE Order 413.3B (Change 5) (Washington, D.C.: Nov. 29, 2010).

[31]The guide states that it is not intended to replace assessment processes developed for nuclear safety and environmental, safety, health, and quality.

[32]According to the DOE and EPA principles, a core team approach is a formalized, consensus-based process in which those individuals with decision-making authority—including DOE, EPA, and state remedial project managers—work together to reach agreement on key remediation decisions.

managing uncertainty through contingency planning. However, this guide does not establish a comprehensive framework for making risk-informed cleanup decisions.

Based on our analysis of DOE orders and policies, we found that DOE does not have any orders or policies that describe a framework for consistently applying its numerous requirements and guidance to cleanup decisions and ensuring that EM's decisions are risk-informed. DOE does not have any orders or policies that direct how EM sites should implement CERCLA or RCRA or how to apply these laws in a risk-informed manner when making environmental cleanup decisions. Further, it does not have an order or policy that directs how resources should be allocated across EM sites. EM officials confirmed that DOE does not provide such guidance and acknowledged that DOE could do more to make risk-informed cleanup decisions.

As discussed above, since the mid-1990s, several organizations—including the National Academies, the DOE Office of Inspector General, CRESP, and GAO—have recommended that DOE adopt a risk-informed approach to decision-making. DOE does not have an order or policy that outlines how its existing requirements and guidance should work together to include essential elements for risk-informed decision-making. By revising EM's 2017 cleanup policy to establish how the EM program and DOE sites should apply the essential elements of a risk-informed decision-making framework into its current decision-making requirements and guidance, DOE sites would be better able to implement consistent decision-making processes and ensure that resource allocation is fully risk-informed.

In addition, in February 2019, we reported that DOE is not effectively managing its cleanup mission as a program. Specifically, we found that EM's 2017 cleanup policy does not follow leading practices for program management.[33] We recommended, among other things, that DOE revise EM's 2017 cleanup policy to include program management leading practices related to scope, cost, schedule performance, and independent reviews. DOE concurred with this recommendation. One program management leading practice is developing a program management plan

[33]Specifically, we found that EM met zero out of nine leading practices for program management. GAO, *Nuclear Waste Cleanup: DOE Could Improve Program and Project Management by Better Classifying Work and Following Leading Practices,* GAO-19-223 (Washington, D.C.: Feb. 19, 2019).

that is updated regularly.[34] As DOE implements our recommendation to revise EM's cleanup policy to include program management leading practices, it could also ensure that its updated program management plan incorporates the concepts of risk-informed decision-making. DOE would then be in a better position to effectively set priorities within and across its sites and direct its limited resources to address those priorities.

The Essential Elements of a Framework for Making Risk-Informed Cleanup Decisions Consists of Four Broad Phases and Specific Steps

Based on key concepts from the literature on risk and decision-making we reviewed and input from experts who participated in our meeting convened by the National Academies, we developed the essential elements of a framework that can be applied to DOE's cleanup mission. As we noted above, DOE is required to follow various federal laws—such as CERCLA and RCRA—federal guidelines, and agreements with states and EPA to clean up environmental hazards at federal sites and facilities. The framework we developed is not intended to replace or supersede the processes required under applicable laws, federal guidelines, or agreements. Rather, it is intended to highlight essential elements of risk-informed decision-making that should be applied when making cleanup decisions in general, regardless of whether those decisions are being made in response to CERCLA, RCRA, or other requirements.

According to the literature we reviewed, decision-making fundamentally involves selecting among different options given reasonably available information and in light of decision-maker and stakeholder preferences, such as preferences about the importance of risk reduction relative to cost and other values.[35] The framework we developed reflects these fundamental concepts. The essential elements of our framework consists

[34]The program management plan formally expresses the organization's concept, vision, mission, and expected benefits produced by the program; it also defines program-specific goals and objectives.

[35]See, for example: Ralph L. Keeney, *Value-Focused Thinking: A Path to Creative Decisionmaking* (Cambridge: Harvard University Press), 1992. In the context of our framework, except where noted, we use "cost" to refer to monetary cost, rather than other types of costs, such as environmental costs.

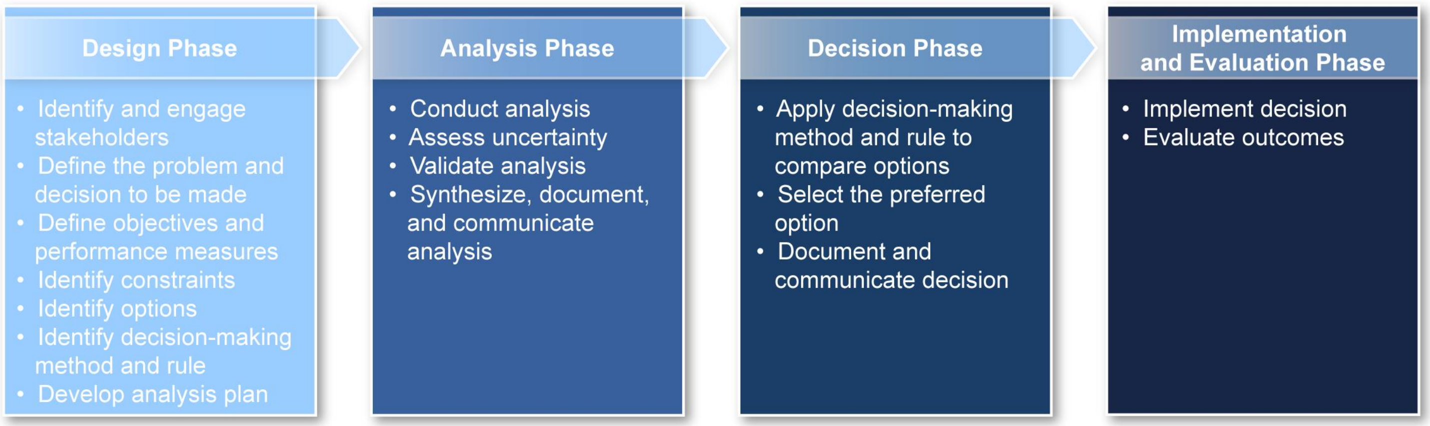
of four broad phases: (1) designing the decision-making process by, for example, defining objectives and identifying potential options; (2) analyzing how well each option performs with respect to the established objectives; (3) deciding which option is preferred; and (4) implementing and evaluating the preferred option.[36] Each phase comprises several steps (see fig. 2).[37] Based on characteristics of an effective and credible risk-informed decision-making process identified in 2005 by the National Academies, entities implementing the framework should ensure that their decision-making process is participatory, logical, transparent, traceable, and that it uses current scientific knowledge and practice to produce technically credible results.[38]

[36]In this context, we define "objective" as an important outcome or consequence that could be affected by a decision.

[37]The ordering and grouping of the steps under these four phases is less important than the substance of the steps. Other organizations have documented decision-making, risk assessment, and risk management practices in widely varying formats. For example, see: Cindy Jardine et al., "Risk Management Frameworks for Human Health and Environmental Risks," *Journal of Toxicology and Environmental Health, Part B*, vol. 6 (2003), 569-641. We intentionally present the phases and steps in our framework in the manner shown in fig. 2 to reflect the analytic-deliberative paradigm set forth by the National Academies in its 1996 report, *Understanding Risk: Informing Decisions in a Democratic Society*. This report concluded that defensible decisions involving risk require the effective and ongoing integration of analysis and deliberation. In our framework, the Design Phase emphasizes collective and intentional consideration of the values driving a decision, the Analysis Phase emphasizes analysis of empirical evidence, and the Decision Phase involves combining deliberation with analytical results to arrive at a decision. See National Research Council of the National Academies, Committee on Risk Characterization, *Understanding Risk: Informing Decisions in a Democratic Society* (Washington, D.C.: The National Academies Press, 1996).

[38]National Research Council of the National Academies, *Risk and Decisions About Disposition of Transuranic and High-Level Radioactive Waste*.

Figure 2: Phases and Steps in a Risk-Informed Decision-Making Framework to Address Environmental Cleanup Decisions



Source: GAO. | GAO-19-339

Data for Figure 2: Phases and Steps in a Risk-Informed Decision-Making Framework to Address Environmental Cleanup Decisions

Flow chart showing 4 phases.

1. Design Phase:

- Identify and engage stakeholders
- Define the problem and decision to be made
- Define objectives and performance measures
- Identify constraints
- Identify options
- Identify decision-making method and rule
- Develop analysis plan

2. Analysis Phase:

- Conduct analysis
- Assess uncertainty
- Validate analysis
- Synthesize, document, and communicate analysis

3. Decision Phase:

- Apply decision-making method and rule to compare options
- Select the preferred option
- Document and communicate decision

4. Implementation and Evaluation Phase:

- Implement decision
- Evaluate outcomes

Waste Isolation Pilot Plant: Stakeholder Engagement Needed to Finalize DOE's Plans to Dispose of Surplus Plutonium

The Department of Energy (DOE) is responsible for disposing of surplus plutonium supplies from retired nuclear weapons and other sources. DOE has developed conceptual plans to dispose of some U.S. surplus plutonium at the Waste Isolation Pilot Plant (WIPP), a geologic repository located near Carlsbad, New Mexico. DOE's plans call for the use of a "dilute and dispose process" in which the surplus plutonium would be diluted by being blended with a chemical adulterant and then transported to WIPP for disposal.

