United States Government Accountability Office

Report to Congressional Addressees

May 2017

NUCLEAR WASTE

Opportunities Exist to Reduce Risks and Costs by Evaluating Different Waste Treatment Approaches at Hanford

Accessible Version

GAO-17-306

GAO Highlights

Highlights of GAO-17-306, a report to congressional addressees

May 2017

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Opportunities Exist to Reduce Risks and Costs by Evaluating Different Waste Treatment Approaches at Hanford

Why GAO Did This Study

DOE oversees the treatment and disposal of about 90 million gallons of radioactive waste from the nation's nuclear weapons program. Most of this waste is stored in tanks at DOE sites in Hanford, Washington, and Savannah River, South Carolina. The less radioactive portion of the tank waste, called LAW, comprises more than 90 percent of the waste's volume but less than 10 percent of the total radioactivity. DOE has chosen different approaches for treating LAW at the two sites, but it has not made a final decision on how to treat Hanford's supplemental LAW.

GAO examined (1) DOE's reasons for choosing its treatment approaches for LAW at the Savannah River and Hanford Sites, (2) the status of DOE's treatment of LAW at these sites, and (3) experts' views on the likely performance of approaches for treating Hanford's LAW. GAO reviewed technical reports on DOE's waste treatment strategies at the two sites, interviewed DOE officials at headquarters and the sites, and convened an experts' meeting through the National Academies to discuss the effectiveness and risks of vitrification and grout.

What GAO Recommends

Congress should consider specifically authorizing DOE to classify Hanford's supplemental LAW based on risk, consistent with existing regulatory authorities. GAO also recommends that DOE develop updated information on the performance of treating LAW with alternate methods, such as grout, before it selects an approach for treating supplemental LAW. DOE agreed with both recommendations.

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What GAO Found

The Department of Energy (DOE) chose different approaches to treat the less radioactive portion of its nuclear weapons waste stored in tanks (tank waste)—which DOE refers to as "low-activity waste" (LAW)—at its two main cleanup sites, primarily in response to input from the two states. At the Savannah River Site, DOE and South Carolina agreed to use an existing facility to grout the site's LAW, a method that DOE determined could treat the waste faster and therefore address risks posed by prolonged storage of liquid waste in tanks sooner. Grout immobilizes waste in a concrete-like mixture. At Hanford, DOE is required by an agreement with the state and the Environmental Protection Agency to treat at least one-third to one-half of the site's LAW with a process called vitrification, which immobilizes the waste in glass. DOE chose vitrification in the 1990s with input from Washington state because studies at that time indicated that vitrification would be the most effective treatment approach for the conditions at Hanford. However, DOE has not yet determined how it will treat the remaining one-half to two-thirds of Hanford's LAW, known as "supplemental LAW," a decision it has proposed making by 2018. Congress passed legislation in 2004 that clarified DOE's authority to manage the LAW at the Savannah River Site as low-level waste. Clarifying DOE's authority at Hanford, in a manner that does not impair the regulatory authorities of Washington state, to determine whether some portions of the supplemental LAW can be managed as low-level waste, could enhance DOE's ability to make risk-based decisions for supplemental LAW.

At the Savannah River Site, DOE has grouted about 4 million gallons of LAW and has effectively addressed minor technical challenges, but at Hanford DOE has not yet treated any LAW and faces significant unresolved technical challenges. In addition, the best available information indicates that DOE's estimated costs to grout LAW at the Savannah River Site are substantially lower than its estimated costs to vitrify LAW at Hanford, and its schedule for completing LAW treatment at the Savannah River Site is decades shorter than its schedule at Hanford.

According to the 21 experts that attended GAO's meeting convened by the National Academies of Sciences, Engineering, and Medicine (National Academies), both vitrification and grout could effectively treat Hanford's LAW. These experts stated that current information shows that grout will perform better than was assumed when DOE made its decision to vitrify Hanford's LAW. According to some of the experts, using grout for supplemental LAW could help DOE complete its treatment mission sooner, reducing the environmental risks of leaving waste in tanks for long periods. Experts at GAO's meeting stated that developing updated information on the performance of treating Hanford's supplemental LAW with other methods, such as grout, may enable DOE to consider waste treatment approaches that accelerate DOE's tank waste treatment mission, thereby potentially reducing certain risks and lifecycle treatment costs. However, DOE has not developed current information on the performance of treating LAW with grout, or alternate methods, at Hanford, which is inconsistent with guidance developed by the National Research Council.

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Abbreviations

DOE	Department of Energy
EIS	environmental impact statement
EPA	Environmental Protection Agency
HLW	high-level waste
LAW	low-activity waste
National Academies	National Academies of Sciences, Engineering, and Medicine
NRC	Nuclear Regulatory Commission
RCRA	Resource Conservation and Recovery Act
TPA	Tri-Party Agreement
WTP	Waste Treatment and Immobilization Plant

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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May 3, 2017

Congressional Addressees

The Department of Energy (DOE) is responsible for the treatment and disposal of radioactive and hazardous waste created as a byproduct of producing nuclear weapons. In 2016, DOE estimated that cleanup of the nation's former weapons production sites would cost $257 billion and would last for decades. The majority of this cleanup responsibility and expense involves treating about 90 million gallons of waste currently stored in underground tanks at DOE sites in Hanford, Washington; Savannah River, South Carolina; and near Idaho Falls, Idaho. At its Hanford Site, in particular, DOE manages one of the world's largest environmental cleanup programs. The U.S. government built and operated nine nuclear reactors at Hanford—including the world's first operating large-scale reactor, developed as part of the Manhattan Project during World War II—to produce plutonium and other special nuclear materials for the country's nuclear weapons program. A significant amount of hazardous and radioactive waste resulted from nuclear materials production at Hanford, and 54 million gallons of this waste is now stored in 177 large underground storage tanks and must be treated before disposal. Because multiple processes were used for plutonium production at Hanford, its tank waste contains a more complex mixture of radioactive and hazardous components, or constituents, than the tank waste at other DOE sites. The volume and complexity of the tank waste have been a persistent challenge for DOE—since beginning its mission to treat and dispose of Hanford's waste over 25 years ago, DOE has spent more than $19 billion on several different tank waste treatment strategies, but DOE has yet to treat any of Hanford's tank waste.[1]

Much of DOE's tank waste is "high-level waste" (HLW) mixed with hazardous chemicals that, under current law, must be vitrified—a process in which the waste is immobilized in glass—prior to land disposal. "Low-activity waste" (LAW) is DOE's term for the portion of this tank waste with

[1]This cost figure is not adjusted for inflation.

low levels of radioactivity.[2] LAW is primarily the liquid portion of the tank waste that remains after as much radioactive material as technically and economically practical has been removed.[3] Cleanup of the Hanford Site is governed by two main compliance documents: (1) the 1989 Hanford Federal Facility Agreement and Consent Order, or Tri-Party Agreement (TPA), an agreement among DOE, the Washington State Department of Ecology, and the Environmental Protection Agency (EPA);[4] and (2) a 2010 Consent Decree, amended in 2016.[5] The Consent Decree currently requires DOE to begin vitrifying LAW by the end of 2023, and the TPA requires DOE to complete waste treatment by 2047.[6]

The Waste Treatment and Immobilization Plant (WTP) is DOE's current planned approach to treating Hanford's tank waste. The WTP includes several waste treatment facilities, including a facility to vitrify Hanford's HLW and a facility to vitrify its LAW. Before treatment, DOE plans for the WTP to separate the tank waste into two streams: the HLW portion, which DOE estimates will contain more than 90 percent of the radioactivity but less than 10 percent of the volume, and the LAW portion, which will

[2]DOE uses the term "low-activity waste" to mean the waste that remains after as much radioactivity as technically and economically practical has been separated from tank waste that, when solidified, may be disposed of as low-level radioactive waste in a near-surface facility. At its Savannah River Site, DOE refers to the low-activity portion of its waste as low-level waste or "salt waste." For the purpose of this review, we will refer to the low-activity portion of the waste at both the Hanford and Savannah River Sites as LAW.

[3]Vitrification and grout are commonly referred to as immobilization methods. For the purposes of this report, we refer to them as treatment approaches because the scope of our review includes the entire process of treating the tank waste, not just the final immobilized waste form.

[4]Hanford Federal Facility Agreement and Consent Order, EPA Docket No. 1089-03-04-120, Ecology Docket No. 89-54, as amended through August 1, 2016. The agreement as available at: http://www.hanford.gov/page.cfm/TriParty/TheAgreement.

[5]Washington v. Chu, Civ. No. 08-05085 (E.D. Wash), entered October 25, 2010, amended in March and April 2016.

[6]The TPA lays out a series of legally-enforceable milestones for completing major activities in Hanford's waste treatment and cleanup process. The purpose of the TPA is to ensure that Hanford's cleanup activities comply with the Comprehensive Environmental Response, Compensation, and Liability Act; Resource Conservation and Recovery Act (RCRA); and Washington's Hazardous Waste Management Act. DOE entered into the TPA pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act; Executive Order 12580; and the Atomic Energy Act of 1954. The Consent Decree addresses a subset of these cleanup activities: completing the construction and achieving initial operations of the Waste Treatment and Immobilization Plant and retrieving waste from 12 single-shell tanks.

contain less than 10 percent of the radioactivity and more than 90 percent of the volume. The WTP, however, is currently designed to treat all of Hanford's HLW but only one-third to one-half of the LAW, including some that DOE intends to treat using a "direct feed" process.[7] DOE will need to identify and select another approach for treating the remaining LAW. The portion of the LAW remaining in the tanks for which DOE has yet to select a treatment approach is commonly referred to as "supplemental LAW." Our report focuses on possible treatment and disposal pathways for the supplemental LAW. It does not otherwise address DOE's responsibilities under the compliance agreements.

Independent reviews conducted over the last 15 years have noted that DOE's approach to treating LAW is not consistent across its cleanup sites and does not appear to be based on the degree of risk the waste poses for treatment, storage, and disposal.[8] These reviews have noted that DOE plans to treat Hanford's LAW using vitrification, but DOE treats LAW at its Savannah River Site by grouting it—a process in which the liquid waste is combined with a concrete-like or grout mixture, called saltstone, which then hardens to immobilize the waste.[9] In 2006, the National Research Council found that these different approaches to treating LAW were not always based on a systematic consideration of risks and, as a result, waste having similar physical, chemical, and radiological characteristics may be managed in disparate ways.[10] Moreover, the National Research

[7]DOE intends to feed a portion of Hanford's LAW directly into the LAW vitrification facility that is part of the WTP, which would bypass the pretreatment component of the WTP. By doing so, DOE believes that waste treatment can begin years earlier than if it waits until all of the Pretreatment facility's technical issues are resolved.

[8]Committee on Risk-Based Approaches for Disposition of Transuranic and High-Level Radioactive Waste, National Research Council of the National Academies, *Risk and Decisions About Disposition of Transuranic and High-Level Radioactive Waste* (Washington, D.C.: National Academies Press, 2005). National Research Council of the National Academies, *Improving the Regulation and Management of Low-Activity Radioactive Wastes,* (Washington, D.C.: National Academies Press, 2006). Committee on Waste Forms Technology and Performance, National Research Council of the National Academies, *Waste Forms Technology and Performance: Final Report* (Washington, D.C.: National Academies Press, 2011). Omnibus Risk Review Committee, *A Review of the Use of Risk-Informed Management in the Cleanup Program for Former Defense Nuclear Sites* (August 2015).

[9]We did not include the Idaho Site in our analysis because DOE does not plan to manage any of the site's waste as low-level waste. Because DOE does not consider any waste at Idaho as LAW, we determined that it is not practical to compare the Idaho Site's treatment approach with that of the Hanford Site.

[10]*Improving the Regulation and Management of Low-Activity Radioactive Wastes*.

Council stated that because DOE's nuclear wastes are regulated primarily by their origins—the nature of the process that produced them—rather than by the actual radiological hazards they present, DOE may select relatively expensive treatment and disposal options for relatively low-risk waste.

We prepared this report under the authority of the Comptroller General to assist Congress with its oversight responsibilities, in light of broad congressional interest in DOE's plans for treating supplemental LAW at the Hanford Site. We examined (1) DOE's reasons for choosing its treatment approaches for LAW at its Savannah River and Hanford Sites, (2) the status of DOE's treatment of LAW at its Savannah River and Hanford Sites, and (3) experts' views on the likely performance of vitrification compared with grout for treating Hanford's LAW.

To conduct our work, we gathered and reviewed information on DOE's waste treatment strategy at the Savannah River and Hanford Sites, including DOE technical reports and internal and external reports on the sites' histories, treatment approaches, schedules, and cost estimates. Specifically, we did the following work.

- To examine DOE's reasons for choosing its treatment approaches for LAW at its Savannah River and Hanford Sites, we reviewed documents describing how DOE's tank waste cleanup strategy has evolved, and we reviewed DOE's environmental impact statements (EIS), which evaluate the potential environmental effects of different waste treatment approaches.[11] We also reviewed applicable legal and regulatory requirements governing the cleanup of hazardous and radioactive wastes. In addition, we interviewed officials at DOE headquarters, as well as officials at the Hanford Site's Office of River Protection and at the Savannah River Site, about the status of treatment at the two sites. We also interviewed officials from the Washington State Department of Ecology and the South Carolina Department of Health and Environmental Control, which are the state agencies that help regulate DOE's cleanup programs at its Hanford and Savannah River Sites, respectively.

[11]Under the National Environmental Policy Act of 1969, agencies evaluate the potential environmental effects of projects they are proposing using an environmental assessment or, if the projects likely would significantly affect the environment, a more detailed environmental impact statement.

- To examine the status of DOE's treatment of LAW at the Savannah River and Hanford Sites, we reviewed numerous reports and studies on DOE's plans to treat its tank waste at these two sites, including the amount of LAW that has been and will be treated; the schedule for constructing and operating the LAW treatment facilities; the cost of treating LAW; and technical challenges, if any. We also visited (1) the Hanford Site, where we observed tank farms and the WTP construction site, and (2) the Savannah River Site, where we observed tank farms, LAW treatment facilities, and the construction site for its future LAW treatment facility. We also analyzed available information on the costs of treating the Hanford and Savannah River Sites' LAW, and we interviewed DOE officials on the estimated or, if available, actual costs of constructing and operating the LAW treatment facilities at the Hanford and Savannah River Sites. Because precise information on the costs of treatment options at Hanford is unavailable, we used the best available information to provide a rough, order-of-magnitude estimate.
- To examine experts' views on the performance of vitrification compared with grout for treating Hanford's LAW, we worked with the National Academies of Sciences, Engineering, and Medicine (National Academies) to select 21 experts and convene a 2-day meeting with those experts. We asked the experts to discuss (1) the state of research on the performance of vitrification and grout; (2) the long-term disposal risks associated with vitrified and grouted waste forms; and (3) economic, technological, and logistical factors that may affect decisions about the treatment of Hanford's supplemental LAW. The experts' meeting focused on the treatment of all of Hanford's LAW because DOE has not yet determined which tanks' waste will be treated by the WTP and which tanks' waste will be treated with a supplemental treatment approach. After the meeting, we analyzed the transcripts to characterize the experts' responses and to identify major themes.

Additional details on our objectives, scope, and methodology can be found in appendix I.

We conducted this performance audit from July 2015 to May 2017 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

This section provides an overview of nuclear materials production at the Hanford and Savannah River Sites, the composition of the Hanford and Savannah River Sites' tank waste, the regulatory framework governing waste treatment and disposal, and the requirements for the disposal of LAW.

Nuclear Materials Production at the Hanford and Savannah River Sites

Established in 1943, the Hanford Site produced plutonium for the world's first nuclear device and continued producing nuclear materials for decades, generating millions of gallons of radioactive and hazardous chemical waste in the process. Some of this waste was deposited directly into the soil; some liquids were evaporated; and some waste was stored in 177 large, underground tanks, which are clustered together in 18 locations called tank farms. In total, these tanks contain about 54 million gallons of waste. Most of these tanks are operating decades past their original design life, and DOE estimates that 62 of these tanks may have already leaked over 1 million gallons of waste into the ground.

The Savannah River Site was established in the 1950s to produce nuclear materials, such as tritium and plutonium, which were needed to manufacture nuclear weapons. It did so by dissolving highly radioactive spent nuclear fuel from the site's nuclear reactors in large, heavily shielded separation facilities. Nuclear materials production at the site from 1954 to the present has resulted in about 160 million gallons of waste. About 42 million gallons of this waste have been stored in 51 underground tanks.[12] The Savannah River Site's tanks continue to receive additional waste from ongoing activities at the site.

Composition of the Hanford and Savannah River Sites' Tank Waste

Hanford's tanks contain a complex mix of radioactive and hazardous components in both liquid and solid form. Waste that contains both types

[12]The volume of the Savannah River Site's waste was reduced over the years as a result of operating a series of evaporators.

of components is called mixed waste.[13] Hanford's tank waste also includes various metals.

- **Radioactive component.** About 46 different radioactive constituents—byproducts of chemically separating plutonium from uranium for use in nuclear weapons—account for the majority of the radioactivity in the Hanford Site's tanks. The atoms of a radioactive constituent disintegrate, or decay, over time, releasing their radiation. Some of these constituents decay to a stable (or non-radioactive) form in a relatively short time, while others remain radioactive for millions of years. The rate of radioactive decay is measured in half-lives—that is, the time required for half the unstable atoms in a radioactive material to decay. The vast majority (98 percent) of the radioactivity of the tank waste comes from two constituents, strontium-90 and cesium-137, which have half-lives of about 29 and 30 years, respectively. The remaining radioactive constituents, which account for about 2 percent of the waste's total radioactivity, have much longer half-lives. For example, the half-life of technetium-99 is 213,000 years, and that of iodine-129 is 15.7 million years.
- **Hazardous component.** The tanks also contain large volumes of hazardous chemical waste. Altogether, about 240,000 tons of hazardous chemicals were added to Hanford's tanks from the 1940s to the mid-1980s. A majority of the chemicals were added to neutralize acids in the waste. Other chemicals, such as solvents and several organic compounds, were added during various waste extraction operations to help recover selected radioactive constituents (uranium, cesium, and strontium) for reuse. These hazardous chemicals are dangerous to human health, and they can remain dangerous for thousands of years.

The Savannah River Site's tank waste also contains both radioactive and hazardous components in both liquid and solid form, as well as various metals.

- **Radioactive component.** The Savannah River Site's waste contains about 60 radioactive constituents. As in the case at the Hanford Site, about 96 percent to 98 percent of the radioactivity comes from strontium-90 and cesium-137. Long-lived constituents—such as

[13]Specifically, the term "mixed waste" means waste that contains both, (1) hazardous waste subject to the Resource Conservation and Recovery Act or authorized state programs that operate in lieu of the federal program; and (2) source, special nuclear, or byproduct material subject to the Atomic Energy Act of 1954.

technetium-99 and iodine-129—account for about 1 percent of the radioactivity.

- **Hazardous component.** The tanks also contain hazardous chemical waste. Before waste generated during reprocessing was transferred to the tank farms, a chemical called sodium hydroxide was added to the waste to neutralize acids.[14] One tank also contains organic constituents that were added during a demonstration project.

At both the Hanford and Savannah River Sites, DOE's plan for treating its tank waste resulting from reprocessing centers on separating the various components of the waste so that the majority of the key or highly radioactive radionuclides are retained in the portion managed as HLW and the remainder are managed as low-level waste, where DOE makes a determination to that effect under applicable procedures. Waste that DOE determines can be managed as low-level waste is called waste incidental to reprocessing.

Table 1 describes the two main types of radioactive mixed waste contained in tanks at DOE's Hanford and Savannah River Sites.

[14]Reprocessing extracts isotopes from spent (or used) nuclear fuel so they can be used again as reactor fuel.

Table 1: Types of Radioactive Mixed Waste Contained in Tanks at the Department of Energy's Hanford and Savannah River Sites

Waste Type	Description
High-level waste (HLW)	HLW is defined by the Nuclear Waste Policy Act as (1) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (2) other highly radioactive material that NRC, consistent with existing law, determines by rule requires permanent isolation.[a]
Low-activity waste (LAW)	The term "low-activity waste" is not specifically defined in statute or regulation.[b] It is DOE's term for the portion of tank waste with low levels of radioactivity. LAW is primarily the portion of the tank waste that remains after as much radioactive material as technically and economically practical has been separated. At the Hanford and Savannah River Sites, DOE estimates that LAW contains less than 10 percent of the radioactivity of the tank waste but more than 90 percent of the tank waste by volume, according to DOE.

Source: GAO analysis of Department of Energy (DOE) documents and the Nuclear Waste Policy Act. | GAO-17-306

[a]42 U.S.C. § 10101(12).

[b]Specifically, DOE uses the term "low-activity waste" to mean the waste that remains after as much radioactivity as technically and economically practical has been separated from the tank waste that, when solidified, may be disposed of as low-level radioactive waste in a near-surface facility. In 1997, DOE requested the Nuclear Regulatory Commission (NRC) to review DOE's proposal to vitrify Hanford's LAW. Based on the information available at the time, NRC reviewed DOE's proposal, including the anticipated concentrations of radionuclides in the resultant waste, and determined that if the waste was vitrified, it would meet one of NRC's criteria for being considered waste incidental to reprocessing. If DOE decided to use a different waste treatment process for the LAW, it was to re-initiate consultations with NRC staff.