The National Academies of Sciences, Engineering, and Medicine issued a report in 2018 evaluating the general viability of DOE's conceptual plans for disposing of surplus plutonium at WIPP. The National Academies found that DOE is likely to face several challenges to implementing its conceptual plans, including challenges related to working with state, tribal, and local stakeholders. The National Academies reported that developing and maintaining public trust will be important to the ultimate success of DOE's plans, but the National Academies found that DOE does not have a well-developed public outreach plan for the dilute and dispose program. Similarly, we reported on DOE's dilute and dispose program in 2017 and noted that DOE will need to account for public outreach requirements during the agency's planning process.

The National Academies recommended steps that DOE could take to engage stakeholders and improve public trust in the dilute and dispose program. Risk-informed decision-making similarly highlights the importance of engaging stakeholders throughout the decision-making process. Many details of the dilute and dispose program are yet to be determined; however, implementing the program will require DOE to engage with a large and diverse set of stakeholders over a long period of time.

Sources: National Academies of Sciences, Engineering, and Medicine, *Disposal of Surplus Plutonium at the Waste Isolation Pilot Plant: Interim Report* (Washington, D.C.: 2018); and GAO, *Plutonium Disposition: Proposed Dilute and Dispose Approach Highlights Need for More Work at the Waste Isolation Pilot Plant* (GAO-17-390). | GAO-19-339

We developed the framework to be relevant to multiple types of cleanup decisions, from selecting a cleanup approach at a single site to prioritizing cleanup activities within and across sites. It could also apply to decisions in which a federal department or agency, such as DOE, is responsible for leading the decision-making process and implementing the final decision. Applied in this way, individuals or groups within an agency would be in charge of carrying out the steps in the framework, with varying levels of input and support from stakeholders (e.g., individuals or groups external to the agency). A single agency official may be in charge of making the final decision, or multiple people or groups may hold decision-making authority. In addition, some decisions may necessitate amending agreements that DOE has with EPA and states that govern cleanup of a site.

When the framework is applied to a decision, the depth and extent of the phases and steps should be tailored to the nature and significance of the decision being made. We present the framework as a sequential series of steps; however, in practice, the results of one step may lead to revisiting a previous step, or some steps may occur at the same time.

Design Phase

The Design Phase of the framework lays the groundwork for making a decision. The purpose of this phase is to define the scope and goals of the decision-making process, as well as to specify who will be involved in informing and making the decision and the analytical methods to be used. This phase emphasizes deliberation in that it involves collective and intentional consideration of the values and preferences driving the decision. The Design Phase consists of seven steps.

Identify and Engage Stakeholders

This step involves identifying stakeholders—that is, those individuals, groups, and organizations that can influence the decision or that will be affected by the decision—and engaging them in the decision-making process. According to the literature we reviewed, various methods may be used to identify stakeholders, including analyzing the distribution of social and economic impacts to identify populations that may be affected by a decision and analyzing relevant laws to identify who is legally required to participate in the decision-making process.[39] For a risk-informed cleanup decision, stakeholders are likely to include ones external to the federal department or agency in charge of making the decision, such as individuals and groups from other government agencies; Indian tribes; industry groups; nonprofit organizations; and community members.[40] In addition, one expert who participated in our meeting told us that considering federal taxpayers as a stakeholder group in a risk-informed decision about cleanup funded by a federal agency can be useful, to the extent taxpayers bear the cost of the selected cleanup approach.

This step also includes defining different stakeholders' authorities and interests and based on this information, defining the roles they will play throughout the decision-making process, such as whether they will inform the decision, help make the decision, or perform other functions, such as reviewing analyses. According to the literature we reviewed, stakeholder involvement is critical to sound decision-making, though the specific type and extent of that involvement should vary depending on the decision being made.[41] Experts who participated in our meeting generally told us that the most appropriate role for stakeholder groups representing members of the public, such as nonprofit organizations and community groups, is likely to be one of helping to inform the decision, rather than of ultimately making it. For example, such stakeholders may help define the problem, define objectives, or identify options.

Given this role, experts generally said that the goals of engaging stakeholder groups representing members of the public in a risk-informed

[39]See, for example: National Research Council of the National Academies, Committee on the Human Dimensions of Global Change, *Public Participation in Environmental Assessment and Decision Making* (Washington, D.C.: The National Academies Press, 2008).

[40]Executive Order 13175 directs federal agencies to establish an accountable process to ensure meaningful and timely input by tribal officials in the development of regulatory policies that have tribal implications. DOE's American Indian and Alaska Natives Tribal Government Policy states that the agency will implement a proactive outreach effort of notice and consultation regarding current and proposed actions affecting tribes. Both the Executive Order and DOE's policy recognize the unique government-to-government relationship between federally recognized Indian tribes and the federal government as well as tribes' treaty rights. In April 2019, we reported on federal agencies and tribal consultation. GAO, *Tribal Consultation: Additional Federal Actions Needed for Infrastructure Projects*, GAO-19-22 (Washington, D.C.: Mar. 20, 2019).

[41]See, for example: National Research Council of the National Academies, *Public Participation in Environmental Assessment and Decision Making*.

cleanup decision should be to incorporate their viewpoints and to seek their acceptance of the decision-making process as transparent and legitimate, rather than to obtain their concurrence with the final decision. Experts who participated in our meeting generally told us that achieving consensus from these stakeholder groups about a cleanup decision is typically unrealistic because their interests are diverse and often conflicting. According to the experts, a more realistic and helpful approach is to seek these stakeholders' input and buy-in to the process by providing meaningful opportunities for engagement early in the process, communicating throughout the process, and providing transparent, understandable information about the science and rationale behind the final decision. In commenting on a draft of the framework, a few experts noted that obtaining stakeholders' acceptance of the process may require extensive outreach over a long period of time, and that acceptance of the process among all stakeholders may not be feasible. Nonetheless, they said that this type of outreach is important and that it can result in a more robust methodology and final decision.[42] Additional information about the ways in which stakeholders can engage in the decision-making process is described in some of the subsequent framework steps.

Define the Problem and Decision to Be Made

This step involves specifying the problem that exists, including its context—such as the regulatory, social, and environmental settings in which the problem occurs—and then defining the decision that is to be made about the problem. Specifically, this step involves collecting new or existing information to characterize the problem as it currently exists. For example, experts who participated in our meeting generally told us that collecting information about the existing contaminants at a site is important to understanding the problem that needs to be addressed. This step also involves articulating the scope and boundaries of the specific decision to be made. Questions to consider may include:

- Will the decision aim to address all of the problem, or a part of it?
- Will the decision involve selecting a single preferred option from a set of candidates, or does it entail another type of decision, such as ranking projects by priority, differentiating between acceptable and

[42]To illustrate this point, these experts noted that extensive stakeholder outreach over a two-year period helped improve the methodology used by CRESP to conduct a site-wide risk review of the Hanford Site. They said that even with this outreach, however, the outcomes of the review have not been universally supported.

unacceptable options, or developing a consistent system for making decisions that are likely to be repeated?

- What other decisions affect or will be affected by this one?

Experts who participated in our meeting generally told us that involving stakeholders in this step is important because they may provide important information and insights that could affect how a problem is characterized. In addition, according to the literature we reviewed, because stakeholders may have differing views about the nature and extent of a problem and the scope of the decision that should be made to address it, their input during this step can help build confidence that the right problem is being addressed.[43]

Define Objectives and Performance Measures

This step involves defining the objectives—the important outcomes or consequences that could be affected by a decision—using input from stakeholders. According to the literature we reviewed, objectives should capture what matters in a decision.[44] Each definition should identify the topic that matters and include a verb indicating whether more or less is preferred, all else being equal. For example, objectives could be defined as “protect water quality” or “increase recreational opportunities.” Objectives may reflect expectations from different levels within an agency, such as an agency’s mission or strategic planning goals, as well as concerns significant to some or all of the stakeholders. For example, an agency’s goal to protect worker safety could result in an objective to increase worker safety, while different stakeholder groups’ concerns about local economic impacts could result in an objective to promote job opportunities. Fairness and equity considerations may also be included as objectives, as well as concerns about administrative feasibility, such as the time required to obtain any necessary approvals or permits from other agencies. To be considered risk-informed, a cleanup decision should include objectives to: (1) reduce risks to human health and the

[43]See, for example: National Research Council of the National Academies, *Understanding Risk: Informing Decisions in a Democratic Society*.

[44]See, for example: Keeney, *Value-Focused Thinking: A Path to Creative Decisionmaking*.

environment and (2) reduce cost, among any other objectives required by law or identified by the agency and stakeholders.[45]

According to the literature we reviewed, to be useful for decision-making, the set of objectives identified for a decision should be both complete and concise, in that it should capture all of the things that matter to the agency and stakeholders in the context of the decision.[46] In addition, objectives should represent the outcomes that matter to the agency and stakeholders, rather than any particular method of accomplishing those outcomes, to help ensure that the decision-making process stays open to a range of potential options.

This step also includes identifying performance measures, or the measures that will be used to estimate and report on the extent to which objectives are achieved by the options. According to the literature we reviewed, while objectives may be broad, performance measures should be specific, since they define how the achievement of an objective is to be quantified.[47] Multiple performance measures may be needed to evaluate achievement of an objective. For example, the short-term radiation dose to workers and long-term radiation dose to residents could be used as performance measures for how well an option achieves the objective of reducing risks to human health. Performance measures provide a basis for consistently and transparently comparing options during the Decision Phase and can be used in the final phase of the framework—the Implementation and Evaluation Phase—to assess the performance of the implemented decision.

Identify Constraints

This step involves identifying any constraints for decision-making, some of which may be fixed and some of which may be flexible. Specifically,

[45]It is acceptable and can be useful to identify “competing” objectives, or those that may be difficult to achieve simultaneously, such as “reduce risks to human health” and “reduce costs.” This is because a key purpose of the framework is to consider trade-offs across multiple objectives and to find the best possible balance across them. Considering trade-offs is discussed in the Decision Phase of the framework.

[46]See, for example: Gregory R., L. Failing, M. Harstone, G. Long, T. McDaniels, and D. Ohlson, *Structured Decision Making: A Practical Guide to Environmental Management Choices* (Oxford: Wiley-Blackwell, 2012).

[47]See, for example: National Aeronautics and Space Administration, *NASA Risk-Informed Decision Making Handbook*, NASA/SP-2010-576 (Washington, D.C.: 2010).

some constraints may be widely accepted as absolute, non-negotiable thresholds or standards that an option must meet in order to be considered for selection. According to the literature we reviewed, such constraints may result from statutory, regulatory, or budgetary requirements.[48] For example, requirements in existing agreements between DOE and federal or state regulatory agencies may serve as constraints. Constraints can be used early in the decision-making process to screen out options that do not meet them, thus allowing more time and resources to be directed toward evaluating better options, or they may help eliminate options later on, during the Decision Phase. A required level of human health protectiveness and an agency's overall budget for cleanup activities are examples of constraints for risk-informed decision-making. For instance, in making a decision about how to prioritize cleanup activities across multiple sites, an agency would need to evaluate a set of activities and stay within its authorized budget.

Conversely, other constraints may be less well-defined at this stage because of scientific uncertainty or because they may be open to negotiation or changes. For example, in some cases, a constraint related to human health risk may be difficult to specify early in the decision-making process because of uncertainty in the science linking human exposure to certain contaminants with negative health effects. Similarly, the maximum level of risk deemed acceptable may change as additional information about the desired or designated future land use of a site is determined. In addition, regulatory or statutory constraints, such as federal or state cleanup requirements, may not be fixed because an agency such as DOE can seek waivers or statutory changes.

Experts who participated in our meeting generally told us that 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.[49] In commenting on a draft of the framework, a few experts noted that regulatory agencies, such as EPA, should be open to affording opportunities for waivers. In addition, experts generally told us that

[48]See, for example: Omnibus Risk Review Committee, *A Review of the Use of Risk-Informed Management in the Cleanup Program for Former Defense Nuclear Sites*.

[49]DOE officials said that there are challenges associated with pursuing such waivers, such as the need to collect many years' worth of evidence to demonstrate that a waiver is justified, and they noted that regulators have infrequently granted waivers. Nonetheless, according to experts who participated in our meeting, these waivers are worth pursuing because they can lead to more cost-effective allocation of resources.

agencies should avoid using these types of flexible constraints to limit or screen out options from consideration early in the decision-making process.

Identify Options

This step involves generating a set of options for addressing the decision that are responsive to the established objectives. The degree to which the options are estimated to perform with respect to the objectives will be studied during the Analysis Phase. According to the literature we reviewed, the options should represent a range of potential actions or changes, including the status quo.[50] Stakeholders, including public stakeholder groups, as well as subject-matter experts, should play a role in identifying options that would be useful to analyze. They should do so by thinking about how to achieve the established objectives, so that the list of options is guided by the values that are driving the decision and does not simply reflect readily apparent options or the favored option of vocal stakeholders. For a risk-informed cleanup decision, the identified options should be broad enough to be expected to offer distinct differences with respect to human health and environmental risks and cost.

Identify Decision-making Method and Rule

This step involves identifying a formal, systematic method that will be used to integrate information from the analyses into a basis for making a decision, along with an associated decision rule that specifies which option should be considered "best" under that method. The decision-making method and decision rule will be applied in the Decision Phase, and, according to the literature we reviewed, the results should aid (though not dictate) the decision.[51] Such formal decision-making methods provide a rigorous, transparent way to evaluate trade-offs between objectives. They help make explicit and manage any subjectivity or personal preference that may enter the decision-making process, such as a decision-maker or stakeholder's views about the relative importance of various objectives. Experts generally told us that identifying a decision-making method early in the process helps enhance accountability by

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[50]See, for example: National Research Council of the National Academies, *Risk and Decisions About Disposition of Transuranic and High-Level Radioactive Waste*.

[51]See, for example: Richard A. Williams and Kimberly M. Thompson, "Integrated Analysis: Combining Risk and Economic Assessments While Preserving the Separation of Powers," *Risk Analysis*, vol. 24, no. 6 (2004), 1613-1623.

outlining how a decision will be reached. One expert noted that it is important to identify the decision-making method before analyses are conducted, so that the analysis results can be formatted in a way that can be used by that method.

According to the literature we reviewed, the choice of decision-making method should depend on a number of factors, including: the time and resources available for implementing it; the number of stakeholders and extent of their expected involvement in providing input to the decision; the extent to which objectives can be quantified or monetized; and whether any relevant statutes require or explicitly exclude certain types of methods.[52] For a risk-informed cleanup decision, examples of appropriate decision-making methods, along with each method's associated decision rule, include those described below.

- **Benefit-cost analysis** is a type of economic analysis that compares the expected social benefits and costs of different options. According to Office of Management and Budget guidelines, benefit-cost analysis involves calculating the net present value for options under consideration by assigning, where computable, monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the sum total of discounted costs from the sum total of discounted benefits.[53] Options with positive net present value are generally preferred.

  For a risk-informed cleanup decision, benefit-cost analysis could be used to assess the net present value of cleanup options that are expected to provide different levels of human health protectiveness. According to Office of Management and Budget guidelines, this analysis should generally be supplemented with information about the distributional effects of the options, where important.[54] In addition, the guidelines state that in cases where net present value is not computable, a comprehensive enumeration of the different types of

[52]See, for example: The Presidential/Congressional Commission on Risk Assessment and Risk Management, *Framework for Environmental Health Risk Management, Final Report Volume 1* (Washington, D.C.: 1997).

[53]Office of Management and Budget, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Program*, OMB Circular No. A-94. For additional information about the application of benefit-cost analysis, see: Office of Management and Budget, *Regulatory Analysis*, OMB Circular No. A-4.

[54]Office of Management and Budget, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Program*.

benefits and costs, monetized or not, can be helpful in identifying the full range of program effects. According to the guidelines, quantifying benefits and costs is worthwhile, even when it is not feasible to assign monetary values.

- **Cost-effectiveness analysis** is another type of economic analysis that compares the expected costs of achieving a specified goal. According to Office of Management and Budget guidelines, this method can be appropriate when the benefits from competing options are the same or where a policy decision has been made that the benefits must be provided.[55] For a risk-informed cleanup decision, cost-effectiveness analysis could be used to identify the least costly way to achieve a defined level of human health protectiveness.
- **Multiattribute utility theory** is a type of multicriteria decision analysis and is an approach for making decisions that have multiple, competing objectives.[56] It 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.

[55]Office of Management and Budget, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Program*.

[56]Multiattribute utility theory is also known as multiattribute value theory. It is one of many methods under the larger umbrella of multicriteria decision analysis, all of which seek to help decision-makers explicitly account for multiple, conflicting objectives. For a detailed description of multicriteria decision analysis methods and their relative strengths and weaknesses, see: Valerie Belton and Theodor J. Stewart, *Multiple Criteria Decision Analysis: An Integrated Approach* (Boston: Kluwer Academic Publishers, 2002).