Regulatory Framework Governing DOE's Tank Waste

The treatment and disposal of tank waste at DOE sites are governed by a number of federal laws—some of which establish state responsibilities—that define the roles of federal agencies and states in managing mixed waste, as well as cleanup agreements among DOE, EPA, and the relevant state that implement these laws.

Radioactive components of the tank waste are regulated primarily by DOE under the Atomic Energy Act of 1954[15] and the Nuclear Waste Policy Act of 1982.[16] These acts define HLW to include (1) the highly radioactive waste material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and (2) other highly radioactive

[15]42 U.S.C. § 2011 et. seq.

[16]42 U.S.C. § 10101 et. seq.

material that is determined, consistent with existing law, to require permanent isolation. Under the Nuclear Waste Policy Act, DOE must send HLW to a geologic repository for disposal. The act does not establish a specific disposal path for radioactive waste other than HLW.

Hazardous components of the tank waste are regulated by EPA under the Resource Conservation and Recovery Act (RCRA) or, under limited circumstances, the Clean Water Act.[17] Where EPA has authorized states to implement hazardous waste programs, those state programs operate in lieu of the federal programs.[18]

- **RCRA.** Under RCRA, high-level mixed waste—waste with a hazardous component regulated under RCRA and a radioactive component regulated under the Atomic Energy Act—that was generated during the reprocessing of fuel rods must be vitrified prior to disposal.[19] Other mixed waste must generally be physically, chemically, and/or thermally treated to substantially diminish its toxicity or to reduce the mobility of the hazardous constituents according to waste-specific regulatory levels. This waste may then be disposed of in a near-surface landfill meeting requirements established under RCRA, including that it have a double liner and a

[17]RCRA regulations governing the treatment, storage, and disposal of hazardous waste generally do not apply to wastewater treatment units, defined to include units that (1) are part of a wastewater treatment facility that is subject to regulation under the permit provisions of the Clean Water Act; (2) receive and treat or store influent wastewater that is a hazardous waste; and (3) meet the definition of a tank or tank system under RCRA. See 40 C.F.R. § § 260.10, 264.1(g)(6).

[18]Under RCRA, EPA may authorize a state to implement its own hazardous waste management program in lieu of the respective federal program, so long as the state program is at least as stringent. State programs may be more stringent than the federal program. EPA has authorized Washington and South Carolina to administer their own hazardous waste programs.

[19]Specifically, the hazardous component of mixed waste is subject to applicable RCRA requirements, which include compliance with land disposal restrictions. This means that generated waste must be treated to specific regulatory levels or according to specified methods of treatment prior to land disposal. Treatment either substantially decreases the toxicity of the mixed waste or reduces the likelihood that hazardous constituents (e.g., metals) will migrate from the mixed waste and contaminate the environment. Under RCRA's land disposal requirements program, certain mixed wastes have specific treatment standards. For example, radioactive high-level wastes generated during the reprocessing of fuel rods that exhibit specified hazardous waste characteristics must be vitrified in compliance with all applicable radioactive protection requirements under control of NRC before the waste can be land disposed. 40 C.F.R. § § 268.42, 268.40(a).

leachate collection system, which collects any liquids that leach from the disposal unit.

- **Clean Water Act.** Under the Clean Water Act, the discharge of pollutants from certain sources, such as industrial facilities, into U.S. waters is prohibited without a permit; facilities obtain permits from authorized states or from the applicable EPA region. Wastewater treatment facilities are among the facilities regulated under the Clean Water Act.

The Federal Facilities Compliance Act of 1992 specifically made federal facilities, including DOE sites, subject to state hazardous waste regulations described below.[20]

- **The Hanford Site.** Under RCRA, EPA has authorized the state of Washington to administer its own hazardous waste regulatory program. The state has issued a dangerous waste permit under its authorized RCRA program that establishes requirements for the treatment, storage and disposal of mixed waste, including the construction and operation of the WTP complex.[21] As previously noted, many of DOE's activities at Hanford are carried out under the Hanford Federal Facility Agreement and Consent Order among DOE, EPA, and the Washington State Department of Ecology. Commonly called the Tri-Party Agreement (TPA), this document was signed in May 1989 and has been amended numerous times since then. The document lays out a series of legally enforceable milestones for completing major activities in Hanford's waste treatment and cleanup process. In 2010, DOE entered into an agreement, called a Consent Decree, to resolve a lawsuit by the state of Washington. The 2010 Consent Decree required DOE to retrieve waste from 19 tanks and

[20]42 U.S.C. § 6961.

[21]Washington issued this site-wide permit under the state's Hazardous Waste Management Act and associated regulations. Rev. Code Wash. Title 70, Ch. 70.105; WAC Ch. 173-303. The permit is currently undergoing revision.

begin operating the WTP and treating waste by 2022.[22] In 2016, the relevant federal district court amended the Consent Decree by revising the schedule for startup and commissioning of the WTP, modifying tank waste retrieval milestones and enhancing DOE's reporting obligations under the Decree. Under this Amended Consent Decree, DOE must complete the specified tank waste retrievals for 12 tanks by March 2024 and must achieve initial plant operations of the WTP by the end of 2036.

- **The Savannah River Site.** Under RCRA, EPA has authorized the state of South Carolina to administer its own hazardous waste regulatory program. The state of South Carolina elected to manage DOE's tanks at the Savannah River Site as wastewater treatment units under the Clean Water Act, an option that RCRA regulations authorize under certain conditions.[23] Cleanup at the Savannah River Site is carried out under industrial wastewater permits issued by the state of South Carolina; a Site Treatment Plan approved by the state of South Carolina; the Consent Order for the treatment and disposal of mixed waste; and the 1993 Federal Facility Agreement among DOE, EPA, and the state of South Carolina.[24] For example, DOE is

[22]See Consent Decree, Washington v. Chu, Civ. No. 08-05085 (E.D. Wash), October 25, 2010, available at http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1011110420 (last visited April 21, 2017). The TPA lays out a series of legally enforceable milestones for completing major activities in Hanford's waste treatment and cleanup process. The purpose of the TPA is to ensure that Hanford cleanup activities comply with the Comprehensive Environmental Response, Compensation, and Liability Act; RCRA; and Washington's Hazardous Waste Management Act. DOE entered into the TPA pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act; Executive Order 12580; and the Atomic Energy Act of 1954. The TPA has been modified numerous times. The Consent Decree addresses a subset of these cleanup activities: completing the construction and achieving initial operations of the WTP and retrieving waste from 12 single-shell tanks. The Consent Decree arose out of a law suit by the state alleging that DOE had missed, or was certain to miss, 10 TPA milestones related to WTP construction and tank waste retrieval and has been amended twice, both in 2016.

[23]See 40 C.F.R. § § 260.10, 264.1(g)(6).

[24]The Federal Facility Agreement lays out a series of legally enforceable milestones for the comprehensive remediation of the Savannah River Site. One of its purposes is to ensure that Savannah River Site cleanup activities comply with RCRA and the Comprehensive Environmental Response, Compensation, and Liability Act. The Federal Facility Agreement specifies milestones for the removal of waste from, and operational closure of, tanks, which do not meet full secondary containment standards specified in the Federal Facility Agreement. The Federal Facility Agreement has been modified several times. According to DOE, it has operationally closed 8 of the required 24 tanks.

required to complete tank waste treatment at the Savannah River Site by 2028.

LAW Disposal

At Hanford, DOE plans to dispose of vitrified LAW in an on-site landfill called the Integrated Disposal Facility. At the Savannah River Site, DOE disposes of grouted LAW on site in large concrete structures called saltstone disposal units. DOE has used two processes to determine that portions of its tank waste can be managed as low-level waste (referred to as a determination that the waste is incidental to reprocessing).

- **DOE Order.** DOE Order 435.1 and Manual 435.1-1 provide that DOE can manage tank wastes as waste incidental to reprocessing if, among other things, the wastes have been processed to remove radionuclides to the maximum extent practicable and will be managed in a manner comparable to the performance objectives established in Nuclear Regulatory Commission (NRC) regulations for the nuclear waste disposal facilities.[25]
- **Section 3116.** Section 3116 of the National Defense Authorization Act for fiscal year 2005 authorizes the Secretary of Energy, in consultation with NRC, to determine that certain waste from reprocessing is not HLW if it meets the criteria set forth in that section: that it does not require disposal in a deep geologic repository, has had highly radioactive radionuclides removed to the maximum extent practical, meets concentration limits and/or dose-based performance objectives for near-surface disposal of radioactive waste set out in subpart C of part 61 of title 10, *Code of Federal Regulations*, and will be disposed of pursuant to a state-issued permit or state-approved closure plan.[26] Section 3116 applies only to Idaho and South Carolina.

West Valley Demonstration Project: Example of DOE's Treatment of Low-Activity Waste with Grout

From 1966 to 1972, Nuclear Fuels Services operated the Western New York Nuclear Service Center—later renamed the West Valley Demonstration Project—in West Valley, New York. This is the only commercial spent nuclear fuel reprocessing plant to have operated in the United States. Spent fuel is the used fuel removed from nuclear power plants. Nuclear Fuels Services reprocessed this fuel to recover uranium and plutonium to be used again as reactor fuel. During operations, the plant generated 660,000 gallons of liquid high-level waste (HLW) that was stored in two underground storage tanks.

In 1988, the Department of Energy (DOE) began to separate out the low-activity portion of the tank waste to reduce the amount of waste to be vitrified. To treat this low-activity waste (LAW), DOE mixed it with grout and poured it into square drums. Treatment was completed in 1995. The drums containing treated, cemented waste were shipped to, and disposed of at, the Nevada National Security Site. After completing treatment of the LAW, DOE vitrified the remaining HLW, which is stored on site until a geologic repository becomes available for its permanent disposal.

DOE officials explained that DOE chose to mix the LAW with cement because it would minimize the amount of tank waste to be vitrified, thereby reducing costs. According to DOE officials, it cost $216.2 million to produce 19,900 70-gallon drums of grouted LAW, and $616.8 million to produce 275 canisters of vitrified HLW (roughly 1/20th the volume of the treated LAW).

Sources: GAO analysis of DOE documents and data and interviews with DOE officials. Image source: DOE. | GAO-17-306

[25]Under Order 435.1, DOE manages waste incidental to reprocessing as either low-level waste or transuranic waste based on the waste's specific radioisotopic inventory. DOE defines transuranic waste as waste that is contaminated with alpha-emitting radionuclides (greater than uranium on the periodic table) with half-lives greater than 20 years and concentrations greater than 100 nanocuries per gram.

[26]Pub. L. No. 108-375, Div. C, Title XXXI, § 3116, 118 Stat. 2162 (2004). As noted above, HLW is the highest-activity primary waste that results from reprocessing spent nuclear fuel. It must be disposed in a deep geologic repository licensed by NRC. Under Section 3116, on the other hand, DOE may dispose of its low-level waste in a near-surface DOE facility subject to state approval and NRC monitoring, but not subject to NRC licensing.

DOE's requirements and NRC guidance establish different periods of performance for low-level waste disposal.

- **DOE requirement.** According to DOE Manual 435.1-1, a low-level waste disposal site must conduct a performance assessment demonstrating that the site meets DOE performance objectives, including demonstrating that the dose to a member of the public will not exceed 25 millirems from all exposure pathways during any 1 year, over the course of a 1,000-year post-closure period. DOE officials told us that this requirement for low-level waste disposal applies to the treatment and disposal of Hanford's LAW, and waste from reprocessing will only be disposed of as low-level waste if a determination under Order 435.1 has been issued. Hanford intends to dispose of this treated low-level waste at its on-site Integrated Disposal Facility.
- **NRC guidance.** The 2004 legislation authorizes DOE to manage certain waste at its Savannah River and Idaho Sites as low-level waste. According to NRC guidance implementing Section 3116, NRC recommends using a 10,000-year period of performance. DOE used the 10,000-year period of performance in its 2012 EIS on the Hanford Site for its assessment of the long-term impacts for groundwater, human health, and ecological risks. NRC is currently considering changing its period of performance.[27]

DOE Chose Different Treatment Approaches at the Savannah River and Hanford Sites Primarily to Address Different State Input

DOE chose to treat LAW differently at the Savannah River and Hanford Sites—with grout at the Savannah River Site and with vitrification at

[27]In 2016, NRC staff issued a draft final rule that would provide for either a 1,000-year or 10,000-year compliance period—depending on the quantities of long-lived radionuclides that have been or plan to be disposed of at the site—followed by a performance period. According to NRC staff, for waste incidental to reprocessing, most waste forms would be expected to contain significant quantities of long-lived radionuclides, and therefore, a 10,000-year compliance period would most likely be used. For sites using a 10,000-year performance period—because the waste contains significant quantities of long-lived radionuclides—the draft final rule would also establish a post-10,000-year performance period to evaluate how the disposal system could mitigate the risk from the disposal of significant quantities of long-lived radionuclides after the compliance period. NRC has not yet taken a vote on the draft final rule.

Hanford—primarily to address input from South Carolina and Washington, respectively, and the different environmental laws that state regulators chose to apply to tank waste management at each site. DOE chose to grout LAW at its Savannah River Site because the state viewed grout as a method that would allow DOE to treat LAW sooner than other methods, thereby reducing environmental and human health risks posed by prolonged waste storage in the tanks. DOE chose to vitrify Hanford's LAW primarily because, in studies conducted at the time, vitrification was shown to perform better (i.e., more effectively immobilize the waste) than grout for disposal in the environmental conditions at the Hanford Site. DOE's choice was also influenced by input from EPA and the state of Washington, as well as public concerns about the long-term effectiveness of grout. DOE has not formally selected a treatment method for supplemental LAW—the portion of the LAW not currently planned to be treated in the WTP.

DOE Chose to Grout LAW at the Savannah River Site Primarily Because of the State's Desire to Address Environmental Risks Sooner Than It Could Using Other Methods

According to officials from the Savannah River Site, DOE chose to grout LAW at the Savannah River Site for several reasons, primarily because DOE had determined that grouted LAW would meet human health and environmental requirements and because DOE could treat LAW sooner with grout than with other methods, thereby reducing the risk to groundwater posed by possible leaks in the underground tanks.[28] According to DOE officials, DOE found that grout was safe for human health and the environment and met applicable environmental

[28]At the Savannah River Site, LAW is called "salt waste," but for the purpose of this report, we refer to it as LAW. The Savannah River Site uses a grout mixture, called "saltstone," but for the purpose of this report, we refer to it as grout. Also, as previously noted, at its Savannah River Site, DOE refers to the low-activity portion of its waste as low-level waste or "salt waste." For the purpose of this review, we refer to the low-activity portion of the waste at both the Hanford and Savannah River Sites as LAW.

Idaho National Laboratory: Example of How DOE will Treat the Site's Liquid High-Level Waste with the Integrated Waste Treatment Unit

The Department of Energy (DOE) does not have low-activity waste (LAW) at its Idaho Site because it did not separate out a lower activity portion from the site's high-level waste (HLW). DOE officials stated that they will have to petition the Environmental Protection Agency to be able to consider any disposal method other than vitrification because only vitrification has been demonstrated to meet Resource Conservation and Recovery Act requirements for high-level mixed waste disposal. At the Idaho Site, 11 underground stainless steel tanks originally stored about 9 million gallons of HLW. This waste was primarily liquid and resulted from reprocessing spent nuclear fuel for defense and other purposes. DOE treated nearly 8 million gallons of the liquid waste through a process called calcination, which converts liquid waste to a granular solid form. The calcined waste is currently stored on site in 43 bins where, according to a DOE official, it is awaiting final treatment with another process that has not yet been determined.

About 900,000 gallons of liquid waste remain in 3 tanks. DOE plans to treat the remaining waste in the tanks using a process called steam reforming. DOE is currently constructing a facility called the Integrated Waste Treatment Unit for this purpose. This first-of-a-kind facility will dry the liquid waste into a solid granular material. The treated waste will then be packaged into stainless steel containers and transported out of state for final disposal.

Sources: DOE and Idaho state documents and interviews with Idaho National Laboratory official. Image source: DOE. | GAO-17-306

requirements, as described in its 1982 EIS for the Savannah River Site.[29] DOE documents[30] stated that grouted LAW would safely retain hazardous constituents at levels below EPA's current drinking water standards for at least 1,000 years.[31]

South Carolina chose a legal approach that gave DOE the flexibility to use grout, according to an official from the South Carolina Department of Health and Environmental Control. Specifically, South Carolina chose to permit the tanks and waste treatment facilities separately from the disposal site. The site's LAW treatment facilities are permitted as wastewater facilities under the Clean Water Act because, according to this official, the Clean Water Act is more flexible and would allow DOE to treat the waste faster than RCRA would allow, while still achieving the same environmental safeguards as RCRA would have required.[32] According to this official, one of the state's top priorities was for DOE to begin treatment as soon as possible and remove the liquid waste from the tanks to reduce the risk to groundwater at the site from potential leaks in the underground tanks. This official noted that by using grout, DOE was able to begin treatment sooner and at a lower cost than if it had used a more complicated treatment approach, such as vitrification.

DOE officials told us that as they learned more about the performance of grout at the Savannah River Site, they added additional safeguards to the disposal site to ensure that human health and the environment would be protected from contaminant exposure over the long term. For example, in 1988, DOE research identified the potential for nitrates—a hazardous contaminant of concern in LAW—to leach from grout when it was poured into underground trenches at the site. In response, DOE added engineered barriers—which are structures intended to improve the

[29]Department of Energy, *Final Impact Statement Defense Waste Processing Facility, Savannah River Plant, Aiken, S.C.*, DOE/EIS-0082 (Washington, D.C.: February 1982).

[30]Department of Energy, *Final Supplemental Environmental Impact Statement Defense Waste Processing Facility*, DOE/EIS-0082-S (Washington, D.C.: November 1994); 60 Fed. Reg. 70 (Apr. 12, 1995). The 1995 Record of Decision stated that the peak radiological dose from groundwater contamination would occur 2,000 years after closure and would be 100 times less than current EPA dose limits for drinking water.

[31]According to DOE Manual 435.1-1, a low-level waste disposal facility must conduct a performance assessment demonstrating that the site meets DOE performance objectives, such as the dose to the public not exceeding 25 millirems from all exposure pathways during any 1 year, over a 1,000-year post-closure period.

[32]See 40 C.F.R. § § 260.10, 264.1(g)(6).

disposal site's ability to retain waste—to the Savannah River Site's waste disposal approach, rather than pouring the treated waste into trenches.[33] Later DOE studies confirmed that grouted LAW would meet human health and environmental safety requirements, particularly when the engineered barriers were used for disposal of the treated waste.[34] According to DOE officials, DOE has evaluated the effects of multiple barriers, both collectively and independently, to provide reasonable assurance that DOE's performance objectives will be met to protect human health and the environment.[35] The barriers evaluated include the grout waste form, engineered disposal structures, closure caps, and the natural environment. In a 2016 study conducted at the Savannah River Site, DOE predominantly affirmed assumptions used in earlier contaminant leaching models that found contaminants would be safely contained for the 1,000-year period of performance.[36]

Another factor also influenced the department's decision to grout LAW at the Savannah River Site, according to a DOE official. DOE already had some infrastructure that had previously been used to grout other wastes at the site, and that infrastructure could be used to grout the LAW. For example, DOE treated contaminated soils from its nuclear materials production program with grout.[37] Already having certain infrastructure in place made it more cost-effective and faster to begin waste treatment with grout than to build a new facility to vitrify LAW or pursue another alternative.

[33]The Savannah River Site currently uses an engineered barrier called a saltstone disposal unit, which is a large, cylindrical concrete tank—about 150 feet in diameter—intended to keep precipitation from reaching the grout.

[34]See, for example, Department of Energy, *Savannah River Site Salt Processing Alternatives Final Environmental Impact Statement*, DOE/EIS-0082-S2 (Aiken, SC: June 2001); Department of Energy, *Supplement Analysis Salt Processing Alternatives at the Savannah River Site*, DOE/EIS-0082-S2-SA-01 (Aiken, SC: January 2006); and Savannah River Remediation, *Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site*, SRR-CWDA-2009-00017 (Aiken, SC: October 2009).

[35]Savannah River Remediation LLC, *FY2014 Special Analysis for the Saltstone Disposal Facility at the Savannah River Site*, SRR-CWDA-2014-00006, rev. 2 (Aiken, SC: September 2014).

[36]Savannah River Remediation LLC, *Property Data for Core Samples Extracted from SDU Cell 2A*, SRR-CDWA-2016-00051 (Aiken, SC: April 2016).

[37]Contaminated soils in the Old F-Area Seepage Basin were stabilized *in-situ* with grout.

DOE Chose to Vitrify a Portion of LAW at Hanford Largely Because Initial Studies Showed It to Be Safer Than Other Methods

DOE chose in 1994 to vitrify the LAW at Hanford in part because studies from the early 1990s showed that vitrification would be safer for long-term disposal than grout, given the conditions at the Hanford Site.[38] DOE's choice was also influenced by input from the state of Washington, and to a lesser extent from EPA in its role of providing support to and oversight of the state's authorized RCRA program, as well as public concerns about the long-term effectiveness of grout. According to DOE and Washington State Department of Ecology documents, vitrification was viewed as preferable to grout for several reasons.

- **Ability of grout to set.** In the early 1990s,[39] the state identified technical concerns with the ability of grout to set properly or uniformly because of the heat released by radioactive constituents within the grout.[40]
- **Volume of waste.** The state also raised concerns in the early 1990s that grout would produce a larger volume of waste that would need to be disposed of than vitrification would. This would have resulted in the need to use a larger area of land to dispose of the waste. In turn, local governments, tribes, and regional groups expressed concerns about possible restrictions on future land use at the site if grout was used and disposed of at Hanford.

[38]Since plutonium production ended at Hanford in the late 1980s, DOE has tried developing various approaches for treating and disposing of its tank waste. In 1989, DOE's initial strategy called for treating only the waste in the double-shell tanks—the HLW would have been vitrified, and the LAW would have been grouted. In 1993, DOE developed a new strategy aimed at treating the waste in all 177 tanks with vitrification, but DOE found that the planned treatment facility would not have had sufficient capacity to treat all the waste in a time frame acceptable to EPA and the Washington State Department of Ecology. In 1994, the TPA was amended to reflect a new goal of vitrifying both the LAW and HLW, instead of treating the LAW with grout.

[39]Washington State Department of Ecology, *History of Grout as Waste Form for Hanford Tank Waste White Paper* (Richland, WA: February 2015).

[40]We previously reported on the problems that DOE had at Rocky Flats in Colorado with mixing cement to treat pond sediment contaminated by radioactive material, nitrates, and heavy metals. This material, known as pondcrete, was improperly mixed and did not set properly, resulting in pondcrete blocks that crumbled, cracked, and were soft enough to be dug into with a stick. See GAO, *Nuclear Health and Safety: Problems Continue for Rocky Flats Solar Pond Cleanup Program,* GAO/RCED-92-18 (Washington, D.C.: Oct. 17, 1991).

- **Ease of retrieval.** The state conveyed public concerns that it would be more difficult to retrieve grouted waste than vitrified waste.[41] Members of the public wanted DOE to have the ability to retrieve waste if DOE developed more advanced treatment methods in the future or if the waste form failed.[42]
- **Safety.** One 1995 study indicated that vitrified waste was more likely than grouted waste to retain radioactive and hazardous constituents.[43] Specifically, vitrified waste was the best-performing waste form during leach testing and was less likely to be considered a "hazardous waste" under RCRA because vitrification would destroy hazardous organic constituents. In addition, several communities in Washington and Oregon expressed concern that their groundwater could be affected by certain radioactive and hazardous constituents leaching from grout.

It is unclear to what extent costs were considered in DOE's 1994 decision to choose vitrification over grout for Hanford LAW. Various studies conducted around that time and since then have provided differing information on the cost of grout compared with the cost of vitrification.

- A 1995 Westinghouse report reviewed alternatives for treating all of Hanford's LAW.[44] This report concluded that vitrification was the best treatment option when risk, cost, and other factors were considered. Among other things, the report found that grout and vitrification both adequately met NRC's environmental requirements for disposal but that vitrification would perform better. In addition, the report noted that grout would cost about $1 billion less than vitrification over the lifecycle of treatment, but the report concluded that vitrification would

[41]Washington State Department of Ecology, "Agencies Propose Changes to the Tri-Party Agreement," *Hanford Update*, vol. 5, no. 1 (1993).

[42]Any repository constructed on a site approved under the Nuclear Waste Policy Act must be designed and constructed to permit spent nuclear fuel retrieval for any reason pertaining to public health and safety or the environment, among other reasons, during operation of the facility. According to Hanford officials, there is no requirement for Hanford's LAW to be retrievable.

[43]Westinghouse Hanford Company, *Evaluation of Low-Level Waste Forms for Immobilization of Hanford Site Tank Wastes*, WHC-SD-WM-ES-319 (Richland, WA: June 1995).

[44]*Evaluation of Low-Level Waste Forms for Immobilization of Hanford Site Tank Wastes*. The Westinghouse report compared three treatment approaches: glass, grout, and polyethylene—a process in which the waste is dried to a powder and then mixed with molten polyethylene, a plastic, and cast into containers for final disposal.

be more cost effective because the contractor that produced the study believed that grout would require an extensive pretreatment process to separate certain radioactive constituents from LAW, which was not included in the cost estimate.[45]

- In 2003, DOE's Office of River Protection analyzed alternatives for treating all of Hanford's LAW under three scenarios: all grout, all vitrification, or a combination of both.[46] This study found that all vitrification was the most cost-effective approach. The study found that the higher cost to grout the waste was largely driven by the costs associated with stopping the current approach of vitrifying LAW and switching to a new approach.
- Another 2003 study by a DOE contractor compared three different potential treatment approaches for a portion of Hanford's LAW.[47] This report found that grout was the least expensive approach from the standpoint of designing, constructing, and operating the treatment facilities, but when transportation to the disposal site and disposal costs were included, grout would cost approximately $100 million to $200 million more than the other alternatives.
- Finally, DOE's 2012 EIS examined four technologies, including grout and vitrification, for treating Hanford's supplemental LAW,[48] and our analysis of the information provided in the EIS found that grouting the supplemental LAW could cost about $2.6 billion less than vitrifying it.[49]

[45]The cost figure is in 1995 dollars.

[46]Department of Energy, *Assessment of Low-Activity Waste (LAW) Treatment and Disposal Scenarios for the River Protection Project* (Richland, WA: Apr. 14, 2003).

[47]CH2M HILL Hanford Group, Inc., Draft *Supplemental Technologies Cost Summary Report* (Richland, WA: Sept. 19, 2003). The CH2M HILL report compared three treatment approaches: cast stone (grout), bulk vitrification, and steam reforming. The bulk vitrification process would convert LAW into solid glass by drying the waste, mixing it with Hanford soils, and applying an electric current within a large steel container. Steam reforming is a process that dries liquid waste into a solid granular material.

[48]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).

[49]Estimated cost differences have been inflation-adjusted to fiscal year 2015 dollars. The estimated cost difference included about $806 million in reduced pre-treatment storage costs, $45 million in reduced retrieval costs because of more rapid treatment completion with the grouting alternative, and $1.8 billion in reduced treatment plant construction and operations costs for the LAW grouting alternative relative to the vitrification-only alternative. Disposal costs for the LAW grouting alternative would be $89 million higher than for the vitrification-only alternative, according to DOE's estimates.

Other factors may have also influenced DOE's decision to vitrify LAW at the Hanford Site. For example, in its foreword to the 2012 EIS, the Washington State Department of Ecology noted that in the mid-1990s DOE delayed construction of Hanford's vitrification facility because other DOE sites were competing for the same budgetary resources.[50] Officials from the Washington State Department of Ecology told us that they agreed to accept a delay in treating Hanford's tank waste and, in exchange, DOE committed to the Washington State Department of Ecology that it would vitrify Hanford's LAW in light of public concerns about the use of grout.

DOE Has Not Yet Chosen a Waste Treatment Approach for Supplemental LAW at Hanford

According to DOE documents and officials, DOE has not selected a treatment method for the supplemental LAW—the portion of the LAW that cannot be treated in the WTP as it is currently designed. As previously discussed, the WTP is currently designed to treat only one-third to one-half of Hanford's LAW, meaning that DOE will have to modify the WTP or build another facility to treat the supplemental LAW, whether or not vitrification is chosen as the treatment method. In its Record of Decision accompanying its 2012 EIS, DOE discussed four alternatives for supplemental LAW treatment, including vitrification and cast stone, which is a form of grout.[51] DOE stated that it had not selected a method for treating supplemental LAW and that it would be beneficial to further study the potential cost, safety, and environmental performance of technologies to treat supplemental LAW.[52]

There is disagreement, however, between DOE and the state of Washington about whether DOE has the legal authority to select a treatment method other than vitrification for supplemental LAW. Washington state officials told us that they acknowledge that DOE has not yet selected a supplemental treatment method, but in the foreword to the 2012 EIS, the Washington State Department of Ecology stated that

[50]*Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*.

[51]DOE also analyzed bulk vitrification and steam reforming.

[52]Department of Energy, Record of Decision: *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*, 78 Fed. Reg., 75913 (Dec. 13, 2013).

glass is the only acceptable waste form for immobilized LAW that is going to be disposed of at Hanford. The foreword states that the 2012 EIS clearly supports vitrification as the only environmentally protective option for treating supplemental LAW and that the Washington State Department of Ecology therefore disagrees with DOE's decision not to identify a treatment method for supplemental LAW. Further, the Washington State Department of Ecology states that it believes the cost comparisons in the EIS show that all the various options are similar in cost, so any assumptions about potential cost savings in choosing other treatment options are invalid.

Regardless of uncertainty about DOE's ability to consider alternative options, the TPA requires DOE to take a set of specific actions in selecting a treatment method for supplemental LAW. Specifically, the TPA required DOE to select a treatment method for supplemental LAW no later than April 30, 2015. However, DOE has not yet selected a treatment method, and this issue is currently in a dispute resolution procedure between DOE and the state of Washington. Negotiations began on September 8, 2016, on a number of milestones that require negotiation within 6 months after DOE's System Plan is updated, including the DOE decision on supplemental treatment. DOE has proposed setting a deadline of April 30, 2018, for the completion of the negotiations related to this milestone in order to be consistent with other agreements, allowing for 6 months after its System Plan is updated for negotiations to be completed. The TPA requires that the next revision to DOE's System Plan—which is scheduled to be released by October 31, 2017—outline specific options for treating supplemental LAW.[53] For example, vitrification options could include modifying the WTP to increase capacity to treat supplemental LAW or building another vitrification facility to treat the supplemental LAW. According to DOE officials, DOE may also consider other treatment options, such as grout. The waste treatment schedule for supplemental LAW has yet to be finalized, but a senior DOE

[53]The primary purpose of the System Plan at Hanford is to evaluate scenarios, including underlying assumptions, selected and defined by DOE and the Washington State Department of Ecology, for the disposition of all tank waste. As noted above, DOE and the state of Washington disagree on whether these options can include waste treatment methods other than vitrification.

official told us that if DOE must vitrify supplemental LAW, completing treatment will take at least until 2061.[54]

In considering different approaches to treating supplemental LAW at Hanford, DOE faces regulatory and legal challenges. Specifically, DOE may be limited in its ability to employ different treatment methods unless it succeeds in managing some tank waste as low-level waste.[55] DOE's authority to apply Order 435.1 and the associated manual to certain tank waste in Idaho was challenged in a 2002 lawsuit.[56] The federal district court held that the relevant provisions of the Order and Manual were inconsistent with the Nuclear Waste Policy Act, but a federal appeals court reversed that decision on procedural grounds in October 2004 and ordered dismissal of the suit without ruling on the underlying claim. While the 2002 litigation was pending, DOE sought legislation clarifying its authority to manage portions of tank waste that have low levels of radioactivity as low-level waste. In response, Congress passed Section 3116 of the National Defense Authorization Act in October 2004. However, the legislation did not apply to Hanford. Our previous work has found that DOE could be open to further legal challenges if it attempts to use Order 435.1 to manage tank waste as low-level waste at Hanford.[57] However, in commenting on a draft of this report, DOE noted that it has successfully used the Order 435.1 process twice since the 2002 lawsuit to determine that certain wastes associated with the West Valley Demonstration Project in New York can be managed as low-level wastes. As we have previously recommended, legislation specifically authorizing DOE to manage some of the waste at Hanford as low-level waste would

[54]Section 3134 of the National Defense Authorization Act for Fiscal Year 2017 contains a provision requiring DOE to enter into an arrangement with a federally funded research and development center to carry out an analysis of approaches for treating the portion of Hanford's LAW currently intended for supplemental treatment. Pub. L. No. 114-328, § 3134 (2016).

[55]Hanford officials told us that the site could classify certain tank waste as "transuranic" waste. The word "transuranic" is used for elements that have atomic numbers greater than that of uranium. Transuranic waste could be treated and sent to the DOE Waste Isolation Pilot Plant near Carlsbad, New Mexico, which serves as the only deep geologic repository in the United States for the disposal of defense-related transuranic nuclear waste.

[56]Natural Resources Defense Council v. Abraham, 271 F.Supp.2d 1260 (D. Idaho 2003), vacated as unripe 388 F.3d 701 (9th Cir. 2004).

[57]GAO, *Nuclear Waste: Uncertainties and Questions about Costs and Risks Persist with DOE's Tank Waste Cleanup Strategy at Hanford*, GAO-09-913 (Washington, D.C.: Sept. 30, 2009) and *Nuclear Waste: Challenges to Achieving Potential Savings in DOE's High-Level Waste Cleanup Program*, GAO-03-593 (Washington, D.C.: Jun. 17, 2003).

insulate DOE from legal challenges regarding its authority to make treatment decisions based on the actual radioactivity of the waste, which in turn could allow DOE to consider potentially less costly and less complicated treatment approaches for supplemental LAW.[58]

DOE Has Treated Some LAW at the Savannah River Site but None Yet at Hanford

DOE has treated about 4 million gallons of LAW at its Savannah River Site but has not yet treated any tank waste at the Hanford Site.[59] In addition, DOE is likely to complete its LAW treatment sooner, with fewer technical challenges, and at lower costs at the Savannah River Site than at Hanford.

DOE Is Successfully Treating LAW at the Savannah River Site but Has Not Yet Begun to Treat LAW at Hanford

DOE officials told us that it has grouted about 4 million gallons of the Savannah River Site's approximately 36 million gallons of LAW since 2007 and has disposed of this waste on site in large concrete vaults pursuant to a determination DOE made under Section 3116 of the National Defense Authorization Act for Fiscal Year 2005.[60] DOE estimates that about 36 million gallons of waste remains in the Savannah River Site's underground tanks, of which DOE estimates that about 32 million

[58]See GAO-09-913 and GAO-03-593. DOE implemented two recommendations in GAO-09-913 but disagreed with our recommendation that they seek clarification from Congress about DOE's authority at Hanford to determine whether some tank waste managed by DOE can be treated and disposed of as a waste type other than HLW. DOE implemented all three recommendations in GAO-03-593; however, the Hanford Site was not covered by Section 3116.

[59]The 4 million gallons represents waste that was originally in the tanks but that has now been treated. The treatment process necessarily increases the volume of the waste treated because water and other constituents are added during the process. Consequently, the total amount of LAW grouted at the Savannah River Site thus far is about 8.3 million gallons.

[60]As previously noted above, HLW is the highest-activity primary waste that results from reprocessing spent nuclear fuel. It must be disposed of in a deep geologic repository licensed by NRC. Under Section 3116, on the other hand, DOE may dispose of its low-level waste in a near-surface DOE facility subject to state approval and NRC monitoring, but not subject to NRC licensing.

gallons is LAW.[61] DOE recently completed construction of a new waste processing facility—called the Salt Waste Processing Facility—that will replace the Savannah River Site's existing facility and will process the remaining LAW faster than DOE could have done with the site's existing facility.[62] Specifically, this new facility is designed to remove most of the highly radioactive constituents—such as cesium and strontium—from the liquid waste, which according to agency officials, will enable DOE to treat the Savannah River Site's waste more quickly.[63]

At the Hanford Site, DOE has not yet treated any of the approximately 54 million gallons of radioactive waste stored in its 177 underground tanks. DOE has delayed the start of waste treatment numerous times, in part because of project management challenges.[64] In 2000, DOE awarded a contract to Bechtel National, Inc., to design, construct, and commission a prototype plant to demonstrate the technology that was to treat 10 percent of the waste by volume and 25 percent by radioactivity. At the time, DOE's plans called for the WTP to begin treating waste in 2011 and complete waste treatment by 2028. In 2002, DOE began an initiative to accelerate the schedule for, and reduce the costs of, cleaning up radioactive and hazardous waste at its sites. This included increasing the WTP's capacity to vitrify waste and using supplemental technologies to

[61]DOE has also treated about 4 million gallons of HLW at the Savannah River Site. DOE began treating this tank waste in 1996 by vitrifying it in a facility called the Defense Waste Processing Facility.

[62]DOE's existing LAW processing facility is known as the Actinide Removal Process and Modular Caustic Side Solvent Extraction Unit. DOE has finished construction of and has begun system testing for the new Salt Waste Processing Facility. DOE grouts its LAW in the Savannah River Site's Saltstone Production Facility.

[63]Once the tanks are empty, DOE plans to fill them with grout. To date, eight tanks have been grouted in this way.

[64]In 1993, we reported that DOE was moving ahead with design and site work for the vitrification facility before uncertainties were resolved and before a complete design was prepared. We recommended that DOE begin construction of the facility only after the design was sufficiently complete. GAO, *Nuclear Waste: Hanford Tank Waste Program Needs Cost, Schedule, and Management Changes*, GAO/RCED-93-99 (Washington, D.C.: Mar. 8, 1993). As we reported most recently in May 2015, DOE's use of the design-build approach—in which the construction, technology development activities, plant design, and construction occur simultaneously rather than sequentially—has led to cost and schedule overruns. DOE discourages use of this approach for complex, first-of-a-kind facilities but has continued to use it for the WTP. GAO, *Hanford Waste Treatment: DOE Needs to Evaluate Alternatives to Recently Proposed Projects and Address Technical and Management Challenges*, GAO-15-354 (Washington, D.C.: May 7, 2015).

treat LAW.[65] However, DOE did not implement the acceleration initiative at the Hanford Site. In 2012, DOE stopped construction on parts of the WTP until the contractor could demonstrate that the systems were aligned with DOE nuclear safety requirements.[66]

In September 2013, DOE proposed the current waste treatment strategy, which is intended to allow some LAW to be treated before WTP's technical challenges are resolved. This new strategy (known as direct-feed LAW) includes the construction of a new LAW pretreatment system to directly feed a portion of Hanford's LAW to the LAW treatment facility to be vitrified.[67] According to DOE officials, direct-feed LAW will be used to treat about 13 million gallons of LAW, which represents about 25 percent of the total LAW to be treated. Nevertheless, DOE will still require the successful construction of the WTP and its specific components, such as the Pretreatment facility, to treat the remaining portion of LAW that was originally planned to be treated in the WTP. In addition, as previously discussed, DOE has not yet chosen a waste treatment approach for supplemental LAW—the LAW that the WTP was not designed to treat. See appendix II for an illustration of DOE's proposed waste treatment plans at the Hanford Site and key facilities involved in each process, and see appendix III for a timeline of treatment plans at the Hanford Site.

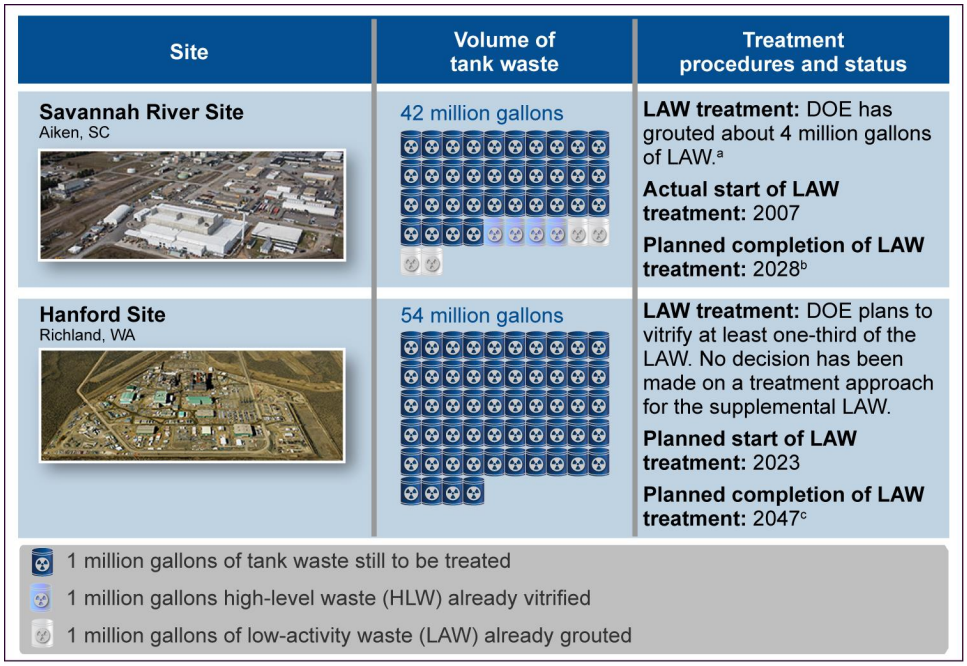
Figure 1 provides an overview of the status of treatment at the Savannah River and Hanford Sites.

[65]Under this initiative, Hanford tank waste treatment was planned to have been completed by 2028 and to cost up to $20 billion less than the estimated baseline. In its August 2002 report, *Performance Management Plan for the Accelerated Cleanup of the Hanford Site*, DOE noted that many tanks contain wastes that are less well suited for vitrification because of high sulfate content, among other things. DOE also noted in this report that treating all of the LAW streams by vitrification has the potential to unnecessarily constrain the rate of waste treatment.