Develop Analysis Plan

This step involves developing a plan that identifies the types of analyses that need to be conducted to assess how well each option performs with respect to the objectives, along with a timeline for completing the analyses. For a cleanup decision to be risk-informed, the types of analyses to be conducted should include human health risk assessments and life-cycle cost estimates (which are described in the Analysis Phase below), including estimates of costs to the private sector and individuals, along with any other analyses that are needed to assess performance of

Hanford Site: DOE Could Benefit from Using a Risk-Informed Approach to Treating Low-Activity Waste

The Department of Energy's (DOE) Hanford Site in Washington State produced plutonium and other nuclear materials for the country's nuclear weapons program dating back to World War II. This production resulted in 54 million gallons of hazardous and radioactive waste that is now stored in large underground tanks and must be treated before disposal. The less radioactive portion of the tank waste—called low-activity waste (LAW)—comprises more than 90 percent of the waste's volume but less than 10 percent of the total radioactivity. DOE is required to treat at least one-third to one-half of Hanford's LAW with a process called vitrification, which immobilizes the waste in glass. However, DOE has not yet determined how it will treat the remaining portion, known as "supplemental LAW."

In May 2017, we reported that experts who attended our meeting on the treatment of Hanford's LAW convened by the National Academies told us that both vitrification and grout—which immobilizes waste in a concrete-like mixture—could effectively treat Hanford's LAW. Experts also stated that current information shows grout will perform better than was assumed when DOE made its decision to vitrify Hanford's LAW in the 1990s. Moreover, we reported that there were significant cost differences between these methods and that DOE could potentially save billions of dollars by using grout to treat a portion of the LAW at Hanford rather than vitrification.

We recommended that DOE develop updated information on the performance of alternate methods of treating LAW, such as grout, before it selects an approach for treating Hanford's supplemental LAW. Using the most up-to-date scientific information is an important part of conducting analyses under a risk-informed decision-making framework, and incorporating such information on the performance of grout would help DOE ensure that it identifies potential treatment approaches that align costs with the relatively low long-term risk of LAW. DOE agreed with our recommendation and has contracted to produce a report evaluating viable treatment options for the supplemental LAW.

Source: GAO, *Nuclear Waste: Opportunities Exist to Reduce Risks and Costs by Evaluating Different Waste Treatment Approaches at Hanford* (GAO-17-306). | GAO-19-339 each option with respect to the objectives. According to the literature we reviewed, the analysis plan should include information about:[57]

- The resources needed to conduct the analyses, including the data and expertise needed, along with an assignment of tasks.
- The budget and time frame within which analyses should occur.
- The depth and rigor of the selected analytical methodologies, which should depend on the complexity and stakes of the decision. The plan may describe an iterative approach to analysis in which the level of analytical detail and rigor increases as needed to support reaching a final decision.
- Data gaps and uncertainties associated with the analyses, including plans for how uncertainty will be assessed.
- Intended outputs of the analyses, which may range from highly uncertain rough order-of-magnitude estimates to rigorously supported distributions and probabilities.
- The approaches that will be used to validate or peer-review the analyses.
- Any existing analyses that can be updated or modified in lieu of conducting new analyses.
- Provisions to facilitate coordination and consistency among the different entities within an agency that may be responsible for conducting the analyses. For example, the plan could describe processes that will be used to ensure that the offices conducting human health risk assessments and cost estimates are working from a common set of data and assumptions.

Stakeholders should have a role in reviewing the analysis plan. According to the literature we reviewed, obtaining stakeholders' input on the types of analyses to be conducted and how results will be used can help improve the likelihood that stakeholders will view the decision-making process as fair and legitimate.[58]

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[57]See, for example: U.S. Environmental Protection Agency, *Framework for Human Health Risk Assessment to Inform Decision Making*, EPA/100/R-14/001 (Washington, D.C.: April 5, 2014).

[58]See, for example: National Research Council of the National Academies, *Understanding Risk: Informing Decisions in a Democratic Society*.

Analysis Phase

The purpose of the Analysis Phase is to determine how the options perform with respect to the objectives.[59] The Analysis Phase provides a factual, analytic basis for making a decision and is to be carried out by subject-matter experts. It consists of four steps.

Conduct Analysis

This step involves implementing the analysis plan by collecting quantitative or qualitative data and developing and conducting analyses that estimate the performance of each option with respect to each objective. Many analyses involve developing statistical or computational models to predict such performance. According to the literature we reviewed, analyses should be conducted in accordance with generally accepted standards and guidelines that apply to that field of study and should use the most up-to-date data.[60] Data may be drawn from a variety of sources, including scientific field data collected about a site's physical properties, information from the literature, and expert opinion obtained using expert elicitation methods. For a risk-informed cleanup decision, analyses should include human health risk assessments and life-cycle cost estimates, including estimates of costs to the private sector and individuals. Other analyses will vary depending on the specific decision and objectives, but may include assessments of ecological risk and technology readiness. The following are types of analyses that may be conducted in a risk-informed cleanup decision.

- **Human health risk assessments** assess the extent to which each option performs with respect to objectives related to human health protection. Specifically, these assessments estimate the likelihood of exposure to a hazard and the likely consequences to human health resulting from such exposure. According to EPA's *Framework for Human Health Risk Assessment to Inform Decision Making*, risk assessments generally involve: (1) identifying a hazard, or a stressor that has the potential to cause adverse effects in humans; (2)

[59]As described in the Design Phase, performance measures corresponding to the objectives are the specific measures used to determine how well the options perform. For consistency and brevity throughout the subsequent steps in the framework, we use the term "objective" to encompass both objectives and their corresponding performance measures.

[60]See, for example: National Research Council of the National Academies, *Improving the Regulation and Management of Low-Activity Radioactive Wastes*.

NNSA Facilities: Better Prioritization and Life-Cycle Cost Analysis Needed to Inform EM's Cleanup Decisions

The National Nuclear Security Administration (NNSA), a separately organized agency within the Department of Energy (DOE), manages many of DOE's contaminated facilities resulting from decades of nuclear weapons production and energy research. Once NNSA considers these facilities to be nonoperational, they may be eligible for transfer to DOE's Office of Environmental Management (EM) for decontamination and decommissioning.

In 2015, we reported that NNSA had identified 83 facilities for transfer to EM. However, EM officials said they may not be able to accept these facilities until at least 2030 due to budget uncertainties and other priorities. We also found that EM did not consider the human health and environmental risks of NNSA's nonoperational facilities when prioritizing its cleanup activities. Moreover, because EM is not considering the full life-cycle costs for these NNSA facilities, EM cannot ensure that its plans for decontaminating and decommissioning facilities result in the most cost-effective use of its limited resources.

We recommended, among other things, that EM should analyze the remaining life-cycle costs of all nonoperational NNSA facilities that meet its transfer requirements and incorporate the information into its prioritization process. Risk-informed decision-making similarly highlights the need to incorporate cost information when defining objectives, conducting analyses, and evaluating trade-offs related to environmental cleanup decisions. Following the release of our 2015 report, DOE took action to address our recommendations, including incorporating information on the life-cycle costs of nonoperational facilities into its prioritization process.

Source: GAO, DOE Facilities: Better Prioritization and Life Cycle Cost Analysis Would Improve Disposition Planning (GAO-15-272). | GAO-19-339

assessing exposure to the hazard; (3) assessing the "dose-response" relationship, or the relationship between the amount of exposure to a hazard (dose) and the extent of likely effects in humans (response); and (4) characterizing the risk by integrating information from the previous activities to draw an overall conclusion about risks to human health.[61]

- **Life-cycle cost estimates** assess the extent to which each option performs with respect to objectives related to cost. A program life-cycle cost estimate provides a complete and structured accounting of all government resources and associated cost elements required to develop, produce, deploy, and sustain a particular program. According to our best practices for developing and managing capital program costs, a life-cycle cost estimate can enhance decision-making, particularly in the early planning stages, by fully accounting for all present and future costs to government associated with a particular program.[62] In addition, OMB guidelines on benefit-cost analysis call for consideration of costs to society, including to the federal government.[63]
- **Ecological risk assessments** assess the extent to which each option performs with respect to objectives related to ecological impacts. According to EPA guidelines, such assessments generally involve determining what plants, animals, habitats, ecosystems, or other ecological entities are exposed to a stressor; how and to what degree they are exposed; and whether that level of exposure is likely or not to cause harmful ecological effects.[64]
- **Technology readiness assessments** help assess the technology maturity of each option. A technology readiness assessment is a systematic, evidence-based process that evaluates the maturity of hardware and software technologies critical to the performance of a larger system or the fulfillment of key goals of an acquisition program. According to our best practices for conducting technology readiness

[61]U.S. Environmental Protection Agency, *Framework for Human Health Risk Assessment to Inform Decision Making*. EPA's guidance reflects the longstanding, basic approach to risk assessment first outlined by the National Academies in its 1983 report, *Risk Assessment in the Federal Government: Managing the Process.* See: National Research Council of the National Academies, Committee on the Institutional Means for Assessment of Risks to Public Health, *Risk Assessment in the Federal Government: Managing the Process* (Washington, D.C.: The National Academies Press, 1983).

[62]GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, GAO-09-3SP (Washington, D.C.: March 2009).