[66]DOE resumed construction on a portion of the WTP in 2014, but according to DOE officials, as of December 2016, construction had not yet fully resumed.

[67]The direct-feed LAW treatment process also requires DOE to build a new Effluent Management Facility to receive secondary waste—that is, waste generated during the treatment process—from the LAW treatment facility.

Figure 1: Overview of the Department of Energy's Tank Waste Treatment Status and Approaches at the Hanford and Savannah River Sites



Source: GAO analysis of Department of Energy (DOE) documents. Image sources: DOE, Mission Support Alliance. | GAO-17-306

[a]The Savannah River Site has treated about 4 million gallons of LAW from the tanks. The treatment process necessarily increases the volume of the waste treated because water and other constituents are added during the process. Consequently, the total amount of LAW grouted at the Savannah River Site so far is about 8.3 million gallons.

[b]According to the Site Treatment Plan, the Savannah River Site must complete tank waste treatment by 2028, but according to DOE documents, DOE currently estimates that it will complete treatment by 2032.

[c]According to the Tri-Party Agreement, Hanford must complete tank waste treatment by 2047, but a senior DOE official stated that internal planning documents estimate that supplemental LAW treatment will last until at least 2061.

DOE Faces Schedule Delays at Both the Savannah River and Hanford Sites, but the Savannah River Site Will Likely Complete LAW Treatment Sooner

Under a plan developed pursuant to its Federal Facility Agreement with South Carolina, DOE is required to complete tank waste treatment at the Savannah River Site by 2028, but according to DOE documents, DOE

aims to complete the majority of LAW treatment in 2032.[68] Site officials are exploring ways to treat the Savannah River Site's LAW more quickly. For example, according to the Savannah River Site's System Plan—which is a DOE plan that is periodically updated and documents the activities required to treat and dispose of the Savannah River Site's tank waste—the site plans to employ an additional waste processing technology, called "Tank Closure Cesium Removal," to selectively remove cesium from liquid waste so that the waste can be processed more quickly.[69] DOE plans to initiate Tank Closure Cesium Removal at the site in 2018. According to the Savannah River Site's Treatment Plan, if DOE does not complete tank waste treatment by 2028, it is subject to financial penalties under the Savannah River Site's Federal Facility Agreement.

Under the TPA, DOE is required to complete tank waste treatment at the Hanford Site by 2047, but according to DOE officials and planning documents, DOE is unlikely to complete LAW treatment, in particular, by this date. DOE currently plans to begin treating some of the waste in 2023, after the WTP's LAW treatment facility is completed. DOE officials told us that because of pending decisions regarding LAW treatment, uncertainties about the amount of LAW that the LAW facility can vitrify, and ongoing technical challenges, DOE does not know how long waste treatment will take. However, in a December 2016 letter to the Washington State Department of Ecology, the manager of DOE's Office of River Protection stated that the site is likely to miss milestones governing waste retrieval from 9 tanks because vapors present at tank farms may require the adoption of additional worker protections that will

[68]The Savannah River Site's System Plan notes that DOE will continue to treat HLW until 2036. Because treating HLW generates a low-level waste stream as a byproduct, the LAW that is created as a byproduct will need be treated, and such treatment will be completed when HLW treatment is complete in 2036.

[69]Savannah River Remediation LLC, *Liquid Waste System Plan Revision 20*, SRR-LWP-2009-00001 (Aiken, SC: March 2016). According to DOE, the Tank Closure Cesium Removal system is a new technology that will help process tank waste in the tank by pumping the waste into a unit designed to collect cesium. When it becomes loaded with cesium, a column within the unit will be removed and replaced. The "spent," or used, column will then be stored for disposition, such as in the HLW Defense Waste Processing Facility or using a disposal alternative that will be determined in the future.

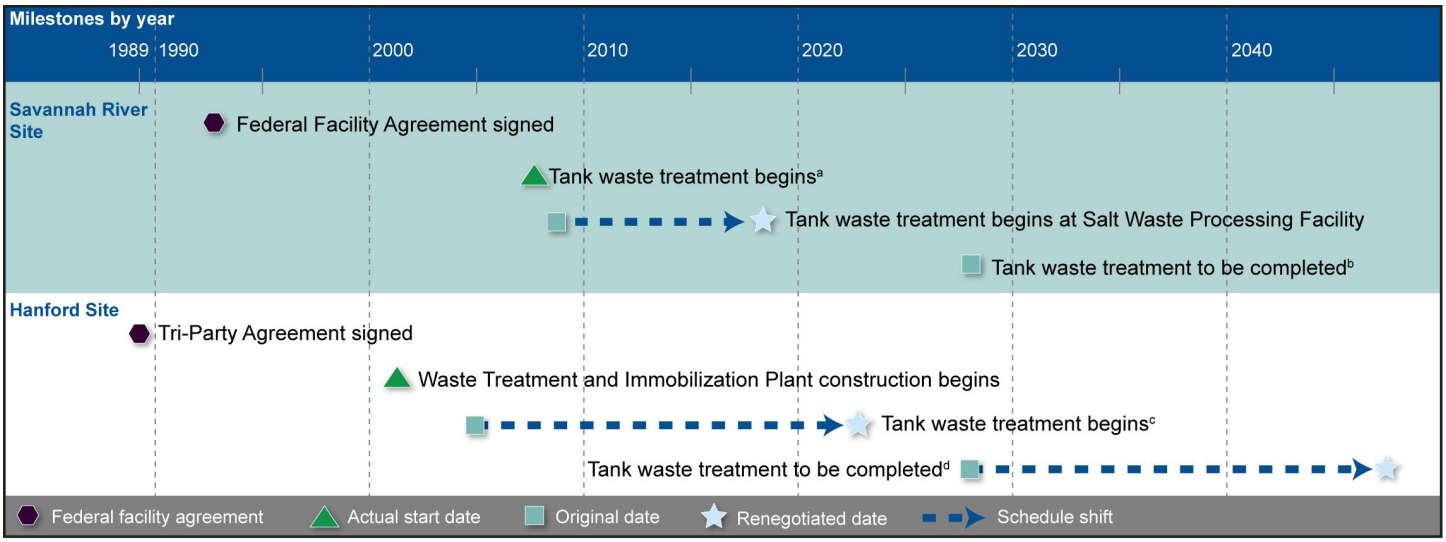
slow waste retrieval from the tanks.[70] Difficulties in retrieving waste from the tanks may delay the start of treatment at the WTP LAW facility, according to the Hanford tank farms contractor, although DOE stated that other options may exist to keep the start of LAW treatment on schedule. Under the TPA, Hanford is subject to penalties if it does not complete the treatment of all tank waste by December 31, 2047. However, DOE officials told us that the state of Washington has agreed that the current tank waste treatment dates are unrealistic, and DOE plans to forecast more realistic tank waste treatment dates after it updates its System Plan in October 2017.[71] A senior DOE official told us that internal planning documents estimate that supplemental LAW treatment will not be completed until at least 2061.

Figure 2 shows the timeline of the Savannah River and Hanford Sites' current treatment milestones.

[70]On July 11, 2016, the Hanford Atomic Metal Trades Council—a labor organization composed of unions whose members work on the Hanford Site—issued a "stop work" order because of concerns about exposure to chemical vapors emanating from Hanford's tank farms. The Hanford Atomic Metal Trades Council demanded that all workers performing work within certain areas at the Hanford Site wear supplied air. On August 31, 2016, the Council agreed to lift its stop work order provided that all work within certain areas was performed with supplied air. The use of supplied air in specific areas of the Hanford Site is under litigation. Specifically, the state of Washington alleged in a motion for preliminary injunction that over 50 Hanford tank farm workers were sickened by toxic vapors shortly after a DOE contractor reduced safety protections at the site, including reductions in the use of supplied air. On November 15, 2016, after consolidating cases brought by the state and other plaintiffs, the court denied the state's and other plaintiffs' motions for a preliminary injunction against DOE. Hanford Challenge, et al. v. Moniz et al., Civ. No. 15-05086 (E.D. Washington), filed November 15, 2016. The court held, among other things, that because of the agreement of the parties regarding the use of supplied air, there was little to no chance of an imminent and substantial endangerment present that would warrant preliminary injunctive relief. The court stated, however, that arguments of DOE and its contractor seeking to minimize the Hanford employees' health related claims were unpersuasive. The consolidated case is still pending, with trial currently scheduled for March 5, 2018.

[71]Changing a TPA milestone requires the approval of DOE, the Washington State Department of Ecology, and in some cases, the EPA. DOE officials told us that they plan to use revision 8 of the System Plan during the schedule renegotiation process.

Figure 2: Current Treatment Milestones at the Department of Energy's Hanford and Savannah River Sites



Source: GAO analysis of Department of Energy (DOE) documents and interviews with DOE officials. | GAO-17-306

Note: According to DOE officials at both sites, treatment completion dates for both the Savannah River and Hanford Sites are likely to be delayed.

[a]According to DOE officials, the Savannah River Site began treating waste from contaminated storm water and residual waste from tank waste evaporators using saltstone in 1990. The site began to vitrify its high-level waste in 1996, and it began grouting low-activity waste (LAW) in 2007.

[b]DOE is required to complete tank waste treatment at the Savannah River Site by 2028; however, according to internal planning documents, DOE expects to have the majority of the Savannah River Site's LAW treatment competed by 2032.

[c]DOE plans to start tank waste treatment at the Hanford Site for a portion of its LAW by 2023, but DOE has not yet chosen a waste treatment approach for Hanford's remaining portion of LAW, called supplemental LAW. According to a court document, DOE is to have technical issues related to the high-level waste facility resolved by 2019 and the facility redesigned by 2021. The high-level waste facility is to begin tank waste treatment by 2033.

[d]DOE is required to complete tank waste treatment at the Hanford Site by 2047, but according to DOE officials and internal planning documents, LAW treatment will not be completed until at least 2061.

DOE Has Addressed Minor Technical Challenges It Has Faced at the Savannah River Site but Continues to Face Significant Unresolved Technical Challenges at Hanford

According to DOE officials, they have not faced major technical challenges treating LAW at the Savannah River Site, and they have addressed minor technical challenges as they have arisen. For example, NRC identified a potential technical challenge at the Savannah River Site related to the ability of grout to retain a certain radioactive constituent over a long period of time. Specifically, in 2012, NRC sent a letter to DOE

expressing concern that the Savannah River Site's grouted LAW may leach technetium-99 at levels exceeding NRC's limit at some point within 10,000 years after the site is closed.[72] DOE officials told us that NRC had expressed concern that DOE's model indicated that radiation doses could reach about 100 millirems at some point within 10,000 years.[73] According to NRC officials, in response to their 2012 letter of concern, DOE has reduced the concentration of technetium-99 in the Savannah River Site's LAW before it is grouted. Savannah River Site officials also told us that a multi-year study examined core samples from one of the site's grout vaults and found that DOE's assumptions about radiation releases from grout have mostly been affirmed.[74] NRC officials told us that they agreed with this assessment but that other studies raised questions about other assumptions that DOE had made with respect to technetium and iodine releases. DOE officials and NRC officials appear to have different opinions on the extent to which engineered barriers were accounted for in the model that prompted NRC's concerns. DOE officials told us that the model prompting this concern was based on a "worst case scenario" that did not use engineered barriers and assumed that all of the grout in the site's grout vaults instantaneously failed. However, NRC officials told us that the model included both optimistic and pessimistic assumptions.[75] DOE officials also told us that NRC does not license or regulate DOE's low-level waste disposal sites, including the Savannah River Site's grout

[72]According to DOE's *Radioactive Waste Management Manual* (DOE M 435.1-1), performance assessments must show that members of the public will not be exposed to radiation doses of greater than 25 millirems per year for 1,000 years after closure of a disposal facility. However, *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations (*NUREG-1854) states that the period of performance for DOE radioactive waste disposal facilities is generally 10,000 years.

[73]According to NRC, the average American receives a radiation dose of approximately 620 millirems per year. Half of this dose comes from natural background radiation, and the other half comes from man-made sources of radiation including medical, commercial, and industrial sources. For example, according to NRC, each year the average person receives an average internal dose of about 30 millirems of radiation from radioactive potassium and radium in the food and water we eat and drink.

[74]*Property Data for Core Samples Extracted from SDU Cell 2A.*

[75]In commenting on a draft of this report, NRC staff stated that, while it may not have been intended to represent engineered barriers, the model derived significant projected dose reduction from the disposal structure floors. Other disagreements focused on the projected performance that the model derived from issues related to the timing of the grout degradation.

United Kingdom: Treating Low-Activity Defense Waste with Grout

The United Kingdom is one of a limited number of countries that have defense nuclear waste as a byproduct of nuclear weapons production. Such waste was produced at the Sellafield site beginning in the 1950s and has been separated into high-level, "intermediate-level," and low-level waste streams.

High-level waste in the United Kingdom, as in the United States, is treated using vitrification. However, the country's less radioactive waste has been treated using grout for the last 20 years. Officials from the United Kingdom told us that they chose grout because it is effective, less costly, and suitable for a wide range of radioactive wastes.

According to officials from the United Kingdom, intermediate-level waste contains constituents similar to Hanford's low-activity waste, including technetium-99 and iodine-129. Officials told us that technetium and iodine are more likely to be effectively retained in a low-temperature treatment method, such as grout, than high-temperature methods, such as vitrification. Officials also told us that they would not recommend using vitrification to treat intermediate-level waste because the technology is much more complex and expensive than grout.

Sources: GAO analysis of Sellafield and International Atomic Energy Association documents and interviews with officials from the United Kingdom. Image shown courtesy of: United Kingdom Nuclear Decommissioning Authority. | GAO-17-306

vaults.[76] NRC has not yet determined whether it will rescind its 2012 letter, according to NRC officials, but it may consider doing so in the future because DOE is taking actions to address NRC's concerns. NRC officials told us that DOE plans in 2017 to continue studying grout's ability to retain technetium-99 and other constituents, and NRC will continue to monitor the results of DOE's studies.

According to site officials, the Savannah River Site may face future technical challenges related to one tank that contains 250,000 gallons of waste with organic constituents.[77] According to DOE's disposal permit with South Carolina, the organic constituents in this tank must be destroyed before the waste is disposed of. DOE officials stated they have not yet selected a method to destroy the organic constituents. According to the site's 2016 Liquid Waste System Plan, DOE expects to begin the process of selecting a method in 2022.

In contrast, DOE faces significant technical challenges at the Hanford Site that are not yet resolved.[78] Based on our analysis of DOE documents and interviews with DOE officials, we identified three key technical challenges associated with DOE's plans to vitrify Hanford's LAW that remain unresolved.

- **Glass formulation.** During the vitrification process, DOE may encounter challenges developing precise glass formulations. DOE will

[76]However, NRC staff noted that Section 3116 does apply to wastes incidental to reprocessing, which includes certain grout vaults at the Savannah River Site. Wastes governed by Section 3116 must be disposed in compliance with the performance objectives set out in subpart C of part 61 of title 10, *Code of Federal Regulations*.

[77]An organic (i.e., carbon containing) constituent was added to this tank in 1995 as part of an effort to separate cesium, strontium, and plutonium from the tank waste. DOE suspended use of this process (called the "in-tank precipitation process") in 1998 because of concerns about the amount of explosive, toxic benzene gas that the facility was generating.

[78]For the purpose of this review, we focus only on challenges related to the vitrification of LAW; however, DOE faces other challenges with the WTP more broadly, which we have previously reported on. For example, in May 2015, we found that significant technical and management challenges continued to affect the WTP and hinder its completion, particularly at the Pretreatment facility and HLW facility. Specifically, we noted that DOE experienced persistent challenges with pulse-jet mixing that could lead to an uncontrolled nuclear chain reaction known as a criticality incident, as well as challenges with erosion and corrosion of piping that could lead to equipment damage and leaks. See GAO, *Hanford Waste Treatment: DOE Needs to Evaluate Alternatives to Recently Proposed Projects and Address Technical and Management Challenges*, GAO-15-354 (Washington, D.C.: May 7, 2015).

need to develop different glass formulations to treat different batches of Hanford's LAW because there are several different chemical mixtures present in the tanks.[79] If the wrong formulation is used, the glass that immobilizes the waste may not meet disposal requirements, or the glass may not encapsulate all of certain waste constituents.[80] For example, according to a 2015 DOE report, if too much sodium—the main constituent in Hanford's LAW—is present in the vitrified waste form, it will have poor durability and will fail to meet site disposal requirements.[81] According to DOE officials, DOE plans to adjust the amount of waste placed in the glass to ensure glass performance, and DOE will establish waste acceptance criteria to apply to each batch of waste before treatment to ensure that the vitrified LAW will meet disposal requirements.

- **Off-gas treatment systems.** During the vitrification process, DOE may encounter issues with its LAW off-gas treatment systems, which confine and treat radioactive and hazardous gases that are a byproduct of the vitrification process. According to a 2015 DOE report, without mitigating actions, the LAW off-gas treatment systems may chronically limit the LAW facility's overall production capacity.[82] For example, the report states that DOE will need to cease operating its melters—which produce the vitrified waste—in order to safely perform maintenance on the off-gas system, which may in turn reduce the

[79]Because of the highly heterogeneous chemical and radiological composition of the Hanford tank wastes, DOE will need to vitrify the waste in batches, calibrating the composition of each batch of waste to be vitrified to maximize waste treatment effectiveness. According to the 2012 EIS, Hanford's Best Basis Inventory, which establishes the chemical inventory of the tanks, may have uncertainties of 50 percent to 400 percent for selected constituents of concern in the tanks. *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington.*

[80]In comparison, the Savannah River Site uses one grout formulation for the treatment of its LAW.

[81]Department of Energy, *Office of River Protection Advanced Low-Activity Waste Glass Research and Development Plan*, ORP-59500 rev. 0, (Richland, WA: November 2015).

[82]Department of Energy, Office of River Protection, *Waste Treatment and Immobilization Plant Low-Activity Waste Facility Design and Operability Review and Recommendations*, 15-WTP-0151 Attachment 2, (Richland, WA: Sept. 4, 2015).

Oak Ridge National Laboratory: Example of DOE Treating Low-Level Waste with Low Temperature Drying

Oak Ridge National Laboratory was constructed during World War II, in part, as a pilot-scale facility to support nuclear energy research. Since the 1940's, the site has generated transuranic waste, low-level waste, and mixed waste during nuclear materials production and research and development activities. In 1995, the Tennessee Department of Environment and Conservation issued an order that mandated specific requirements for Oak Ridge's waste treatment and disposal.

Oak Ridge reviewed several options for treating its low-level waste, including vitrification, grout, and low-temperature drying. According to a former Department of Energy (DOE) project manager who oversaw waste treatment, the estimated cost for treating the waste with low-temperature drying was about $250 million, while the estimated cost for grout was $350 million, and the estimated cost for vitrification was $1 billion.

In August 2000, Oak Ridge decided to treat the waste with low-temperature drying. According to the former DOE project manager, this method used a low-temperature dryer to concentrate the liquid portion of the waste before it was mixed with metasilicate—which, according to this DOE official, is a material that sets like cement but can be dissolved if needed by adding water—and fed into storage casks for shipment to the Nevada National Security Site for disposal. By treating the low-level waste through low-temperature drying and combining it with metasilicate, the volume of waste disposed of was reduced to about a quarter of the original volume.

Sources: GAO analysis of DOE documents and interviews. Image source: DOE. | GAO-17-306

facility's production capacity.[83] This report also notes that the off-gas systems do not have redundant back-up systems, which may cause the equipment to fail more frequently.[84]

- **Tank space.** After DOE begins vitrifying Hanford's LAW, it may not have sufficient tank space if additional tanks leak or if a higher-than-expected amount of effluent—which is the liquid waste generated from the LAW facility—needs to be returned to the tanks. Specifically, the vitrification process will generate liquid waste that is created by the off-gas system. A portion of this waste will be returned to the tanks.[85] However, according to a 2015 DOE document, if the waste that is returned to the tanks does not meet certain criteria, it could cause corrosion in the tanks.[86] DOE officials told us that the portion of the effluent that is returned to the tanks will undergo chemical adjustments in order to prevent tank corrosion, but this will require expanding the volume of waste returned to the tanks by two or more times the effluent volume. According to this 2015 DOE document, discharging this waste back into the tank farms is a short-term solution because space constraints will severely impact the tank system.[87]

These and other challenges may prevent DOE from vitrifying Hanford's LAW with the WTP at the rate required by the Consent Decree, which

[83]Melters are used to produce vitrified waste. Waste, in combination with glass-forming materials, is heated to high temperatures by an electrical current that passes through the molten glass-forming materials and waste in the melter. The waste and the glass-forming materials melt, forming a vitrified product that is poured into containers.

[84]According to DOE officials, the contractor has agreed to resolve all issues identified in the *Design and Operability Review*, including vulnerabilities associated with the off-gas system, and has "closed out" 499 of 516 vulnerabilities. DOE officials stated that DOE's Office of River Protection is verifying the accuracy of the contractor's assessments and expects to "close out" most of the remaining vulnerabilities in 2017.

[85]To support direct-feed LAW operations, DOE is building the Effluent Management Facility, which will evaporate and concentrate the liquid waste that results from the vitrification process. After initial treatment, the effluent will either be (1) sent to the Effluent Treatment Facility—a different facility from the Effluent Management Facility—for further treatment, (2) recycled back into the LAW facility to be vitrified, or (3) returned to the tanks. According to a 2015 DOE plan, of the effluent that is not sent to the Effluent Treatment Facility, 15 percent will be returned to the tanks, while 85 percent will be recycled back to LAW facility. See: *Advanced Low-Activity Waste Glass Research and Development Plan*.

[86]Department of Energy, *River Protection Project Technology Roadmap*, RPP-PLAN-43988, rev. 1 (Richland, WA: Jun. 30, 2015).

[87]*River Protection Project Technology Roadmap*.

could result in additional future schedule delays and increased costs. According to the WTP contract and the Consent Decree, the LAW treatment facility must produce vitrified waste at an average rate of 70 percent of its stated design capacity.[88] DOE's 2015 LAW facility *Design and Operability Review* states that there is significant evidence that this rate is an overly optimistic assessment of the LAW treatment facility's production capabilities.[89] Moreover, the report notes that this required rate significantly exceeds what vitrification facilities at other DOE sites and those in the United Kingdom have been able to achieve. For example, the Savannah River Site's Defense Waste Processing Facility, which vitrifies HLW, has operated at an average of 36 percent of design capacity, and the West Valley Demonstration Project operated its HLW vitrification facility at a rate of about 17 percent of design capacity.[90] Also according to the report, HLW vitrification facilities in the United Kingdom have sustained an operating capacity of less than that of the Savannah River Site.

DOE's Costs to Grout LAW at the Savannah River Site May be Substantially Lower than Its Approximate Costs to Vitrify LAW at Hanford

Although existing information is incomplete, the best available information suggests that DOE's costs to grout LAW at the Savannah River Site may be substantially lower than its approximate costs to vitrify LAW at Hanford.[91] As discussed previously, at the Savannah River Site, DOE began grouting LAW in 2007 using existing grouting facilities while constructing a new, higher capacity facility to prepare the LAW to be grouted.

[88]To produce vitrified waste at that rate, the LAW treatment facility—which has a design capacity of 30 metric tons of glass per day—must produce, on average, 21 metric tons of glass per day.

[89]Department of Energy, Office of River Protection, *Waste Treatment and Immobilization Plant Low-Activity Waste Facility Design and Operability Review and Recommendations*, 15-WTP-0151 Attachment 2, (Richland, WA: Sept. 4, 2015).

[90]The West Valley Demonstration Project is the only commercial spent fuel reprocessing plant to have operated in the United States. The site produced tank waste that was separated into a HLW stream and a LAW stream. The HLW was treated with vitrification, and the LAW was treated with grout.

[91]All costs and cost estimates in this section are presented in 2015 dollars, unless otherwise noted.

- **Construction of the Savannah River Site's LAW treatment facilities.** In 2016, DOE completed construction on the new Salt Waste Processing Facility, which DOE expects will allow it to process the Savannah River Site's LAW at a faster pace than its existing facilities could. Construction of this new facility cost $2.3 billion (adjusted to $2.4 billion in 2015 dollars), and DOE plans to begin using this facility in 2018 to prepare the Savannah River Site's remaining LAW to be grouted.[92] However, DOE could not provide us complete information on the cost to construct the existing facilities that have been in use for years. According to officials from the Savannah River Site, DOE does not have the information because the work was done in the 1980s by different contractors than the ones currently employed by the site. Our review of DOE documents indicates that DOE spent about $45 million ($85 million in 2015 dollars) to construct the existing facilities in the late 1980s.[93] In addition, a 2007 DOE budget document noted that DOE spent about $160 million ($190 million in 2015 dollars) to modify the existing facilities at the Savannah River Site to prepare the first 4 million gallons of LAW to be grouted.
- **Operation of the Savannah River Site's LAW treatment facilities.** The estimated cost to operate the Savannah River Site's existing grout facilities for the duration of the treatment mission, including the approximately $250 million already spent to grout the first 4 million gallons of LAW, will be about $1.2 billion. DOE estimates that operating the new Salt Waste Processing Facility to prepare the rest of the Savannah River Site's LAW to be grouted will cost about $1.6 billion.

Based on the information available to us, DOE's total cost to modify and construct the Savannah River Site's existing and newly constructed facilities was about $2.7 billion, and DOE's total costs for operating these facilities is estimated to be about $2.8 billion.

With regard to the Hanford Site, as previously discussed, DOE has not yet completed construction of Hanford's LAW vitrification facility, nor has

[92]According to DOE officials, this includes the total project cost to design, construct, perform startup testing, and commission the new Salt Waste Processing Facility.

[93]We obtained information from various DOE and budget documents. According to these documents, construction of the existing Saltstone Facility and the first two disposal vaults was completed between February 1986 and July 1988 at a cost of $45 million. The documents do not discuss how the costs were allocated for the Saltstone Facility and the two vaults. To be conservative in our analysis, we are reporting the full $45 million for the construction of the Saltstone Facility.

it selected an approach for treating Hanford's supplemental LAW. As a result, DOE does not have complete estimates for the costs of constructing and operating LAW treatment facilities at Hanford, but the cost information that is available indicates that the costs to vitrify LAW at Hanford may be substantially more than the estimated costs to grout LAW at the Savannah River Site.

- **Construction of Hanford's LAW treatment facilities.** At Hanford, DOE estimates that constructing the WTP's LAW treatment facility, along with the ancillary facilities needed for LAW treatment, will cost about $6.5 billion.[94] This estimate accounts for DOE's original estimate of $1.4 billion (in 2006 dollars) to construct the LAW vitrification facility, as well as $316 million for construction of additional facilities to support LAW treatment. In addition, in 2016, DOE estimated that inflation adjustment and additional modifications needed to treat LAW will add $4.8 billion in construction costs. DOE has not yet selected an approach to treat the supplemental LAW at Hanford and therefore does not have an estimate for the costs to complete LAW treatment. However, DOE's current life-cycle estimate assumes that DOE will build and operate a second LAW vitrification facility with the same technical assumptions as the first one. In addition, senior DOE officials told us that if DOE chooses to vitrify supplemental LAW, the costs to construct and operate a second vitrification facility for supplemental LAW would be roughly as much as the costs associated with constructing and operating the existing LAW facility.
- **Operation of Hanford's LAW treatment facilities.** Construction of the WTP's LAW treatment facility is not complete, and according to DOE officials, they do not yet have an estimate for how much it will cost to operate the facility because they have not selected a contractor to operate it. However, according to January 2017 estimates from the DOE contractor that is constructing the WTP, the cost for commissioning and operating the LAW facility is currently

[94]Available information indicates that it will cost about $6.5 billion to construct the facilities needed for LAW treatment. However, in a March 2017 internal monthly status report, DOE estimated that the direct feed LAW approach, which encompasses the WTP LAW facility and other infrastructure needed for treating the initial portion of LAW, will cost $8.3 billion. We did not include this higher figure in the estimated construction costs because we were unable to review the source documents associated with it. Nevertheless, if the cost to construct the facilities needed for LAW treatment is $8.3 billion, this will increase the cost per gallon figure for vitrifying LAW. As noted above, DOE will still require the successful construction of the WTP and its components to treat the remaining portion of LAW that was originally planned to be treated in the WTP.

estimated at about $600 million per year ($530 million in 2015 dollars). According to DOE officials, LAW treatment would likely not be completed until 2061, requiring the facility to operate for 39 years for a total of about $20 billion. As discussed above, DOE's life cycle estimates assume that it will cost the same to operate a second vitrification facility for supplemental LAW, and senior DOE officials confirmed that it would cost roughly as much to operate a second LAW facility.

Overall, DOE officials indicated that $13 billion is their best estimate for the total cost to construct (1) the LAW treatment facility currently under construction and (2) a new vitrification facility for supplemental LAW. DOE officials indicated that their best estimate for the costs to operate these facilities is about $40 billion.

Table 2 compares best available cost information for treating LAW at the Savannah River and Hanford Sites. These estimates indicate that the costs to vitrify LAW at Hanford may be substantially higher than the costs to grout LAW at the Savannah River Site. This is consistent with DOE's assessment of treatment costs at the Savannah River Site: senior DOE officials estimated in 2004 that by grouting LAW at the Savannah River Site, DOE would have saved at that time about $55 billion (in constant 2004 dollars) over the lifecycle of waste treatment operations, when compared with vitrification.[95]

[95]This estimate was developed by a senior official in DOE's Office of Environmental Management in 2004; officials from the Savannah River Site were not able to reproduce this estimate for us at the time of this review.

Table 2: Comparisons of Total Estimated Costs for Grouting Low-Activity Waste (LAW) at the Savannah River Site and Vitrifying LAW at the Hanford Site, Based on Best Available Information

	Savannah River Site	Hanford Site	Hanford Site	Hanford Site
	Existing and new salt waste processing facilities	LAW Treatment facility	Vitrification facility for supplemental LAW[a]	Total
Estimated cost to construct treatment facilities (millions of dollars)	$2,700	$6,500[b]	$6,500	**$13,000**
Estimated cost to treat LAW (millions of dollars)	$2,800	$20,000[c]	$20,000	**$40,000**
Total estimated cost (millions of dollars)	**$5,500**		**na**	na **$53,000**
Total LAW (gallons)[d]	**36 million**		na	na **49 million**
Estimated average cost per gallon of LAW treated (dollars)	**$153/gallon**		na	na **$1,081/gallon**

Source: GAO analysis of Department of Energy (DOE) data and interviews. | GAO-17-306

Note: All costs and cost estimates in this table are presented in 2015 dollars. In addition, the estimates for both sites do not include costs to dispose of the treated waste. We did not evaluate whether the grouted waste form at the Savannah River Site would meet Washington State's hazardous waste management requirements. Further, because DOE does not have complete information on the costs of various treatment options, nor has it precisely specified the treatment options it will pursue, our analysis is based on the best information we could obtain. In particular, the precise costs of vitrifying Hanford's LAW are not known. To the extent possible, we corroborated estimated costs with available budget documents, DOE reports, and DOE officials. Because some of DOE's estimated costs were approximations, we conducted a sensitivity analysis by examining the cost-per-gallon difference between the Hanford and Savannah River Sites under different scenarios. This helped us assess how, if at all, imprecise information could affect the results of this comparison. For example, if DOE operated Hanford's LAW treatment facility and a vitrification facility for supplemental LAW for 20 years, rather than its projected 39 years—which would cost about $10 billion in total—DOE's costs would be about $673 per gallon. In this scenario, DOE's costs per gallon to vitrify all of Hanford's LAW would still be about four times the costs to grout the Savannah River Site's LAW.

[a]DOE has not yet made a decision on how it will treat supplemental LAW. However, DOE's current life-cycle estimate assumes that a second LAW vitrification facility will be built and operated with the same technical assumptions as the first one.

[b]Until 2016, DOE had estimated that construction of the LAW facility would cost $1.4 billion. According to DOE's December 2016 estimates, additional modifications to DOE's approach to treating LAW have added $4.8 billion. In addition, DOE is building a new $316 million facility to prepare the tank waste before it is brought into the LAW treatment facility ($6.5 billion total). However, although available information indicates that it will cost about $6.5 billion to construct the facilities needed for LAW treatment, DOE estimated in a March 2017 internal monthly status report that the direct feed LAW approach—which encompasses the WTP LAW facility and other infrastructure needed for treating the initial portion of LAW—will cost $8.3 billion. We did not include this higher figure in the estimated construction costs because we were unable to review the source documents associated with it. Nevertheless, if the cost to construct the facilities needed for LAW treatment is $8.3 billion, this will increase the cost per gallon figure for vitrifying LAW.

[c]DOE does not have an estimate for the cost to treat LAW. However, according to contractor estimates, the cost for commissioning and operating the LAW facility and associated support systems is currently estimated at about $600 million per year ($530 million when adjusted for inflation). DOE is currently planning to begin operating the facility in 2022, and treatment is not expected to finish until 2061 (39 years) (about $20 billion total).

[d]These figures reflect the total amount of waste previously treated and currently stored in the tanks. However, the total amount of waste treated will be significantly higher because the waste will need to be diluted before it can be treated.

Experts Believe That Both Vitrification and Grout Can Treat Hanford's LAW and Identified Options to Accelerate Cleanup and Reduce Future Costs

According to experts who participated in our meeting convened by the National Academies, both vitrifying and grouting Hanford's LAW could be protective of human health, including limiting the risk of exposure over the long term.[96] These experts also noted that new information since DOE made its decision to vitrify Hanford's LAW suggests that grout will perform better than assumed in previous studies. Moreover, these experts stated that by adopting a risk-informed decision-making approach to treating Hanford's supplemental LAW, DOE could address certain risks sooner and avoid significant costs.[97]

According to Experts, Vitrification and Grout Could Both Effectively Treat Hanford's LAW

According to experts who participated in our meeting, both vitrification and grout could effectively treat Hanford's LAW and be protective of human health by, for example, limiting the risk of exposure over the long term.[98] Many experts who participated in our meeting asserted that the risk posed to human health and the environment by both vitrified and grouted waste is small at a modern disposal site, such as the one that will be used at Hanford. A few experts noted that the long-term risks of

[96]The experts did not address issues related to the construction and operation of the WTP. In addition, the experts' meeting focused on the treatment of all of Hanford's LAW because DOE has not yet determined which tanks will be treated by the WTP and which tanks' waste will be treated with a supplemental treatment approach.

[97]In November 2016, several months after our experts' meeting, Congress passed the National Defense Authorization Act for Fiscal Year 2017. Pub. L. No. 114-328 (2016). Section 3134 of the act requires DOE to enter into an arrangement with a federally funded research and development center to conduct an analysis of approaches for treating the portion of LAW at Hanford intended for supplemental treatment. The analysis is to include an assessment of the benefits and costs of various treatment approaches, including vitrification, grouting, and steam reforming, and other alternative approaches identified by DOE. DOE has not yet entered into the agreement required by this section.

[98]DOE plans to dispose of its treated LAW on site in Hanford's Integrated Disposal Facility, a RCRA-permitted landfill with two separate expandable cells.

Nevada National Security Site: DOE's Disposal of Low-Level Waste in the Arid Nevada Environment

The Nevada National Security Site accepts low-level waste and mixed low-level waste—which is low-level radioactive waste that also contains hazardous constituents regulated under the Resource Conservation and Recovery Act—for disposal from the Department of Energy (DOE), as well as certain waste from the Department of Defense. According to an official from the National Nuclear Security Administration who is an environmental management operations manager for the low-level waste facility at the Nevada National Security Site, the waste disposal site is ideal for radioactive waste disposal because of its arid environment, deep groundwater table, and low likelihood of rain reaching the groundwater. In addition, the Nevada National Security Site facilities sit atop deep aquifers and potential leaks have no pathway to the groundwater.

To be accepted at the site, waste must meet specific criteria, such as limits on the amount of free liquids, and the waste must adhere to applicable packaging criteria. The official stated that the site does not require a certain waste form and that waste has been accepted in grouted and other forms. The official was not aware of any vitrified waste having been disposed of at the site.

Sources: Interview with NNSA official and GAO analysis of DOE documents. Image source: DOE. | GAO-17-306

vitrified and grouted LAW in a modern disposal site are so low that the difference in exposure risk between the two forms might not be measurable.[99] One expert noted that a 2013 DOE report that studied grout formulations found that for the range of parameters studied, all 26 of the grout formulations tested met the land disposal standards for hazardous constituents and met the anticipated waste acceptance criteria for on-site disposal at Hanford.[100] Appendix IV provides a detailed summary of experts' views on the performance of vitrification and grout, including the benefits and shortcomings of each in treating LAW with certain constituents at Hanford.

Some experts who participated in our meeting also stated that recent studies have shown significant improvement in the performance of grout. This view is underscored by a 2015 DOE report, which stated that grouted LAW has been shown to effectively immobilize waste and retain constituents of concern, including technetium-99 and iodine-129.[101] The report further stated that grouted LAW has been shown to meet the RCRA waste treatment standards for land disposal of hazardous waste. Moreover, a 2016 study of the long-term performance of the Savannah River Site's grout in its Saltstone Disposal Facility showed that the grout will retain constituents of concern for the required period of time.[102]

When accounting for the environment in which LAW is planned to be disposed of at Hanford, experts who participated in our meeting viewed

[99]However, some experts stated that while both waste forms would meet requirements, vitrification might perform slightly better than grout over the long term.

[100]Department of Energy, *Supplemental Immobilization of Hanford Low-Activity Waste: Cast Stone Screening Tests*, PNNL-22747, (Aiken, SC and Richland, WA: September 2013). Each of the 26 formulations was characterized based on its processing properties including gel time, hardening time, and the heat generated during curing; and cured waste properties including compressive strength, density, leaching, and chemical composition. The report noted that, to be acceptable for disposal at the Integrated Disposal Facility on the Hanford Site, cast stone containing hazardous metals must pass EPA's toxicity characteristic leaching protocol. RCRA's land disposal restrictions require that the concentration of the metals in the leachate be below the treatments standards contained in 40 C.F.R. part 268.

[101]Department of Energy, *Technical Approach for Determining Key Parameters Needed for Modeling the Performance of Cast Stone for the Integrated Disposal Facility Performance Assessment*, PNNL-24022 rev. 0 (Richland, WA: March 2015).

[102]Additionally, this report noted that while the grout did not encapsulate iodine as well as had been modeled, the leaching of iodine would not affect the risk of exposure to the surrounding environment. *Property Data for Core Samples Extracted from SDU Cell 2A.*

the long-term exposure risks of vitrified LAW and grouted LAW as low and nearly identical. A few experts said that Hanford is a favorable place for the long-term disposal of LAW with either vitrification or grout. Experts explained that Hanford is an arid climate with low rainwater soil infiltration rates, which will slow down the rate at which waste would be released into the soil if the vitrified or grouted waste form and the engineered barriers were not effective. As a result, these experts stated that there is a very low risk that waste treated with either grout or vitrification would contaminate the groundwater. One expert noted that even if waste from the vitrified or grouted waste form leached from the disposal site, it could take approximately 2,000 years for any waste to enter the groundwater, and a few experts stated that any waste that reached the groundwater after that period of time would be significantly diluted so as to pose virtually no risk.

Moreover, some experts who participated in our meeting stated that the engineered barriers planned for use at the Hanford disposal site will further reduce risks. Specifically, these experts stated that the engineering of the disposal site plays a role in minimizing risks and that engineered barriers—such as adding a cap to prevent water infiltration into the disposal site—could help to limit the possible spread of some contaminants from grouted waste forms for up to the 1,000-year period of performance.[103] For example, one expert explained that engineered barriers greatly reduce the amount of water that flows through a disposal site. A few experts noted that such barriers can be maintained to preserve their effectiveness over time.

Experts Stated That New Information Shows Grout Will Perform Better than Was Assumed When DOE Made Its Decision to Vitrify Hanford's LAW

Some experts who participated in our meeting stated that some of the research on the effectiveness of grout and vitrification included in early studies—as well as DOE's 2012 EIS, which supported DOE's decision to vitrify at least some of Hanford's LAW—relied on assumptions that are no

[103]According to DOE Manual 435.1-1, low-level waste containment facilities must conduct a performance assessment demonstrating that the site meets performance objectives such as the dose to the public not exceeding 25 millirems from all exposure pathways during any 1 year, over the course of a 1,000-year after-closure period of compliance. According to NRC, the average American receives a radiation dose of approximately 620 millirems per year.

longer viewed as accurate or that no longer apply. According to multiple experts, DOE used overly conservative models in assessing the long-term risk of grouting LAW for its 2012 EIS, which underestimated the long-term performance of grout. A few of these experts stated that when models are overly conservative, they do not accurately reflect site conditions. For example, according to the 2012 EIS, approximately 0.14 inches (3.5 millimeters) of rain infiltrates the soil at the Hanford Site each year, but a few experts stated that the rain infiltration rate is probably closer to 0.04 inches (1 millimeter) each year.[104] As a result, less water may reach the waste form than the EIS indicated, thereby reducing the likelihood of contaminating groundwater. One expert further explained that Hanford's 2012 EIS used conservative assumptions on how well grout would retain technetium-99 that were based on outdated research, and the EIS used more realistic assumptions on how well a vitrified waste form would retain technetium-99. Another expert noted that when such overly conservative assumptions are all accounted for, they become collectively significant. The expert noted that the performance of grout in the 2012 EIS could have been misleading, and that if DOE had used more realistic assumptions, it might have reached different conclusions about the ability of grout to safely and effectively treat Hanford LAW.