[63]Office of Management and Budget, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Program*, OMB Circular No. A-94.

[64]U.S. Environmental Protection Agency, *Guidelines for Ecological Risk Assessment*, EPA/630/R-95/002F (Washington, D.C.: April 1998).

assessments, such assessments can help highlight critical technology maturity concerns before such concerns are carried into the later and more expensive stages of system development.[65]

Other types of analyses may be appropriate, depending on the objectives established for the decision. For example, according to the literature we reviewed, it may be appropriate to conduct an analysis of whether each option may be viewed as acceptable to different stakeholder groups, or to examine the equity or environmental justice implications of each option.[66]

Assess Uncertainty

This step involves identifying the sources of uncertainty in any analyses conducted, assessing the amount of uncertainty, and taking steps to reduce uncertainty where reasonably feasible. According to the literature we reviewed, uncertainty exists in decisions that involve predicting impacts over time, since it is not possible to obtain perfect information or to precisely anticipate the future consequences of an action.[67] It also exists when one makes an assumption or judgement call in the course of conducting an analysis. DOE's cleanup decisions involve substantial uncertainty stemming from multiple sources. For example, uncertainty may exist because of limited data on the exact contents of the waste stored in DOE's underground tanks or limits in scientific understanding of the precise health impacts of exposure to specific radiological materials.[68] In addition, using models to predict risks to human health posed by radiological waste 1,000 to 10,000 years into the future involves considerable uncertainty because of unknowns about future human

[65]GAO, *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects,* GAO-16-410G (Washington, D.C.: August 2016).

[66]See, for example: U.S. Environmental Protection Agency, *Final Report of the Federal Facilities Environmental Restoration Dialogue Committee: Consensus Principles and Recommendations for Improving Federal Facilities Cleanup,* EPA/540/R-96/013 (Washington, D.C.: April 1996).

[67]See, for example: Stephen Polasky, Stephen R. Carpenter, Carl Folke, and Bonnie Keeler, "Decision-making under great uncertainty: environmental management in an era of global change," *Trends in Ecology and Evolution*, vol. 26, no. 8 (Aug. 2011), 398-404.

[68]For example, according to DOE's 2012 Environmental Impact Statement, Hanford's Best Basis Inventory—which establishes the chemical inventory of Hanford's underground waste storage tanks—may have uncertainties of 50 percent to 400 percent for selected constituents of concern in the tanks. See Department of Energy, *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford* Site*, Richland, Washington*, DOE/EIS-0391 (Benton County, WA: November 2012).

populations, land use, climate change, and other variables. Some types of uncertainty, such as random variability that is inherent to natural systems, may be quantified or characterized through additional data collection. Other types, such as that related to major unanticipated future events, cannot be quantified due to an absence of data or scientific understanding that is unlikely to be addressed within a time frame relevant to the decision.

The purpose of this step is to explicitly characterize uncertainty as it relates to predicting the performance of each option and taking appropriate measures to reduce it and to make the best possible decisions in the face of it. According to the literature we reviewed, depending on the timeline and resources available for the decision, and depending on the type and extent of information needed to inform the decision, methods to assess or reduce uncertainty may include: improving the quality of data, modeling, and research; eliciting judgements from experts about the range and likelihood of potential outcomes; and developing assessment tools that use statistical methods to estimate a probability distribution of potential outcomes.[69] For example, a predictive model associated with a cost estimate could show a range of estimated total costs for various cleanup options, as well as the probability associated with the values within that range.[70] One expert who participated in our meeting noted that, to make appropriate estimates of uncertainty, it is important to consider issues such as matching the scale of available data to the scale of the model being used and understanding and accounting for correlation in model parameters.

According to the literature we reviewed, no matter the method used, particular emphasis should be placed on understanding and reducing uncertainty associated with objectives that will most influence the decision, so that the individual or group making the decision can be confident that the selected option is optimal given the information

[69]See, for example: National Research Council of the National Academies, Committee on Improving Risk Analysis Approaches Used by the U.S. EPA, *Science and Decisions: Advancing Risk Assessment* (Washington, D.C.: The National Academies Press, 2009).

[70]For instance, a predictive model could show that the estimated cost of one cleanup option is $41 to $67 billion, with a mean of $53 billion, while the estimated cost of another cleanup option is $27 to $39 billion, with a mean of $32 billion. For additional information and an example of a cost estimate we developed using Monte Carlo simulation to account for uncertainties, see GAO, *Nuclear Waste Management: Key Attributes, Challenges, and Costs for the Yucca Mountain Repository and Two Potential Alternatives*, GAO-10-48 (Washington, D.C.: Nov. 2009).

available.[71] Sensitivity analysis and value-of-information analysis can be used to determine whether collecting new or additional data or taking other steps to reduce uncertainty would change the results of the analyses to a degree that affects which option is preferred. For example, value-of-information analysis can help clarify the level of effort required to obtain more precise information on any uncertain variable.[72]

Decision-makers—with input from stakeholders, as appropriate—can then weigh whether that level of effort is worth the reduced level of uncertainty. For a risk-informed cleanup decision, efforts to reduce uncertainty related to human health risk assessments and cost estimates may be beneficial in clarifying distinctions between contending options. For example, assume that a human health risk assessment shows that cleanup option A is slightly better, on average, at protecting human health than cleanup option B, but that there is some chance that cleanup option B is actually better due to uncertainty in outcomes. In such a case, steps to reduce uncertainty related to human health outcomes may help clarify the distinction between the options. In addition, experts who participated in our meeting generally told us that improving the accuracy of data and modeling can help reduce uncertainty and avoid unduly conservative or liberal estimates of risks to human health. DOE officials also told us that reducing uncertainty can help avoid unwarranted cleanup and excessive costs.

Validate Analysis

This step involves thoroughly evaluating the data, models, and results from the analyses and addressing any problems that are detected. This step may include peer review by an independent panel of individuals who have expertise in the data and analytical approaches used. Such review can help ensure the credibility and quality of the analyses. In addition, one expert who participated in our meeting said that a qualitative method for evaluating results is to check whether the results are reasonable in light of real-world experiences. A 2005 National Academies report recommends a similar approach, saying that testing even a portion of a

[71]See, for example: Institute of Medicine of the National Academies, Committee on Decision Making Under Uncertainty, *Environmental Decisions in the Face of Uncertainty* (Washington, D.C.: The National Academies Press, 2013).

[72]One expert who participated in our meeting noted that because rigorous uncertainty analysis can be a major task, screening methods that establish the level of effort required to quantify uncertainty are important.

model against observed behavior of a system can help make the model easier to believe and harder to discredit.[73]

Synthesize, Document, and Communicate Analysis

This step involves synthesizing results from the analyses showing the estimated performance of each option with respect to each objective and any constraints, and then documenting and communicating these results in writing. To be useful for decision-making, these results should be presented in a way that facilitates consistent comparison of the relative performance of the options and exposes key trade-offs and uncertainties. For example, the results may show whether some of the options are less well understood or certain than others. Documentation of the analyses should also describe the data inputs and assumptions used to characterize the options, the modeling methodology, the methods used to consider uncertainty, and any caveats relevant to the methodology and results. According to the literature we reviewed, this information should be communicated in a way that is accurate, thorough, and that can be understood and accessed by decision-makers and various stakeholders.[74]

Decision Phase

The goal of the Decision Phase is to choose an option (or set of options) that meets constraints and achieves an acceptable balance of performance across the objectives. This phase involves making judgments about how much of one objective, such as reducing risk, is worth how much of another, such as reducing cleanup cost. In the Decision Phase, such judgments are made by applying the decision-making method and decision rule identified in the Design Phase to the credible technical information developed in the Analysis Phase. The Decision Phase consists of three steps.

Apply Decision-making Method and Rule to Compare Options

Using results of analyses, this step involves carrying out the decision-making method identified in the Design Phase to compare how well each option performs with respect to the objectives and to evaluate trade-offs

[73]National Research Council of the National Academies, *Risk and Decisions About Disposition of Transuranic and High-Level Radioactive Waste*.

[74]See, for example: National Research Council of the National Academies, *Understanding Risk: Informing Decisions in a Democratic Society.*

among competing objectives. In some decisions, an option may perform well with respect to one objective without coming at the expense of other objectives. However, according to the literature we reviewed, for many decisions, the options will each offer a different balance across the objectives, requiring judgments to be made about how much of one objective to give up in exchange for gains in another.[75] For example, judgments may need to be made about whether it is worth giving up the incremental human health protection offered by one option in order to achieve the reduced costs offered by another option. The decision-making method and decision rule identified in the Design Phase should provide a basis for making such judgments and for identifying an option that provides the best balance across objectives.