A few experts who participated in our meeting noted that engineered barriers also help to improve waste form performance, but their impacts were not fully accounted for in the models used for the Hanford Site. According to the 2012 Hanford EIS, the site's engineered barriers are assumed to last for 500 or 1,000 years—depending on the type of barrier used—before failing.[105] In contrast, a 2009 DOE report on the performance of the Savannah River Site's Saltstone Disposal Facility found that the performance of engineered barriers used there is assumed to degrade slowly over more than 5,000 years.[106]

Some Experts Noted That a Risk-Informed Decision-Making Process Could Help DOE Possibly Avoid

[104] *DOE Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland.*

[105] *DOE Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland.*

[106] *Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site.*

Significant Costs and Develop Options to Address Certain Risks Sooner

Experts who participated in our meeting noted that current scientific information should be used as part of a risk-informed decision-making process. Some of these experts suggested that using grout could significantly reduce the costs of treating Hanford's supplemental LAW. Moreover, experts stated that under a risk-informed decision-making process, options exist that could help DOE reduce certain risks in treating Hanford's supplemental LAW.

Experts Noted that Recent Scientific Information Should Be Used as Part of a Risk-Informed Decision-Making Process

According to experts who participated in our meeting, DOE would benefit from incorporating information on significant advances in grout performance as part of a risk-informed decision-making approach to treating Hanford's supplemental LAW. The National Research Council has reported several times that DOE's cleanup strategy could benefit from a risk-informed process—in essence, a process that aligns treatment approaches with the risk the waste poses. In a 2005 report, the National Research Council found that an effective and credible risk-informed decision-making process is one that is consistent with current scientific knowledge and practice, reasonably independent of decision makers, and subjected to thorough independent peer review.[107] A 2011 National Research Council report asserted that incorporating new science and technology does not have to halt a cleanup program's progress and that by incorporating new science and technology, a cleanup program can increase efficiencies and reduce life-cycle costs and risk.[108] By developing updated information on the likely performance of alternate methods for treating Hanford's supplemental LAW, such as grout, DOE may be able to develop waste treatment approaches that would

[107]Specifically, the report stated that such a decision-making process is (1) participatory; (2) logical; (3) consistent with current scientific knowledge and practice; (4) transparent and traceable; (5) structured with reasonable independence of the decision authority from the petitioner; (6) subjected to thorough, independent peer review; (7) technically credible with believable results; and (8) framed to address the needs of the decision process. *Risk and Decisions About Disposition of Transuranic and High-Level Radioactive Waste*.

[108]*Waste Forms Technology and Performance: Final Report*. This study was performed at the request of DOE's Office of Environmental Management.

accelerate the tank waste treatment mission, thereby reducing certain risks, and may reduce tank waste treatment costs.

Experts who participated in our meeting stated that DOE could consider other options for treating supplemental LAW at Hanford that may better align treatment approaches with the risks the waste poses, which could reduce certain risks and possibly avoid significant costs. These experts noted that the greatest risks to human health and the environment arise from leaving the waste in the tanks for prolonged periods of time and that this risk is far greater than those associated with possible leaching of waste from a disposal site. According to some experts, the longer the waste stays in the tanks, the greater the risk that potential tank leaks pose to human health and the environment, and one expert noted that the longer that tank farms continue to operate, the greater the risk to workers.[109] According to another expert, a significant risk could arise if the dome of one of the aging tanks were to collapse because this could cause the contamination to become airborne. This point was also underscored in a 2015 Omnibus Risk Review Committee report, which found that important infrastructure systems at Hanford are operating past their designed lives and are showing the stress of extended operations and that failures of infrastructure could lead to unforeseen major human health risks.[110] We have also previously reported that Hanford's tanks are aging and that 153 of the 177 tanks are beyond their design life.[111]

[109]According to DOE officials, 61 of DOE's 149 single-shell tanks at Hanford are assumed to be leaking. In October 2012, DOE announced that nuclear waste at the Hanford site had leaked into the space between the inner and outer shell of one of its double-shell tanks. Four months later, in February 2013, DOE announced that waste was leaking into the environment from at least one single-shell tank. More recently, in April 2016, DOE reported that Hanford officials detected a major leak of waste from the inner shell of one double-shell tank, and DOE reported that it was investigating whether a second tank had also developed a leak from the inner shell.

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

[111]GAO, *Hanford Cleanup: Condition of Tanks May Further Limit DOE's Ability to Respond to Leaks and Intrusions*, GAO-15-40 (Washington, D.C.: Nov. 25, 2014). In this report, we recommended that DOE assess the alternatives for creating new RCRA-compliant tank space for the waste from the single-shell tanks, including building new double-shell tanks.

According to a 2014 DOE document, tank leaks could extend tank waste treatment efforts by 25 years and cost an additional $91 billion.[112]

Some Experts Suggested That Using Grout Could Significantly Reduce Costs at Hanford

Experts who participated in our meeting explained that employing a multi-pronged approach to treating Hanford's LAW could allow DOE to avoid significant costs. Several experts indicated that, on the basis of their professional experience and opinion, vitrifying LAW—in general and at the Hanford Site in particular—would likely be more expensive than grouting it. For example, one expert said that cost estimates for the treatment of LAW at Hanford indicated that grouting the waste could be 20 percent to 50 percent cheaper than vitrifying it. Other experts pointed out that the costs of maintaining Hanford's tanks influence long-term life-cycle costs, and shortening the length of time that DOE must manage the tanks could save significant costs.[113] Another expert suggested that DOE's major opportunity for avoiding future costs is to "dump the one-size-fits-all approach for the remainder of the waste" (i.e., supplemental LAW) and adopt a risk-based approach because the hazardous and radioactive constituents in the waste vary by tank, and different treatment options may be more efficient for different tanks. Certain experts did not fully agree that grouting Hanford's LAW would be cheaper than vitrifying it. For example, a few experts stated that it may be costly to disrupt DOE's current plans to vitrify Hanford's LAW and change treatment approaches. However, other experts noted that DOE does not necessarily need to curtail its current approach and that, by grouting supplemental LAW while continuing the direct-feed LAW approach, DOE would not incur costs associated with abandoning its vitrification plans.

While the precise costs of grouting or vitrifying Hanford's LAW are not known, experts who participated in our meeting stated that to inform a risk-based approach to Hanford's tank waste treatment mission, DOE should have reliable cost data for the various LAW treatment options that could be considered at Hanford. Several experts who participated in our

Waste Isolation Pilot Plant: DOE's Disposal of Transuranic Waste

The Waste Isolation Pilot Plant is a waste repository located near Carlsbad, New Mexico, where the Department of Energy (DOE) disposes of defense-related transuranic waste. The term "transuranic" refers to those elements with an atomic number greater than that of uranium, and transuranic waste generally includes radioactive wastes containing more than 100 nanocuries of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years. The site also accepts transuranic mixed waste, which is transuranic waste that also contains hazardous constituents regulated under the Resource Conservation, and Recovery Act and the New Mexico Hazardous Waste Act.

The Waste Isolation Pilot Plant is located in a semiarid climate that was selected because of its deep, thick salt formations; minimal groundwater; low population density; and geological stability. The disposal facility is located about 2,150 feet below the surface in a 2,000-foot-thick salt deposit.

The site began disposing of waste in 1999 and is the only operating U.S. defense nuclear waste repository. However, operations were suspended in February 2014 because of two unrelated underground incidents: (1) a fire on a salt-hauling truck and (2) a radiological release from a waste container that contaminated portions of the underground facility and released a small amount of radiation into the environment above ground. In response to these two events, DOE issued a recovery plan and has undertaken recovery efforts. DOE resumed limited operations at the Waste Isolation Pilot Plant in January 2017.

Sources: DOE and analysis of DOE documents. Image source: DOE. | GAO-17-306

[112]Department of Energy, Office of River Protection, *River Protection Project System Plan Revision 7* (Richland, WA: October 2014). This cost figure is from a budget document and includes escalation.

[113]In November 2014, we reported that DOE spends nearly $500 million each year managing the underground waste storage tanks at Hanford, including monitoring them for leaks and assessing their integrity. See: GAO-15-40.

meeting noted that DOE's estimates for treating LAW are outdated and unreliable. For example, a few experts stated that the cost estimates included in DOE's 2012 EIS are not useful because the data underlying the EIS are out-of-date and have since been revised. Specifically, in December 2016, DOE updated its estimate for constructing just one portion of the WTP and stated that this portion alone will cost about $4.5 billion more than the previous $12.3 billion estimate that was developed in 2006.[114] In addition, some experts stated that DOE's current cost estimates are unreliable and therefore of limited use in making treatment decisions. Another expert stated that DOE's lack of a reliable cost estimate for different treatment options is "unconscionable" and recommended that DOE obtain an independent cost estimate before making additional decisions on treating LAW. According to our *Cost Estimating and Assessment Guide,* when done correctly, an independent cost estimate provides decision makers with additional insight into a program's potential costs—in part, because independent cost estimates frequently use different methods and are less burdened with organizational bias.[115] Moreover, our guide notes that independent cost estimates tend to incorporate risk and, therefore, tend to be more conservative than program offices that develop cost estimates by forecasting high costs. To be of value, however, an independent cost estimate must be performed by entities far removed from the acquiring program office and must also be accepted by management as a valuable risk reduction resource that can be used to minimize unrealistic expectations.

According to Experts, Options Exist That Could Help Reduce Certain Risks

Experts who participated in our meeting stated that DOE should not discontinue its current treatment plan for direct-feed LAW, which involves vitrification. Rather, these experts stated that DOE should consider treating at least some of the supplemental LAW with alternatives, such as grout, which would allow DOE to treat the waste sooner than the currently projected WTP start date of 2036 and with less costly methods, reducing

[114]The cost figures come from a budget estimation document and include escalation.

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

both risks and costs.[116] Numerous experts stated that by considering multiple treatment methods, DOE would have the flexibility to treat different portions of the waste with different treatment methods best suited for the radioactive and hazardous constituents of the waste. These experts described several options that could be used in parallel to treat and dispose of Hanford's supplemental LAW and address the risks associated with leaking tanks sooner:

- **Vitrify LAW in certain tanks.** A few experts noted that certain constituents in LAW might be better candidates for vitrification. For example, a few experts noted that waste containing high concentrations of organics, which one expert said could include about 18 to 20 tanks, may be better treated by vitrification.
- **Grout LAW in certain tanks.** A few experts noted that certain types of waste might be better candidates for grout, particularly a portion of the LAW that contains especially low levels of radioactivity. According to one expert, for example, a grout facility can be constructed faster and is less capital-intensive than a vitrification facility. Another expert noted that grouting is a simple process that can be employed on a relatively small scale. This expert further stated that grout could treat waste that contains elevated concentrations of constituents that can be problematic to immobilize in glass, such as sulfate and halogens, which include fluorine and chlorine.[117] A 2002 DOE report noted that 68 of Hanford's 149 single-shell tanks, were—as part of Hanford's 2002 mission acceleration initiative[118]—considered as candidates for

[116]One expert further stated that the waste treatment facilities at the Hanford Site should be constructed closest to the tanks they are intended to treat, which may help to reduce the fixed costs. Hanford's tank farms are located in two areas, 200 East and 200 West, 4 miles apart. The WTP is located in the 200 East area. According to DOE officials, the transfer line that moves tank waste between the two areas is 7 miles long.

[117]Sulfate may limit the amount of waste that can be loaded into glass, which can increase the amount of glass that must be made. If too much sulfate is present in the waste stream, a layer of molten sulfate can form on the surface of the molten glass during the vitrification process which could damage the melter. Halogens, such as fluorine and chlorine, reduce the amount of waste that can be loaded into the glass. Most of the halogens will not be incorporated in the glass and will instead be emitted from the melter as a gas.

[118]In 2002, DOE began an initiative to accelerate the schedule and reduce the costs of cleaning up HLW at its sites including the Hanford and Savannah River Sites. At Hanford, this plan would have accelerated the site cleanup completion date from 2070 to 2035 and reduced risk. This plan included employing supplemental technologies—such as grout and bulk vitrification—to treat Hanford's LAW, but the plan was never fully implemented. Department of Energy, *Hanford Mission Acceleration Initiative—Draft Preliminary Testing Recommendations for Supplemental Treatment*, PNNL-14005 (Richland, WA: August 2002).

having their waste treated by a supplemental treatment technology, such as grout.[119] Agency officials told us that this waste remains in these 68 tanks.

- **Ship transuranic waste to another facility.** A few experts stated that some tanks could contain transuranic waste and should not be considered HLW.[120] Specifically, according to agency officials, the site has 4 million gallons of waste stored in 11 tanks that may be able to be managed as transuranic waste. A few experts stated that this waste could then be treated in ways that would cost less than vitrification, and if the state of New Mexico allowed it, DOE could send this waste to its Waste Isolation Pilot Plant in New Mexico.[121]
- **Consider alternate disposal sites.** A few experts noted that much of Hanford's LAW could be treated and disposed of at an alternate location. DOE is currently conducting a demonstration project that would grout some of Hanford's LAW and transport it to the Waste Control Specialists' site in Texas for permanent disposal. According to DOE officials, disposal of grouted Hanford LAW at the Waste Control Specialists' site has the potential to save significant costs associated with the construction and operation of an additional vitrification

Waste Control Specialists: Federal and Commercial Entities' Disposal Facility

Waste Control Specialists is a commercial disposal facility in Texas that accepts low-level waste and mixed low-level waste—which is low-level radioactive waste that contains hazardous constituents regulated under the Resource Conservation and Recovery Act—for disposal from federal government generators, such as the Department of Energy. The site also accepts low-level waste from Texas and Vermont commercial waste generators, such as nuclear power plants, hospitals, and research centers. Additionally, Waste Control Specialists accepts low-level commercial waste from generators in 34 other states whose waste has been approved by the Texas Compact Commission for disposal.

According to a Waste Control Specialists official, the site is ideal for radioactive waste disposal because of its remote location, arid environment, and no drinkable groundwater. The site's disposal license with the state of Texas was modified in August 2014 to remove limits on the amount of iodine-129 and technetium-99 that the site can accept.

Waste accepted at the site for disposal must meet applicable waste acceptance criteria, such as limits on the amount of free liquids. According to a Waste Control Specialists official, the site grouts waste containers in modular concrete canisters that weigh over 100,000 pounds. The official noted that the site did not consider vitrifying waste because vitrification is expensive and complex, and grout exceeds federal and state environmental requirements.

Sources: GAO analysis of Waste Control Specialists and Department of Energy documents and interviews. Image source: Waste Control Specialists. | GAO-17-306

[119]In 2003, to accelerate the treatment of Hanford's LAW, DOE decided to proceed with development of bulk vitrification technology—a process similar to the technology planned for the LAW vitrification facility except that in the case of bulk vitrification, the melter serves as the final disposal container. However, DOE did not pursue additional funding for the project for fiscal year 2009 because bulk vitrification was more technologically difficult to develop and costly than previously envisioned. GAO, *Nuclear Waste: Uncertainties and Questions about Costs and Risks Persist with DOE's Tank Waste Cleanup Strategy at Hanford*, GAO-09-913 (Washington, D.C.: Sept. 30, 2009).

[120]The word "transuranic" is used for elements that have atomic numbers greater than that of uranium. The DOE Waste Isolation Pilot Plant near Carlsbad, New Mexico, serves as the only deep geologic repository in the United States for the disposal of defense-related transuranic nuclear waste.

[121]The federal legislation governing the Waste Isolation Pilot Plant bans the disposal of HLW in the repository. Pub. L. No. 102-579, § 12, 106 Stat. 4791 (1992). In addition, according to DOE officials, the Waste Isolation Pilot Plant's permit with the state of New Mexico prohibits the site from taking Hanford's transuranic tank waste. DOE officials told us that they would need to go through a detailed process to modify the Waste Isolation Pilot Plant's permit with New Mexico in order to accept this waste at the site.

facility.[122] According to an estimate conducted by Waste Control Specialists, disposal of Hanford's LAW at the site in Texas could save DOE up to $16.5 billion when compared with the costs of constructing and operating a second vitrification facility for the treatment of supplemental LAW.[123]

Conclusions

Treatment of DOE's tank waste at Hanford is among the world's largest environmental cleanup programs. Because multiple processes were used for plutonium production, Hanford's tank waste contains a more complex mixture of radioactive and hazardous constituents than the tank waste at other DOE sites. Nearly 25 years ago, when DOE chose vitrification as the treatment approach for Hanford's LAW, it did so based on the best available information at that time, which showed that vitrification was better than other methods at encapsulating the radioactive and hazardous waste at Hanford in a way that protects human health and the environment over the long term. Since that time, DOE has experienced significant technical challenges at Hanford, unforeseen when it made the treatment decision, and has spent more than $19 billion on tank management and plant construction without yet treating any waste. Conversely, at its Savannah River Site, DOE has successfully treated about 4 million gallons of LAW with grout at a substantially lower cost than Hanford's estimated costs for vitrification.

As both grout and vitrification technologies matured at DOE sites over the last 25 years, new scientific information on the ability of grout and vitrification to immobilize radioactive and hazardous waste at the Hanford Site has also been developed. This new information, combined with the statements of many experts who participated in our meeting convened by the National Academies, has shed new light on the assumptions about grout performance at Hanford that were used in the early 1990s to inform

[122]The demonstration project would involve removing certain constituents—cesium-137 and strontium-90—and grouting the waste and then transporting it for disposal at the Waste Control Specialists' site in Texas. According to a senior official from Waste Control Specialists, the site is well-suited for LAW disposal because of its deep groundwater; arid climate; and clay soil, which acts like a dense barrier to prevent any waste from reaching the groundwater. A DOE official told us that this option could eliminate the need for supplemental treatment and has the potential to cost significantly less than building and operating a second vitrification facility.

[123]This cost figure includes escalation.

DOE's waste treatment approach for LAW and that were reiterated in DOE's 2012 EIS describing waste treatment options for supplemental LAW. These assumptions no longer appear to be accurate, particularly when considering the engineered and natural barriers at the site that are designed to help ensure long-term safe disposal. The National Research Council has advised DOE to make risk-informed decisions when selecting waste treatment approaches. Because DOE must soon make a decision on how to treat supplemental LAW at Hanford, incorporating current scientific information on the performance of grout would help DOE ensure that it identifies potential treatment approaches that align the costs of treatment and disposal pathways with the relatively low long-term risk of LAW. With more than $250 billion in estimated costs to clean up the nation's former weapons production sites, DOE must seek ways to address risks nation-wide under a limited budget.[124] But until DOE develops information that reflects what is now known about the performance and costs of alternate treatment and disposal methods, such as grout, congressional and agency decision makers will not have access to current scientific and cost information as they decide how to best allocate limited financial resources among many competing needs. Moreover, having updated information on the effectiveness of alternate methods for treating supplemental LAW will help to inform DOE's discussions with the state of Washington. Given the Savannah River Site's experience of saving billions of dollars by grouting its LAW rather than vitrifying it, DOE may have an opportunity to also save costs at Hanford while beginning sooner to remove waste from the aging Hanford tanks. As experts asserted, by taking a hybrid approach to LAW treatment at Hanford, DOE may be able to target different portions of the waste with different treatment methods based on the radioactive and hazardous constituents of the waste, thereby reducing both short-term risks and long-term costs.

While the state of science may suggest alternatives for DOE to consider when selecting a treatment approach for supplemental LAW, DOE may be vulnerable to legal challenge if it attempts to manage Hanford's supplemental LAW as low-level waste. In 2004, Congress specifically authorized the Savannah River and Idaho Sites to manage some of their low-activity tank waste as low-level waste, but this specific authority was not extended to Hanford. Without the specific authority to manage Hanford's supplemental LAW as low-level waste, DOE may face

[124]The cost estimate is in 2016 dollars.

challenges to taking a risk-based approach and treating and disposing of the supplemental LAW as a waste type other than HLW.

Matter for Congressional Consideration

To enhance DOE's ability to make risk-based decisions for the treatment of Hanford supplemental LAW, Congress should consider clarifying, in a manner that does not impair the regulatory authorities of EPA and the state of Washington, DOE's authority at Hanford to determine, in consultation with NRC, whether portions of the supplemental LAW can be managed as a waste type other than HLW.

Recommendations for Executive Action

To help ensure that DOE's treatment of Hanford's supplemental LAW is risk based and cost effective, we are making two recommendations to the Secretary of Energy. In implementing these recommendations, DOE should take into account the results of the analysis required by Section 3134 of the National Defense Authorization Act for Fiscal Year 2017.

1. Develop updated information on the effectiveness of treating and disposing of all the different portions of Hanford's supplemental LAW with alternate methods or at alternate disposal sites, and based on this information, identify potential treatment and disposal pathways for different portions of Hanford's supplemental LAW, considering the risks posed by the LAW.
2. Have an independent entity develop updated information on the lifecycle costs of treating and disposing of Hanford's supplemental LAW with alternate methods or at alternate disposal sites.