For some decision-making methods, such as multiattribute utility theory, this step may involve assigning weights to objectives as a way to incorporate decision-maker or stakeholder preferences about the relative importance of the objectives. Surveys, workshops, and other structured tools and methods may be used to elicit an individual's or group's preferences and assign weights to objectives. According to the literature we reviewed, to be useful and defensible, the weights should be assigned by considering concrete information about how well each option performs with respect to the objectives.[76]

Because it is neither possible nor practical to reduce all uncertainty, some uncertainty will remain in the Decision Phase, and decision-making will likely need to proceed despite incomplete information about the exact

[75]See, for example: Gregory R., L. Failing, M. Harstone, G. Long, T. McDaniels, and D. Ohlson, *Structured Decision Making: A Practical Guide to Environmental Management Choices*.

[76]According to Keeney (2002), weighting or prioritizing objectives in the abstract—without concrete information about how well each option performs with respect to the objectives—may not provide meaningful insight. Keeney provides an example of asking people to rank in importance: (1) economic costs of cleaning up a hazardous waste site, (2) potential human life loss or sickness due to the hazard, and (3) potential damage to the environment. He reports that almost everyone ranks (2), loss of life or sickness, as the most important. He then asks them to rank the importance of: (1) spending $3 billion to clean up the site, (2) avoiding a mild 2-day illness to 30 people, and (3) destroying 10 square miles of mature forest. Almost everyone then ranks (1), cost, as most important. Keeney's example illustrates that people need to understand the specific amounts of gains and losses for each objective in order to make informed evaluations of trade-offs. Information about these specific amounts is not known until analyses have been conducted. See Ralph L. Keeney, "Common Mistakes in Making Value Trade-Offs," *Operations Research*, vol. 50, no. 6 (2002).

Cleanup Agreements: Milestone Data Do Not Provide an Accurate View of DOE's Progress in Cleaning Up Sites

A variety of cleanup agreements negotiated between the Department of Energy (DOE) and federal and state regulatory agencies govern DOE's cleanup work at different sites. Among other things, these agreements establish enforceable milestones, which are the dates by which DOE has agreed to complete specific cleanup activities. DOE uses milestones as a tool for managing site cleanup and tracking progress, and such milestones may be helpful in evaluating the success of a selected option.

In February 2019, we reported on several shortcomings in DOE's milestone data that limit the usefulness of milestones for managing cleanup activities and tracking progress. For example, DOE headquarters tracks milestones differently from some sites, making it difficult to determine the total number of milestones that are in place. In addition, sites regularly renegotiate milestones they are at risk of missing, resulting in discrepancies between DOE's milestone data and the status of the cleanup efforts. In particular, even though a number of DOE's cleanup projects have experienced significant delays, DOE has reported that very few of its cleanup milestones have been missed. As a result, we found that DOE's self-reported performance in achieving milestones does not provide an accurate view of the actual progress made in cleaning up contaminated sites.

We recommended that DOE take four actions to help address shortcomings in its milestone data, including establishing a standard definition for milestones across the DOE complex. Evaluating the outcomes of cleanup decisions according to an established timeline is an important part of a risk-informed decision-making framework. Milestones are a tool that DOE and others can use to assist in this evaluation process, and taking action to implement our recommendations would help to improve the quality of milestone information available for assessing cleanup progress.

Source: GAO, *Nuclear Waste: DOE Should Take Actions to Improve Oversight of Cleanup Milestones* (GAO-19-207). | GAO-19-339

way any of the options—if selected and implemented—would perform. According to the literature we reviewed, to compare options under this remaining uncertainty, decision-makers should consider their willingness to accept the chance that an option will fail to perform as expected for any given objective.[77] As a simplistic example, assume that a cost estimate indicates that the probable cost of cleanup option A is $10 billion, though it could be $15 billion, while the probable cost of cleanup option B is $5 billion, though it could be $30 billion, then the best choice will depend on the decision-maker's tolerance for accepting the chance that the worst-case outcome will occur. In this example, a decision-maker could select Option A, with the "best" worst-case outcome, or a decision-maker could decide to try for the possible cost savings offered by Option B, even though this option presents a chance of large cost overruns. Depending on the circumstances, a decision-maker could also opt to revisit the value of obtaining more precise information before selecting either of the options, as described in the Analysis Phase. An agency's stance on risk; the potential consequences of an option failing to perform as expected; and any relevant regulatory, statutory, or budget constraints will likely influence which option is preferred. In addition, one expert who participated in our meeting said that stakeholders should also have the opportunity to weigh in on their willingness to accept the chance that an option will fail to perform as expected.

Select the Preferred Option

The step involves selecting an option to implement or, if necessary, returning to an earlier phase or step within the framework to consider or gather additional information prior to making a final decision. The results of applying the decision-making method and decision rule should provide strong support for selecting an option. If multiple decision-makers must agree on the final decision, then negotiation, mediation, or other conflict resolution methods may be necessary to achieve consensus. For example, according to the literature we reviewed, a neutral, informed mediator can facilitate discussion among individuals about areas of and reasons for agreement and disagreement, thus increasing the possibility

[77]See, for example: National Aeronautics and Space Administration, *NASA Risk-Informed Decision Making Handbook*.

of consensus.[78] In addition, formal, quantitative methods for evaluating trade-offs, as described above, can be useful in situations with multiple decision-makers because they produce results that readily identify areas of agreement and disagreement. One expert who participated in our meeting noted that decision-makers should avoid including stakeholders who do not hold decision-making authority in this step, as doing so may lead to disagreement and delay. Rather, this expert said that agencies should focus on designing and implementing a process that allows for meaningful input upfront, such as in defining objectives and identifying options.

Document and Communicate Decision

This step involves communicating the decision and the rationale—including any trade-offs that were considered—to stakeholders and other interested parties. According to the literature we reviewed, this step should include communicating information about how uncertainty affected the decision.[79] It should also include communicating about how and to what extent the results of the decision-making method and decision rule were used in making the decision. For example, if the decision is inconsistent with the results of the decision-making method, then a discussion providing the justification would help ensure accountability.

Implementation and Evaluation Phase

The framework's final phase involves implementing the selected option, and then monitoring and learning from the results.

Implement decision

This step involves taking action to implement the selected option. In implementing a decision, an agency should follow applicable leading

[78]See, for example: George E. Apostolakis and Susan E. Pickett, "Deliberation: Integrating Analytical Results into Environmental Decisions Involving Multiple Stakeholders," *Risk Analysis*, vol. 18, no. 5 (1998), 621-634.

[79]See, for example: Institute of Medicine of the National Academies, *Environmental Decisions in the Face of Uncertainty.*

practices, such as program and project management leading practices related to scope, cost, schedule performance, and independent reviews.[80]

Evaluate outcomes

This step involves establishing and following a timeline to monitor and evaluate the outcomes of the implemented decision. In general, the objectives used to assess the options in the Analysis and Decision Phases should also be used to evaluate the success of the selected option once it has been implemented. According to experts who participated in our meeting, if evaluation results show that the implemented option is not performing as expected, then it is important to revisit the decision rather than continuing to invest resources in an option that is not working. In addition, according to the literature we reviewed, evaluating the decision using adaptive management methods can help promote learning and build capacity to make better decisions in the future.[81]

Conclusions

DOE is responsible for more than 80 percent of the federal government's environmental liability because of its responsibility for cleaning up contamination from nuclear weapons production and nuclear energy research dating back to World War II and the Cold War. Since the mid-1990s, several independent reviews have found that DOE would benefit from adopting risk-informed cleanup approaches to better address risks within the constraints of the agency's limited resources. Moreover, both experts and literature have noted that having a framework for risk-informed decision-making may help DOE identify cost-effective approaches for addressing risks to human health and the environment across and within sites. However, DOE does not have such a framework for implementing its requirements and guidance to make cleanup decisions that would comply with all relevant legal requirements in a risk-informed manner to the extent practicable. By revising EM's 2017 cleanup policy to establish how the EM program and DOE sites should apply the

[80]In February 2019, we recommended that EM revise its 2017 cleanup policy to include program and project management leading practices related to scope, cost, schedule performance, and independent reviews. See GAO-19-223.

[81]See, for example: I. Linkov et al., "From comparative risk assessment to multi-criteria decision analysis and adaptive management: Recent developments and applications," *Environment International*, vol. 32 (2006), 1072-1093.

concepts of a risk-informed decision-making framework into its current decision-making requirements and guidance, DOE sites would be better able to follow consistent decision-making processes and ensure that resource allocation is as risk-informed as practicable. As DOE implements our prior recommendation and revises its 2017 cleanup policy, an opportunity exists to further improve its development of a program management plan by incorporating the concepts of risk-informed decision-making in its plan. By doing so, DOE would be in a better position to effectively set priorities within and across its sites and enhance its ability to direct its limited resources to address those priorities.

Recommendations for Executive Action

We are making two recommendations to DOE:

The Secretary of Energy should direct DOE's Office of Environmental Management to revise EM's 2017 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 current decision-making requirements and guidance. (Recommendation 1)

The Secretary of Energy should direct DOE's Office of Environmental Management, in the development of a program management plan, to incorporate essential elements of risk-informed decision-making. (Recommendation 2)

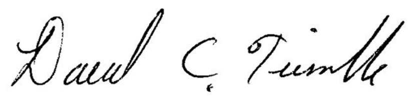
Agency Comments and Our Evaluation

We provided a draft of this report to the Department of Energy and the Environmental Protection Agency for comment. In its comments, reproduced in appendix II, DOE agreed with our two recommendations and said that it is 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. DOE also provided technical comments, which we incorporated as appropriate. EPA did not provide comments on the draft report.

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies to the appropriate congressional committees, the Secretary of Energy, the EPA

Administrator, and other interested parties. In addition, this report will be available at no charge on the GAO website at http://www.gao.gov.

If you or your staff members have questions about this report, please contact David C. Trimble at (202) 512-3841 or trimbled@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 III.



David C. Trimble
Director,
Natural Resources and Environment

List of Requesters:

The Honorable Frank Pallone, Jr.
Chairman
The Honorable Greg Walden
Republican Leader
Committee on Energy and Commerce
House of Representatives

The Honorable Bobby L. Rush
Chairman
The Honorable Fred Upton
Republican Leader
Subcommittee on Energy
Committee on Energy and Commerce
House of Representatives

The Honorable Paul D. Tonko
Chairman
The Honorable John Shimkus
Republican Leader
Subcommittee on Environment and Climate Change
Committee on Energy and Commerce
House of Representatives
The Honorable Diana DeGette
Chair
Subcommittee on Oversight and Investigations

Committee on Energy and Commerce
House of Representatives

Appendix I: Objectives, Scope, and Methodology

The objectives of our review were to (1) examine the extent to which DOE has a framework for making risk-informed cleanup decisions; and (2) identify essential elements of a framework for making risk-informed cleanup decisions.

To examine the extent to which DOE has a framework for making risk-informed cleanup decisions, we reviewed key legal requirements, including the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 as amended (CERCLA) and the Resource Conservation and Recovery Act of 1976 as amended (RCRA). We also interviewed officials from DOE's Office of Environmental Management's (EM) Office of Regulatory Compliance regarding the extent to which DOE has a framework for risk-informed decision-making and the challenges, if any, that it faces in making risk-informed cleanup decisions. We also analyzed DOE's policies and guidance to determine what orders, policies, or guidance it has to make risk-informed cleanup decisions. These policies and guidance documents are listed and described in the body of our report.

To identify essential elements of a framework for making risk-informed cleanup decisions, we took two steps. First, we conducted a literature review of reports and studies on risk and decision-making in the context of environmental cleanup (see below for further information on our literature review). Second, we worked with the National Academies of Sciences, Engineering, and Medicine (National Academies) to convene an experts' meeting pertaining to our draft framework on risk-informed decision-making (see below for further information on our selection of experts, meeting content, and analysis of the experts' meeting transcript).

Literature Review

We conducted a literature review on risk and decision-making in the context of environmental cleanup. The literature in our review included reports from U.S. and foreign government agencies, studies and articles from research journals and academic institutions, reports from the National Academies, and publications from trade and nonprofit associations.[1] We included literature that was peer-reviewed or from credible sources that were relevant to our focus on risk-informed decision-making.

Literature Search

To select the reports and studies for our literature review, we used a snowball technique to first identify a set of 38 core reports and studies on risk and decision-making in the context of environmental cleanup. This technique involved identifying prior GAO and National Academies' reports on risk, risk assessment, risk management, and decision-making, particularly in the context of environmental cleanup; reviewing these reports to identify additional relevant sources; and searching those sources for additional ones. We continued searching until we determined that we had identified a recurring set of themes related to risk-informed decision-making. We reviewed the core set of documents, identified key findings, and organized these findings into a draft framework for risk-informed decision-making.

We then continued our literature search by identifying reports and studies to help refine our draft framework for risk-informed decision-making. To do this, we identified a set of five out of the 38 core reports and studies that most closely aligned with our review objectives. Specifically, we selected five reports and studies that cover key aspects of risk-informed decision-making and that were produced by authoritative, credible sources, such as the National Academies. A GAO research librarian conducted searches of Scopus and Web of Science to identify sources that: (a) were cited by any of the five reports and studies in our set, or (b) cited one of the five reports or studies in our set. In total, the search resulted in a list of about 2,600 reports and studies.

To narrow the results to those reports and studies most relevant to our scope, we reviewed summary level information, including key words, titles, and abstracts, and requested certain full-text versions of reports and studies that met the following criteria:

- Summary level information included specific key words related to our scope of work, including nuclear, radiation, dose, risk-informed, Department of Energy, and DOE.

[1]For brevity, we use the term "reports and studies" below to refer to the literature in our review.

- Titles or abstracts were related to risk-informed decision-making or to DOE cleanup decisions.

We excluded reports and studies that were clearly outside of our scope (i.e., not related to risk-informed decisions, risk assessment, decision-making, or cleanup decisions), that were duplicative of the core reports and studies identified in the first step of our literature review, and that had incomplete citations, since we were unable to determine the nature of such reports and studies. In all cases, if we were unsure whether or not a report or study was relevant to our review, then we kept it in our list for further consideration. This review and selection process resulted in about 400 reports and studies.

We then prioritized our review of the reports and studies into several categories based on their relevance to our scope. For example, we identified about 100 reports and studies as the highest priority for review because their summary information indicated they were highly relevant to our scope—that is, they appeared to comprehensively discuss risk-informed decision-making; to have relevance to or lessons learned that could apply to DOE's cleanup decisions; or to discuss a core methodology related to risk, such as risk assessment.

Throughout our review, we also obtained about 30 additional reports and studies that were: (1) suggested by internal GAO staff with expertise in risk or a related topic, (2) suggested by experts who participated in our May 2018 experts' meeting (see below for information on our experts' meeting), and (3) cited in the sources we were reviewing and appeared to be relevant to our scope. We reviewed these reports and studies for the purpose of supplementing and reinforcing the literature that resulted from our main search.

Analysis of Literature

We analyzed more than 110 reports and studies that resulted from our literature search. First, we read reports and studies, starting with those identified as highest priority during our literature search, and then we used NVivo, a qualitative analysis software program, to code information related to risk-informed decision-making. We coded information into categories that corresponded to the steps in our draft framework for risk-informed decision-making. For example, these categories included assessing the risk of an option, comparing options, and making a decision. Through coding, we sought to gather information from the reports and studies about what steps to include in a framework for risk-informed decision-making, why each step is important, who should perform each step, and examples of implementation. We continued reading and coding reports and studies until we determined that we had identified the major steps and concepts involved in risk-informed decision-making.

We reviewed findings from the coding and identified six areas in which to target additional reading and coding. These six areas corresponded to a subset of steps and concepts in our draft risk-informed decision-making framework; they included: engaging with stakeholders; goals, values, and risk perception; risk assessment; factors other than risk that influence decision-making; decision criteria; and decision-making roles and processes. Working with internal GAO staff with expertise in social sciences, statistics, and economics, we read and coded additional reports and studies related to the six areas, with the goals of filling in information gaps and deepening our understanding of these areas.

We synthesized the results of our analysis into names and definitions of the phases and steps in a draft framework for risk-informed decision-making. We created a graphic of the draft framework and then shared the graphic and written description of the draft framework with experts prior to our in-person experts' meeting.

Experts' Meeting

We worked with the National Academies to convene an experts' meeting to obtain experts' input on our draft framework for risk-informed decision-making.[2] We worked with the National Academies to identify 15 experts in this subject matter and conducted telephone interviews with the experts prior to holding a 2-day, in-person meeting in May 2018. At our in-person meeting, we discussed key topics of interest. Following the experts' meeting, we analyzed the transcript from the meeting and used the experts' comments to refine our framework.

[2]This meeting of experts was planned and convened with the assistance of the National Academies to better ensure that a breadth of expertise was brought to bear in its preparation; however, all final decisions regarding meeting substance and expert participation were the responsibility of GAO. Any conclusions and recommendations in our report are solely our own.

Selection of Experts

GAO collaborated with the National Academies to identify and recruit 15 experts from the government, academia, and industry. We selected a broad mix of experts with professional expertise in areas such as risk, risk assessment, risk management, decision-making, stakeholder collaboration, and nuclear waste treatment and disposal. We asked the experts to disclose any potential conflicts of interest, such as any current financial or other interests that might conflict with their service. The 15 experts were determined to be free of conflicts of interest, and collectively the group was judged to have no inappropriate biases. The views of these experts cannot be generalized to everyone with expertise on risk-informed decision-making; they represented only the views of the experts who participated in our meeting hosted by the National Academies. The experts who participated in our meeting are listed in table 1.