Agency Comments and Our Evaluation

We provided a draft of this report to the Department of Energy, Environmental Protection Agency, and Nuclear Regulatory Commission for comment. In its comments, reproduced in appendix V, DOE agreed with our two recommendations. DOE made one substantive comment on our report about our use of the phrase "low-activity waste." We did not make this change because the primary focus of our report is on the low-activity waste stream at Hanford. We specifically alert the reader to the differences in terminology used at each site, and our report recognizes

that there are some differences in the composition of the lower radioactivity waste streams at the Savannah River and Hanford Sites. For consistency and comparative purposes, however, we refer to the low-activity portion of DOE's tank waste at all sites as LAW. We have added an additional footnote at the beginning of our first objective reminding the reader that the Savannah River Site refers to its low-activity waste stream as low-level waste. Following the agency comment period, we slightly modified our recommendations to add further clarity. We also received a written response from NRC, which is reproduced in appendix VI. DOE and NRC both provided technical comments, which we incorporated as appropriate. EPA did not provide comments on the draft report.

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

If you or your staff members have questions about this report, please contact David C. Trimble at (202) 512-3841 or trimbled@gao.gov or Timothy M. Persons at (202) 512-6412 or personst@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Key contributors to this report are listed in appendix VII.

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The Honorable John McCain
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The Honorable Adam Smith
Ranking Member
Committee on Armed Services
House of Representatives

The Honorable Greg Walden
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The Honorable Frank Pallone, Jr.
Ranking Member
Committee on Energy and Commerce
House of Representatives

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Appendix I: Objectives, Scope, and Methodology

The objectives of our review were to examine (1) the Department of Energy's (DOE) reasons for choosing its treatment approaches for low-activity waste (LAW) at the Savannah River and Hanford Sites, (2) the status of DOE's treatment of LAW at these sites, and (3) experts' views on the likely performance of vitrification compared with grout for treating Hanford's LAW.

For the purpose of this review, we focused on the Savannah River and Hanford Sites because these are DOE's two sites with the most radioactive tank waste. The Idaho Site, near Idaho Falls, Idaho, also has some radioactive tank waste. We did not include the Idaho Site in our analysis because DOE currently does not plan to manage the waste at this site as low-level waste. For this reason, we determined that it was not practical to compare the Idaho Site's treatment approach with the Hanford Site or the Savannah River Site.

To inform and provide context for all three objectives, we reviewed numerous reports and technical studies. We first identified reports and studies using sources cited in our prior work, as well as through literature searches (using key words, such as grout, vitrification, low-activity waste, Hanford, and Savannah River Site) of sources including national laboratories; DOE contractors; academic institutions; research journals; and the National Academies of Sciences, Engineering, and Medicine (National Academies). We also obtained reports and documents requested from and provided by DOE, as well as studies suggested by experts who participated in our May 2016 experts' meeting (see below for information on our experts' meeting). We selected studies for further review that were peer reviewed or were from credible sources that were relevant to our focus on the treatment of LAW at the Hanford and Savannah River Sites. We reviewed the studies to gather information about the performance of vitrification and grout, technical challenges facing the Savannah River and Hanford Sites, the costs of treatment, the evolution of decision making on treatment at the two sites, and the advancement of science on vitrification and grout. After reviewing each selected study, we identified and obtained the major sources that were cited in the studies and reviewed the additional studies, as appropriate.

We repeated this process several times until we determined that we had identified the major themes related to the topics listed above. We also used these studies to corroborate information obtained from interviews with DOE officials and from experts who participated in our May 2016 experts' meeting.

To determine DOE's reasons for choosing its treatment approaches for LAW at the Hanford and Savannah River Sites, we reviewed numerous reports and studies addressing DOE's overall plan to retrieve, treat, and dispose of its tank waste at the Hanford and Savannah River Sites. We reviewed documents to understand how DOE's tank waste cleanup strategy has evolved, as well as DOE's environmental impact statements. Because we found that precise information on DOE's estimated costs of treating Hanford's LAW with different treatment approaches is not available, we present the cost estimates from various studies to illustrate the evolution of cost estimates over time, rather than to imply that any of these estimates are precise. To identify the legal and regulatory reasons for DOE's chosen treatment approaches, we reviewed applicable legal and regulatory requirements and guidance documents governing the cleanup of hazardous and radioactive wastes, as well as information on past and pending lawsuits (as cited in our report). We also reviewed documents analyzing DOE's need for supplemental LAW treatment capacity at the Hanford Site and DOE's analysis of potential options for treating LAW. In addition, we interviewed officials from DOE's Office of Environmental Management, as well as DOE officials from the Hanford Site's Office of River Protection and the Savannah River Site. We also visited (1) the Hanford Site, where we observed Hanford's tank farms and waste treatment plant construction site, and (2) the Savannah River Site, where we observed its tank farms, operating high-level waste (HLW) and existing LAW treatment facilities, and the construction site for its future LAW treatment facility. We interviewed officials from other agencies—specifically, the Washington State Department of Ecology, the South Carolina Department of Health and Environmental Control, the Environmental Protection Agency, and the Nuclear Regulatory Commission. We selected these agencies because they play a role in LAW treatment at the Hanford and Savannah River Sites.

To determine the status of LAW treatment at DOE's Savannah River and Hanford Sites, we examined DOE reports and studies, environmental impact statements, budget and financial documents, and other relevant DOE documents. Specifically, we sought information on the amount of LAW that has been and will be treated, the schedule for constructing and operating the LAW treatment facilities, the cost of treating LAW, and

technical challenges, if any. To identify DOE's timeline for treating waste at each site, we reviewed milestones DOE agreed to under its Federal Facility Agreement with South Carolina and the Tri-Party Agreement (TPA) and Consent Decree, as well as modifications made to the milestones since 1989 when the TPA was initially signed. We also asked officials from the Savannah River and Hanford Sites to review our identified schedule milestones for accuracy. To identify technical challenges at each site, we reviewed reports and technical studies prepared by DOE and contractors as well as academic reports. We also interviewed DOE officials and officials at both the Savannah River and Hanford Sites. We identified challenges based on key themes identified across the documents and on whether challenges could affect the sites' costs and/or schedules.

Further, we analyzed available information on the costs of treating Hanford's LAW, such as internal cost estimates and estimates included in DOE's 2012 Environmental Impact Statement. We also reviewed DOE's budget justification documents, Hanford's System Plan, DOE contractor estimates, and project cost and schedule baselines. We asked DOE officials at the Hanford and Savannah River Sites to provide expenditures and planned costs related to the construction and operation of LAW treatment facilities. To the extent possible, we took steps to corroborate estimated costs with available budget documents, DOE reports, and DOE officials, but the estimates we present are based only on available information and rough estimates provided by DOE. Because precise information on the costs of treatment options at Hanford is unavailable, we used the best available information to provide a rough, order-of-magnitude estimate. We adjusted budget numbers for inflation and reported all figures in 2015 dollars, unless otherwise noted. Because some of DOE's estimated costs were approximations, we conducted a sensitivity analysis by examining the cost-per-gallon difference between the Hanford and Savannah River Sites under different scenarios. This helped us assess how, if at all, imprecise information could affect the results of this comparison. For example, we assessed how DOE's costs would change if the estimates provided by DOE officials were incorrect (e.g., if Hanford's vitrification facilities operated for 20 years, rather than its projected 39 years). In this scenario, DOE's costs per gallon to vitrify all of Hanford's LAW would still be more than four times the costs to grout the Savannah River Site's LAW. We believe that the information presented in our report provides an approximate order-of-magnitude comparison and is sufficiently reliable to suggest that DOE's cost to treat Hanford's LAW with vitrification appears to be substantially more than DOE's costs to treat the Savannah River Site's LAW with grout.

To determine experts' views on the likely performance of vitrification compared with that of grout for treating LAW at the Hanford Site, we convened an experts' meeting, as described below. In order to corroborate statements made by the experts on this topic, to the extent possible, we also identified and analyzed technical studies and reports by DOE, contractors, and academic institutions regarding the use of vitrification, grout, and other treatment approaches to treat LAW. During and after the meeting, several experts provided us with information on published studies and information on how other sites treat their radioactive waste. To the extent possible, we collected and analyzed this information on the performance of vitrification compared with other treatment methods.

Selection of Experts

We collaborated with the National Academies to convene a 2-day meeting with 21 experts on the treatment of Hanford's LAW. The meeting was held on May 3 and 4, 2016. We collaborated with staff from the National Academies to select a broad mix of experts from state and federal government agencies, academia, national laboratories, and industry with scientific expertise in nuclear waste treatment, immobilization, or disposal. We also sought experts with knowledge about issues that may help to inform decisions related to treating Hanford's LAW, such as experts with a background in the treatment and disposal of radioactive and hazardous waste as it pertains to economics, risk analysis, and the environment. We sought to obtain a balance of experts with expertise in vitrification (glass) and expertise in grouting (or saltstone or cement). We asked the experts to disclose any potential conflicts of interest, such as any current financial or other interest that might conflict with their service. The 21 experts were determined to be free of conflicts of interest, and the group as a whole was judged to have no inappropriate biases.[1] The views of these experts cannot be generalized to everyone with expertise on LAW or Hanford; they represent only the views of the experts who participated in our meeting hosted by the National Academies. The experts who participated in our study are listed in table 3.

[1]Two of the experts noted that, while they did not have any conflicts of interest, they are periodically involved in work associated with DOE. Both experts told us that they did not believe this work would interfere with their ability to provide an unbiased perspective during our experts' meeting. We evaluated their statements and determined that they did not have any inappropriate biases.

Table 3: Experts Participating in GAO's May 2016 Experts' Meeting

Expert	Affiliation
George Apostolakis	Massachusetts Institute of Technology, Emeritus
John Applegate	Indiana University
Arden L. Bement, Jr.	Purdue University
Craig H. Benson	University of Virginia
Paul Black	Neptune and Company, Inc.
Thomas Brouns	Pacific Northwest National Laboratory
Patricia J. Culligan	Columbia University[a]
David Esh	U.S. Nuclear Regulatory Commission
Fred Glasser	University of Aberdeen
Carol Jantzen	Savannah River National Laboratory
David W. Johnson, Jr.	Journal of the American Ceramic Society
David S. Kosson	Vanderbilt University
Igor Linkov	Army Corps of Engineers
Graham Mitchell	State of Ohio Environmental Protection Agency (retired)
Ian Pegg	Catholic University of America
Eric Pierce	Oak Ridge National Laboratory
James Rispoli	North Carolina State University
Rebecca Robbins	International Atomic Energy Agency
David J. Swanberg	Washington River Protection Solutions[b]
Catherine Veyer	AREVA
Chris Whipple	Environ (retired)

Source: GAO. | GAO-17-306

[a]Patricia Culligan participated via teleconference.

[b]David Swanberg participated via video-teleconference.

Meeting Content

During this meeting, we asked the experts to discuss issues related to the treatment and disposal of LAW and how these issues fit into the risk-informed decision-making process. We designed the meeting to follow the structure of a 2006 National Research Council report addressing the regulation and management of LAW.[2] According to this report, a risk assessment provides a framework for organizing information in a form that is meant to provide input to risk-management decision making. The

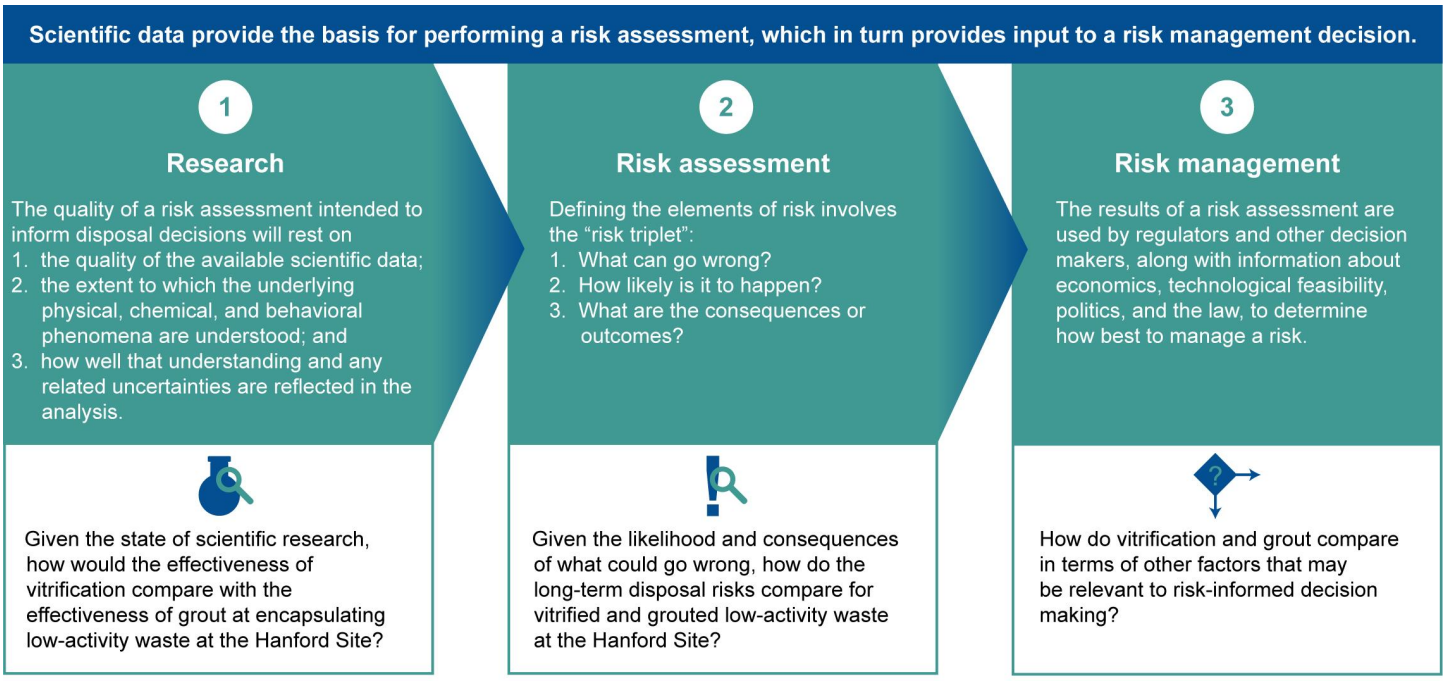
[2]*Improving the Regulation and Management of Low-Activity Radioactive Wastes*.

National Research Council developed a framework for the relationship among scientific information, risk assessments, and risk management; this framework and the basic risk terminology supporting it have served as the basis for environmental health risk assessment, both regulatory and non-regulatory, since the mid-1980s. According to the framework, scientific data provide the basis for performing an environmental risk assessment, which in turn provides input to a risk management decision. The results of a risk assessment are used by regulators and other decision makers, along with information about economics, technological feasibility, politics, and the law, to determine how best to manage a risk.[3]

See figure 3 for a graphic depiction of a risk-informed approach to decision making, as applied to our review of the treatment of Hanford's LAW. Using this framework, we divided the 2-day meeting into four sessions: (1) the state of research on vitrification and grout; (2) the long-term disposal risks associated with vitrification and grout; (3) how other factors—such as economic, technological, and logistical factors—may affect decisions about the treatment of Hanford's LAW; and (4) an open-ended discussion of other issues related to the treatment of Hanford's LAW and topics and themes that arose during the prior three sessions. The experts' meeting focused on the treatment of all of Hanford's LAW because DOE has not yet determined which tanks' waste will be treated by the Waste Treatment and Immobilization Plant (WTP) and which tanks' waste will be treated with a supplemental treatment approach. In addition, the experts did not address issues related to the construction and operation of the WTP.

[3]The National Research Council report notes that the origin of waste is not relevant in determining risk.

Figure 3: A Risk-Informed Approach to Decision Making



Source: GAO analysis of 2006 National Research Council report. | GAO-17-306

The meeting was recorded and transcribed to ensure that we accurately captured the experts' statements. In addition, after each session during the meeting, we summarized the key points and themes that arose during that session and invited the experts to offer any additional themes that they believed should be included. Before and after the experts' meeting, we also conducted targeted interviews with certain experts to ask questions pertaining to the experts' specific areas of expertise or to follow up about specific comments they made during our May 2016 experts' meeting.

Content Analysis

After the meeting, we analyzed the transcripts to characterize the experts' responses and to identify major themes. Specifically, we used a software program for qualitative analysis to assist with coding the comments using categories that we identified based on (1) the overall structure that we established for the experts' meeting and (2) topics highlighted during each session of the experts' meeting. To assess the content of the transcripts, we classified experts' statements into a preliminary set of

categories, and then refined this into a final categorization of themes that included the following.[4]

- **Effectiveness.** We also considered terms related to effectiveness, such as "encapsulate," "retain," "perform," "immobilize, "technetium-99," and "iodine-129."
- **Risks.** We also considered terms related to risks, such as "hazards," "threats," "contaminate," "mitigate," and "likely."
- **Costs.** We also considered terms related to costs, such as "economic," "savings," "comparison," "expensive," "cheap," and "feasible."
- **Benefits of starting or completing treatment sooner.** We also considered related issues, such as the risks or costs of delaying treatment.
- **Regulatory factors.** We also considered comments about the considerations and impacts of regulatory factors on cleanup.
- **Comparisons to other sites.** We also considered comparisons between the sites, such as the Savannah River and Hanford Sites.

To code sensitive and prominent key terms—such as on concepts related to cost—we had three different analysts check the coding. Each analyst reviewed the comments falling under each theme for completeness and level of detail, as well as for areas of potential bias, and made a judgment about appropriate codes that described the themes in the experts' comments. The analysts compared their decisions and reconciled any disagreements regarding appropriate codes by refining the criteria used to categorize the responses. We also conducted a word frequency count of the transcript to identify terms that were most commonly used during our experts' meeting. We reviewed these terms to ensure that our content analysis of the transcript accounted for each of the key terms. We then identified key themes that arose from the experts' meeting by looking for patterns and comparing comments made by different experts.

For reporting purposes, we chose to include experts' comments that (1) captured the essence of a perspective that was raised more than once; (2) provided illuminating detail or illustrative examples; (3) cited specific evidence, such as a specific study or research; (4) were within the core of the commenting expert's base of knowledge; and (5) were well-

[4]In all applicable cases, we used variations of the key word. For example, we considered both "risk" and "risks." As another example, we considered both "hazard" and "hazardous."

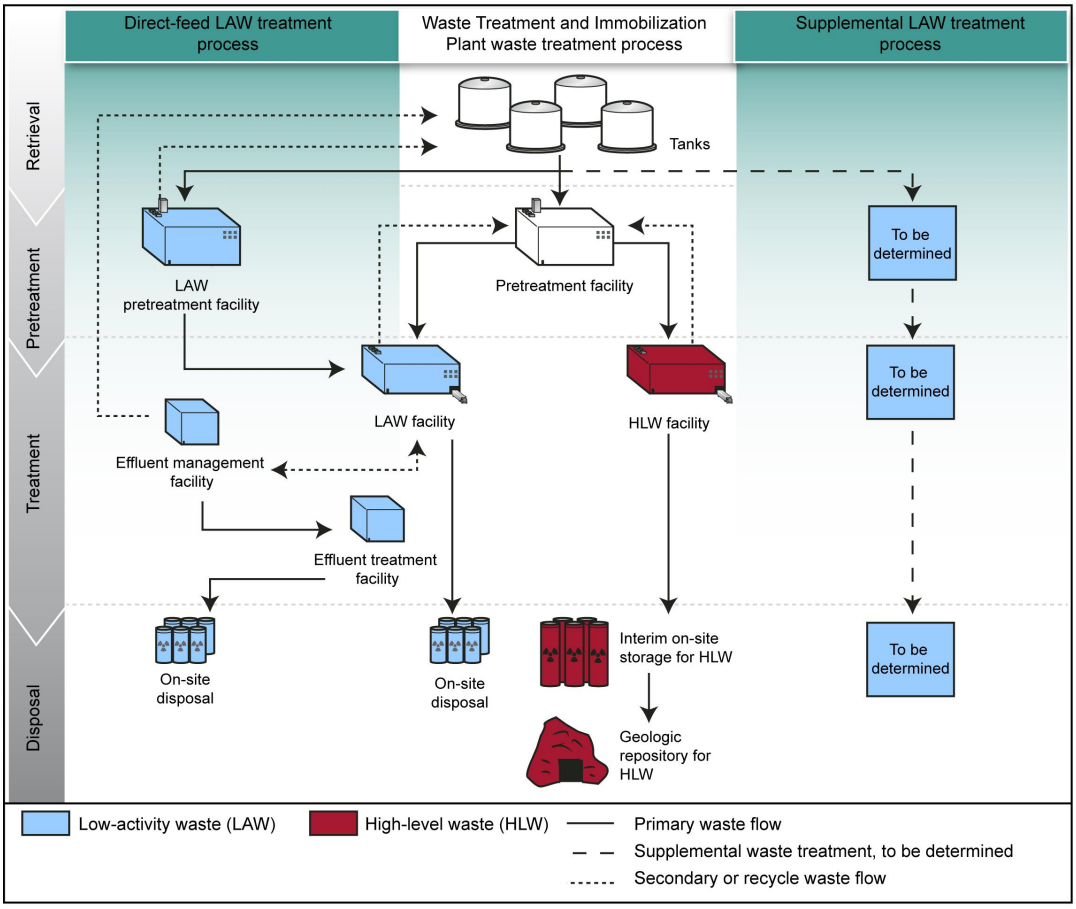
articulated. We also considered the strength of evidence presented by the experts, such as whether they cited any reports to support their views and the level of details included in their statements. For reporting purposes, we cannot include a complete list of themes and comments made by the experts—because, for example, of the technical complexities of this subject and the various ways that each theme could be articulated—but we believe we were able to identify the main themes that emerged from the experts' meeting, note areas of disagreement, and select specific comments to include in our report to serve as illustrative examples of the key themes. To the extent possible, we corroborated experts' statements with technical literature. For reporting purposes, "a few experts" refers to two or three experts, "some experts" refers to four or five experts, "several experts" refers to six to eight experts, and "numerous experts" refers to nine or more experts.[5] The general use of the term "experts" refers to four or more experts and is used to set up a broad concept that the experts discussed. When practical and appropriate, we note where there were dissenting views.