Table 1: Experts Who Participated in GAO's May 2018 Experts' Meeting

Expert	Affiliation
Lake Barrett	L. Barrett Consulting, LLC
Paul K. Black	Neptune and Company, Inc.
Larry Camper	Talisman International
Gail Charnley	HealthRisk Strategies
Allen Croff	Vanderbilt University
Carol Eddy-Dilek	Savannah River National Laboratory
Timothy Fields	MDB, Inc.
B. John Garrick	University of California, Los Angeles[a]
Christine Gelles	Longenecker & Associates
Michael Greenberg	Rutgers University
Jeffrey Keisler	University of Massachusetts Boston
David Kosson	Vanderbilt University
Glenn Suter	U.S. Environmental Protection Agency (retired)
Jane B. Stewart	New York University
Seth P. Tuler	Worcester Polytechnic Institute

Source: GAO. | GAO-19-339

[a]B. John Garrick participated via teleconference.

Experts' Meeting Content

The meeting was held on May 16 and 17, 2018, at the National Academies' Keck Center in Washington, D.C. Prior to this in-person meeting, we provided the experts with a draft version of a framework for risk-informed decision-making and conducted phone interviews with the experts to obtain their initial impressions of the framework's accuracy. The goals of the in-person meeting were to obtain experts' views on: (1) whether the draft framework provided a logical, reasonable, valid representation of a risk-informed decision-making process; (2) how DOE could apply and operationalize the framework to actual cleanup decisions; and (3) how, if at all, the framework could be applied to different types and scales of decisions, such as at the project, site, and programmatic levels. As such, the meeting focused on the phases of the framework as well as crosscutting issues that were identified during our literature review, such as existing legal requirements, stakeholders, and uncertainty.

We divided the 2-day experts' meeting into seven sessions: (1) risk-informed decision-making framework: history, value, and characteristics; (2) planning phase of the framework; (3) analysis phase of the framework; (4) decision-making phase of the framework; (5) implementation and evaluation phase of the framework; (6) crosscutting issues; (7) synthesis and implementation of the framework.[3] A GAO methodologist moderated the sessions. The meeting was recorded and transcribed to ensure we accurately captured the experts' statements. In addition, after each session during the meeting, we summarized the key points and themes that arose during each session and invited the experts to offer any additional themes that they believed should be included.

Analysis of Experts' Meeting Transcript

After the experts' meeting, we analyzed the transcript to characterize the experts' responses and to identify major themes. Specifically, we used NVivo to analyze and code the transcript. To do this, we first developed categories for coding that corresponded to: (1) steps in our draft framework for risk-informed decision-making, (2) themes that we identified by reading the meeting transcript, and (3) summaries of key points created at the end of each session of our experts' meeting.

[3]In refining the framework after the in-person meeting, we changed the name of the "Planning Phase" of the framework to "Design Phase."

Second, we conducted a word frequency search of the transcript to identify the words and terms that experts used most frequently. We reviewed the list of the most frequently used words to ensure that the words and related concepts were included in our categories. This search confirmed that we did not overlook any major themes discussed throughout our experts' meeting. In total, we identified 40 categories for coding. The categories included those that correspond to steps in our draft framework for risk-informed decision-making, such as stakeholders, options, and objectives, as well as those that reflect broader principles, such as transparency and iteration.

We coded the contents of the transcript under the categories we identified and reviewed and verified the coding. To code, one analyst used a text search tool within NVivo to find text that contained the category name and related terms. For example, for the "options" category, the analyst searched the transcript for instances of the term "option," along with related terms "alternative" and "solution."[4] The analyst then coded the search results under each category. A second analyst reviewed the coding results for accuracy and relevance and made adjustments as needed. We then queried the coding results to extract the text from the transcript associated with each of our categories and summarized the categories. We refined our draft framework for risk-informed decision-making using the results of this analysis.

In the body of this report, we present key comments made by experts during this meeting. In selecting these comments, we considered whether the comments: (1) had agreement among multiple experts; (2) were supported by corroborating evidence, such as reports and studies in our literature review; (3) were within the core of the commenting experts' base of knowledge; and (4) did not fundamentally contradict a specific comment made by another expert. We considered comments that met some or all of these characteristics to be strong evidence and, as a result, we use language such as "experts generally said," "experts generally agreed," or "according to experts" to describe these comments in the report. If a comment met the above characteristics but was made by only one expert with particular expertise in that area, then we also considered the comment to be strong evidence. We report such a comment as "one expert said" or "according to one expert."

[4]In all applicable cases, we used variations of the search term. For example, we searched for both "option" and "options." As another example, we considered both "iterative" and "iteration."

Because experts did not speak on every topic and did not have the same level of expertise on every topic, we do not specify the number of experts who agreed or disagreed with various statements. In addition, for reporting purposes, we cannot include a complete list of themes and comments made by the experts—because, for example, of the technical complexities of this subject and the various ways that each theme could be articulated. We believe we were able to identify the main themes that emerged from the experts' meeting and select specific comments to include in our report to serve as illustrative examples of the key themes. We did not identify any specific areas of disagreement among the experts related to topics included in our report. To the extent possible, we corroborated experts' statements with our literature review, and vice versa.

Following the experts' meeting, we provided our framework to each of the experts and asked them to review the framework for technical accuracy, completeness, and applicability. We incorporated experts' comments related to technical accuracy, completeness, and applicability as appropriate.

We conducted this performance audit from July 2017 to September 2019, 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.

Appendix II: Comments from the Department of Energy

Department of Energy
Washington, DC 20585

August 30, 2019

David C. Trimble
Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, N.W.
Washington, DC 20548

Dear Mr. Trimble:

This letter provides the Department of Energy (DOE) response to the draft U.S. Government Accountability Office (GAO) report, "Environmental Liabilities: DOE Would Benefit from Incorporating Risk-Informed Decision-Making into Its Cleanup Policy".

DOE appreciates the GAO overview of essential elements of risk-informed decision-making, and provides in this letter clarifications and responses to the GAO recommendations made in the draft report. DOE agrees in principle that risk-informed decision-making is appropriate in making cleanup decisions. Risk is an important factor in determining clean-up remedies and prioritization under both the Comprehensive Environmental Response, Compensation, and Liability Act, and the Resource Conservation and Recovery Act. DOE is required to follow the methodologies identified in the applicable statutes and regulations, while working with each site's regulators and the public to select remedies for cleaning up the sites. DOE is committed to achieving the desired outcome of directing available resources to best address human health and environmental risks associated with cleanup at Environmental Management sites.

The actions being taken on GAO's recommendations and comments on the draft report, are described in the enclosure. If you have any questions, please contact me or Ms. Elizabeth A. Connell, Associate Principal Deputy Assistant Secretary for Regulatory and Policy Affairs, at (202) 586-0637.

Sincerely,

William I. White
Senior Advisor for Environmental Management
to the Under Secretary for Science

Enclosure

Management Response
GAO Draft Report, GAO-19-339
Environmental Liabilities: DOE Would Benefit from Incorporating Risk-Informed Decision-Making into its Cleanup Policy."

Recommendation 1: The Secretary of Energy should direct DOE's Office of Environmental Management to revise EM's 2017 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 current decision-making requirements and guidance.

Management Response: Concur

The Department of Energy (DOE) agrees with this recommendation. The Office of Environmental Management (EM) has recently reinvigorated efforts to develop a comprehensive program-wide strategy to address risks in a more consistent manner to better align cleanup plans and activities with programmatic priorities and available budgets. Key efforts are developing program and project management policies to replace the 2017 Cleanup Policy, performing a program-wide strategic options analysis, and continuing site risk assessments and reviews.

Estimated Completion Date: Program Management Policy development estimated completion January 31, 2020.

Recommendation 2: The Secretary of Energy should direct DOE's Office of Environmental Management, in the development of a program management plan, to incorporate essential elements of risk-informed decision-making.

Management Response: Concur

DOE agrees with this recommendation. Essential elements of risk-informed decision making will be assessed and incorporated as appropriate into the new EM program management policy.

Estimated Completion Date: Program Management Policy development estimated completion January 31, 2020.

Text of Appendix II: Comments from the Department of Energy

Page 1

August 30, 2019

David C. Trimble Director
Natural Resources and Environment
U.S. Government Accountability Office 441 G Street, N.W.
Washington , DC 20548

Dear Mr. Trimble:

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Sincerely,

William I. White

Senior Advisor for Environmental Management to the Under Secretary for Science

Page 2

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Management Response: Concur

DOE agrees with this recommendation. Essential elements of risk-informed decision making will be assessed and incorporated as appropriate into the new EM program management policy.

Estimated Completion Date: Program Management Policy development estimated completion January 31, 2020.

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

David C. Trimble at (202) 512-3841 or trimbled@gao.gov

Staff Acknowledgments

In addition to the individual named above, Nico Sloss, Assistant Director; Mark Braza; Ricki Gaber; Richard Johnson; Katherine Killebrew; Amanda K. Kolling; Jeanette Soares; Phillip Steinberg; and Joshua Wiener made key contributions to this report. Also contributing to this report were David Blanding; Antoinette Capaccio; Ellen Fried; Sarah Gilliland; Jeff Larson; Serena Lo; Katrina Pekar-Carpenter; Amber Sinclair; and Sara Sullivan.

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