We provided information on the technical benefits and shortcomings of vitrification and grout for treating Hanford's LAW to the experts who participated in our meeting to review for technical accuracy. We incorporated experts' technical comments as appropriate. We also provided a full draft of our report to two experts who participated in our meeting. We selected experts who are members of the National Academies or who were former senior leaders in the federal government. We incorporated their technical comments as appropriate.

We conducted this performance audit from July 2015 to May 2017 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.

[5]Not all experts were able to offer informed views on every topic of the two-day meeting. Therefore, it would be unreasonable to expect all 21 experts to comment on every issue discussed.

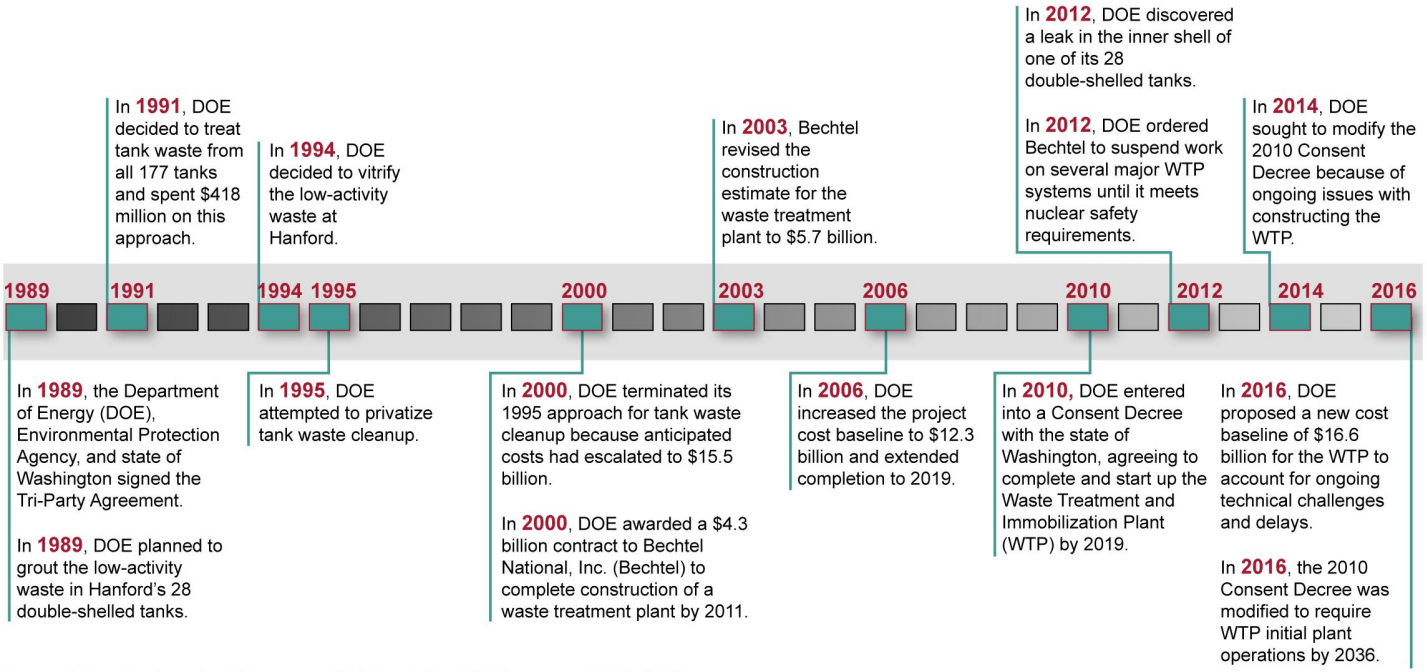
Appendix II: DOE's Current Plans for Treating Low-Activity Waste at the Hanford Site



Source: GAO analysis of Department of Energy information. | GAO-17-306

Notes: LAW comprises about 90 percent of the total volume of tank waste, while HLW comprises the remaining 10 percent. DOE estimates that supplemental treatment will be needed to treat about one-half to two-thirds of the LAW at Hanford. The supplemental LAW treatment path has not yet been defined. DOE could, for example, modify the existing Waste Treatment and Immobilization Plant to accommodate the additional capacity, or DOE could construct a new waste treatment facility.

Appendix III: Timeline of Treatment Plans at the Hanford Site



Sources: Information from prior GAO reports and GAO analysis of DOE documents. | GAO-17-306

Note: The $418 million figure has not been adjusted to 2015 dollars. The cost estimates from 2005 forward are from budget and contract documents and include escalation.

Appendix IV: Experts' Views on the Technical Benefits and Shortcomings of Vitrification and Grout for Treating Hanford's Low-Activity Waste

According to experts who participated in our meeting convened by the National Academies of Sciences, Engineering, and Medicine (National Academies), both vitrification and grout could effectively treat Hanford's low-activity waste (LAW). These experts noted that there are benefits to treating the waste with either vitrification or grout but that both vitrification and grout have some key shortcomings that the Department of Energy (DOE) would need to address. Table 4 provides a summary of the benefits and shortcomings associated with each method, as identified by these experts.

Table 4: Technical Benefits and Shortcomings Associated with Vitrification and Grout at the Hanford Site, According to Experts

	Benefits	Shortcomings
Vitrification	• More research has been done on vitrification than on grout at the Hanford Site. • Organics and nitrates are destroyed during the high-heat vitrification process.	• The vitrification process requires high temperatures, which increases the complexity of the treatment process. • Radioactive constituents—such as technetium-99 and iodine-129—may not be completely retained during the vitrification process. • Certain constituents—such as technetium-99 and iodine-129—will need to be recycled through the vitrification facility or treated with a secondary waste form, which will likely be grout.
Grout	• Grout has been optimized in recent years. • Grout is a "well established" and mature process. • Grout has been used successfully at the Savannah River Site and by commercial disposal sites.	• Grout may face technical challenges related to its ability to retain radioactive constituents—particularly technetium-99 and iodine-129—over long periods of time. • Organics could prevent grout from setting. • Smaller blocks of grouted waste degrade more quickly.

Source: GAO analysis of experts' views. | GAO-17-306

Experts who participated in our meeting discussed the benefits of both vitrification and grout. According to one expert, one reason it may be beneficial to vitrify LAW at Hanford is that much more is known about designing LAW glass formulations than grout formulations for the particular chemical compositions of Hanford's LAW. This expert explained that because DOE chose to vitrify Hanford's LAW in the 1990s, more research has been done on vitrification than on grout at the site.[1] One expert stated that high-level waste (HLW) has been successfully vitrified in other countries, including France and Germany. A few experts also noted that it may be beneficial to vitrify LAW because organics and nitrates are destroyed during the high-heat vitrification process, which means that these chemicals would not be a concern for disposal.

According to a few experts who participated in our meeting, it may be beneficial to grout LAW because there have been significant advances in the use of grout that enable grout to perform much more effectively than it was assumed to perform when DOE made its decision to vitrify Hanford's LAW. One expert stated that grout is a "well established" and mature process. A second expert explained that grout is a less complex process than vitrification. Another expert stated that recent studies have shown that grout performs significantly better than indicated in DOE's 2012 Environmental Impact Statement (EIS).[2] This expert also explained that recent studies on grouted secondary waste—the waste generated during the treatment process—have demonstrated that grout retains waste almost as well as vitrified LAW.[3] Specifically, grout testing has focused on several aspects of its performance, including increasing the amount of waste loaded into the grout and adding materials to increase the retention of technetium and iodine in grouted wastes. A 2015 DOE report stated that grouted LAW has been shown to have acceptable waste form properties, such as its leachability indexes—which measure the mobility

[1]This expert also noted that Hanford's testing of the LAW pilot melters was conducted using four different sized melters. According to this expert, after testing on the largest LAW pilot melter—which operated for nearly 5 years—was completed, the melter was shut down, disassembled, and subjected to extensive testing to validate the melter's design lifetime and performance.

[2]Department of Energy, *DOE Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington*, DOE/EIS 0391 (November 2012).

[3]Specifically, the expert stated that grout has been demonstrated to perform at least two orders of magnitude better than was presented in the 2012 EIS.

of constituents from a waste form—for technetium and iodine.[4] The report further stated that grouted LAW test mix had been shown to meet the treatment standards for land disposal of hazardous waste. Experts also noted that DOE's Savannah River Site has been successfully treating its LAW with grout with few challenges.

According to experts who participated in our meeting, there are some shortcomings associated with vitrification, including process complexity, waste retention, and recycling.

- **Process complexity.** Vitrification is a process by which glass is made at high-temperatures, and experts noted that high temperatures increase the complexity of the treatment process in several ways, including by creating the potential for radionuclide constituents to become volatile.[5] According to a 2011 DOE report, most vitrification issues occur, in part, because of the high operating temperature.[6] According to this report, high operating temperatures can cause equipment failure, but the potential for such failure is low. More specifically, this report states that molten glass is corrosive, and at high enough operating temperatures, the molten glass can corrode internal melter components or breach the melter walls.[7] One expert suggested that DOE may need to acquire a more sophisticated melter to improve reliability and processing versatility. A few experts noted that vitrification uses a complex off-gas system, which captures waste constituents that volatilize during the vitrification process.[8] According to a 2015 DOE report, without mitigating actions, the LAW off-gas

[4]Department of Energy, *Technical Approach for Determining Key Parameters Needed for Modeling the Performance of Cast Stone for the Integrated Disposal Facility Performance Assessment*, PNNL-24022 rev. 0 (Richland, WA: March 2015

[5]Some volatile chemicals may vaporize into gasses at the relatively high temperatures involved in the vitrification process

[6]Department of Energy, Office of River Protection, *A Joule-Heated Melter Technology for the Treatment and Immobilization of Low-Activity Waste,* RPP-48935, rev. 0 (Richland, WA.: March 2011).

[7]Melters are used to produce vitrified waste glass. Waste, in combination with glass forming materials, is heated to high temperatures by passing an electrical current through the melter. The waste and glass forming materials melt, forming a vitrified waste glass product that is poured into containers.

[8]Off-gasses must be treated prior to release to remove radioactive and hazardous components to protect personnel, the public and the environment from radionuclide and chemical exposure. In the off-gas system, some liquid will become part of the secondary liquid waste stream instead of being vitrified.

systems may chronically limit the LAW treatment facility's overall production capacity.[9] In addition, experts noted that DOE may encounter challenges developing precise glass formulations to treat different batches of Hanford's LAW, which has numerous different chemical mixtures in the tanks.[10] One expert noted that, in order to encapsulate waste during the vitrification process, the formulation of the vitrification materials—such as sugar and silica, which is found in sand—must be matched to specific types of chemicals in the waste. If the wrong formulation is used, the glass that immobilizes the waste might not meet the disposal requirements, or the glass might not encapsulate all of certain waste constituents. Moreover, one expert also noted that not all types of waste contained in Hanford's tanks have been demonstrated to be effectively vitrified in the facility as designed. According to the 2015 DOE report on Hanford's LAW vitrification process, if a certain glass-forming component is not added to a batch of waste to be vitrified, it could, over time, lead to the melter failing prematurely.[11] One expert also stated that concerns about the melters failing prematurely apply specifically to Hanford's vitrification process because Hanford uses a different chemistry than the Savannah River Site's HLW vitrification process does.[12]

- **Waste retention.** Experts stated that radioactive constituents, such as technetium-99 and iodine-129, as well as non-radioactive constituents, such as sulfate, may be volatilized at the high temperatures used in the vitrification process, meaning that the glass may not completely retain these constituents. One expert also noted that certain chemicals, such as sulfate, technetium, and iodine, are

[9]Department of Energy, Office of River Protection, *Waste Treatment and Immobilization Plant Low-Activity Waste Facility Design and Operability Review and Recommendations*, 15-WTP-0151 Attachment 2, (Richland, WA: Sept. 4, 2015).

[10]Because of the highly heterogeneous chemical and radiological composition of the Hanford tank waste, DOE will need to vitrify the waste in batches, calibrating the composition of each batch of waste to be vitrified to maximize waste treatment effectiveness. According to the 2012 EIS, Hanford's Best Basis Inventory, which establishes the chemical inventory of the tanks, may have uncertainties of 50 to 400 percent. *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington.*

[11]Department of Energy, Office of River Protection, *Waste Treatment and Immobilization Plant Low-Activity Waste Facility Design and Operability Review and Recommendations*, 15-WTP-0151 Attachment 2, (Richland, WA: Sept. 4, 2015).

[12]According to this expert, Hanford plans to operate a "oxidizing flow sheet," while Savannah River's HLW facility operate a "reducing flow sheet." This expert explained that an oxidizing flow sheet reduces the lifespan of a melter and increase waste volatility.

not well retained in glass.[13] Experts described techniques that can be employed to increase waste retention, such as controlling the waste chemistry or adding a layer of waste plus glass-forming chemicals that float on top of the melter's molten glass (called a cold cap), creating conditions to enhance the mixing of waste. According to one expert, during HLW vitrification and LAW immobilization with grout, the Savannah River Site employs chemistry designed to keep constituents in their least volatile state to more effectively encapsulate waste. This expert stated that Hanford does not plan to use this chemistry to the extent that the Savannah River Site does.[14] In November 2015, the Office of River Protection issued a report describing its glass research program, which aims to develop advanced glass formulations that will increase the amount of waste encapsulated in the glass while meeting waste form performance requirements.[15]

- **Recycling.** Experts noted that certain constituents will not be incorporated into the molten glass by the vitrification process and will need to be recycled through the vitrification facility or treated with a secondary waste form.[16] Experts stated that recycling can increase the amount of certain constituents, such as technetium and iodine, incorporated in the glass.[17] However, according to a 2015 DOE report, recycling technetium also decreases the amount of tank waste that can be immobilized in each glass canister because of increased amounts of chemicals from the recycling process.[18] Those

[13]According to a 2015 DOE report on LAW glass development, the amount of technetium retained in LAW glass can vary depending on factors, such as waste chemistry and how the melter is operated. Department of Energy, *Office of River Protection Advanced Low-Activity Waste Glass Research and Development Plan*, ORP-59500 rev. 0 (Richland, WA: November 2015).

[14]According to the *Office of River Protection Advanced LAW Glass Research and Development Plan*, Hanford is studying controlling the waste chemistry to increase the retention of technetium during vitrification.

[15]*Office of River Protection Advanced Low-Activity Waste Glass Research and Development Plan.*

[16]In order to retain more of certain constituents (such as technetium) in glass, the liquid stream from off-gas treatment may be recycled back through the melter.

[17]For any one pass of waste through the melter, approximately 20 percent to 70 percent of the technetium is expected to be retained by the glass.

[18]*Office of River Protection Advanced Low-Activity Waste Glass Research and Development Plan*.

constituents that are not immobilized are captured by the off-gas system and must be treated with a secondary waste form, such as low-temperature waste forms, including grout, that are being considered or developed for liquid secondary wastes; however, a treatment method has yet to be selected. At the Hanford Site, DOE is working to create glass formulations designed to better retain certain constituents. One expert explained that although recycling is a common practice in chemical processing—and vitrification is a type of chemical processing—recycling reduces the amount of waste that can be loaded into each glass canister, thereby increasing the volume of vitrified waste.

According to experts who participated in our meeting, there are also some shortcomings associated with grout, including ones related to radionuclide retention, organic constituents, and waste form stability.

- **Radionuclide retention.** A few experts noted that grout may face technical challenges related to its ability to retain radioactive constituents—particularly technetium and iodine—over long periods of time. One expert stated that grout is a porous material, meaning that water can enter more easily and leach out the technetium and iodine. In contrast, another expert noted that the grout recently developed for secondary waste has technetium release rates almost equivalent to those of Hanford's LAW glass. According to a third expert, it is possible to retain technetium and iodine in grout by adding in other materials that decrease leaching. Another expert noted that grout improves in its ability to retain constituents after long periods of curing. Other experts suggested that by removing the technetium from LAW, Hanford could create a viable waste form that meets performance requirements. DOE officials from the Savannah River Site and a few experts also stated that the Savannah River Site has been successfully grouting its LAW, which contains both technetium and iodine.[19] According to a January 2016 DOE report, the tank waste at the Savannah River Site has more technetium than Hanford—41,500 curies at the Savannah River Site compared with 26,500

[19]One expert presented a different view, noting that the environment at Hanford is arid, whereas the environment at the Savannah River Site is very humid and wet and is therefore a better location to dispose of treated LAW. The expert further noted that Hanford could face additional challenges because of these environmental differences. As discussed earlier in this report, several experts disagreed with this perspective and stated that Hanford is an optimal location to dispose of LAW, compared with the Savannah River Site, because of its arid climate and low rainfall levels.

curies at Hanford.[20] Moreover, DOE officials from the Savannah River Site noted that initial results of a multi-year study of core samples from one of the Site's vaults—conducted to address uncertainties about grout's long-term performance—show that radiation releases from grout will not exceed those allowed for protection of the public.[21] This study showed that the assumptions for leach rates used in the Savannah River Site's Saltstone Disposal Facility performance model were sufficiently conservative and that the grout will retain the waste for the required period of time.[22]

- **Organic constituents.** Experts stated that organic hazardous constituents could prevent grout from setting, thereby reducing the grout's effectiveness.[23] One expert noted that organics could also interfere with the strength of the grouted product.[24] According to a few experts, waste with high levels of organic constituents could require thermal treatment, such as vitrification. One expert noted that prior to grouting waste that contains organics, the site would need to conduct tests to make sure that the organics did not interfere with the grout-setting process. This expert further noted that some organics in the waste may be present at low enough concentrations that they may be within site limits. According to another expert, grout can be formulated to tolerate organic constituents without affecting its ability to set. According to a 2002 DOE report, approximately 20 percent of the tank

[20]Department of Energy, Office of Environmental Management, *Technetium Management Program Plan* (January 2016).

[21]The Savannah River Site's grout testing is ongoing. According to agency officials, the site has been conducting studies on grouted waste forms for its low-level and low-activity waste since the late 1970s.

[22]The report noted that the grout did not encapsulate iodine-129 as well as had been modeled, but leaching of iodine-129 from grout would not impact the magnitude or timing of the peak dose in the surrounding environment. Department of Energy, *Property Data for Core Samples Extracted from SDU Cell 2A*, SRR-CWDA-2016-00051 rev. 0 (Aiken, SC: April 2016).

[23]Grout is a low-temperature process. It does not destroy organics and nitrates. However, one expert noted that nitrates may accelerate the set of grout without causing any adverse impacts to the final grout product, and another noted that the release of nitrates into the environment can be controlled by facility design.

[24]To meet disposal criteria, grout must achieve a minimum compressive strength. If the grout does not achieve this compressive strength, it may not withstand the disposal facility's overlying deposit of materials.

waste at Hanford contains soluble organic compounds.[25] One expert stated that waste containing these organic constituents is mostly concentrated in two double-shell tanks and that the remaining waste with organic constituents is segregated from other waste that does not contain organic constituents.[26] According to the Savannah River Site's *Liquid Waste System Plan Revision 20,* the site has not yet determined how it will treat the waste in its one tank that contains organic constituents and plans to begin the technology selection process around the 2022 time frame.[27]

- **Waste form stability.** According to one expert, the size of the grouted waste form impacts its performance. Specifically, this expert noted that large blocks of grout retain waste for longer periods of time, whereas smaller blocks of both vitrified and grouted waste forms degrade more quickly. A second expert explained that by increasing the size of the grouted waste form, the grout will degrade more slowly, thereby reducing the rate that constituents are released into the environment. Savannah River Site officials told us they decided to use large units with engineered barriers, called saltstone disposal units, instead of underground trenches because models indicated that nitrate, a hazardous contaminant of concern, may leach into the groundwater from a smaller disposal unit. According to agency officials, the Savannah River Site's saltstone disposal units also serve to prevent precipitation from reaching the grout and leaching iodine, as well as to prevent technetium from leaching. Containerized grout, which is a smaller-sized waste form, was used in Hanford's more recent assessments, such as DOE's 2012 EIS in which containerized grout did not meet requirements, and a 2003 DOE assessment of LAW treatment in which the containerized grout did not meet

[25]Department of Energy, *Recommendation for Supplemental Technologies for Potential Mission Acceleration*, RPP-11261, rev. 0 (Richland, WA: July 26, 2002). According to one expert, 18 to 20 of Hanford's tanks contain 40 percent to 50 percent of Hanford's total organic content.

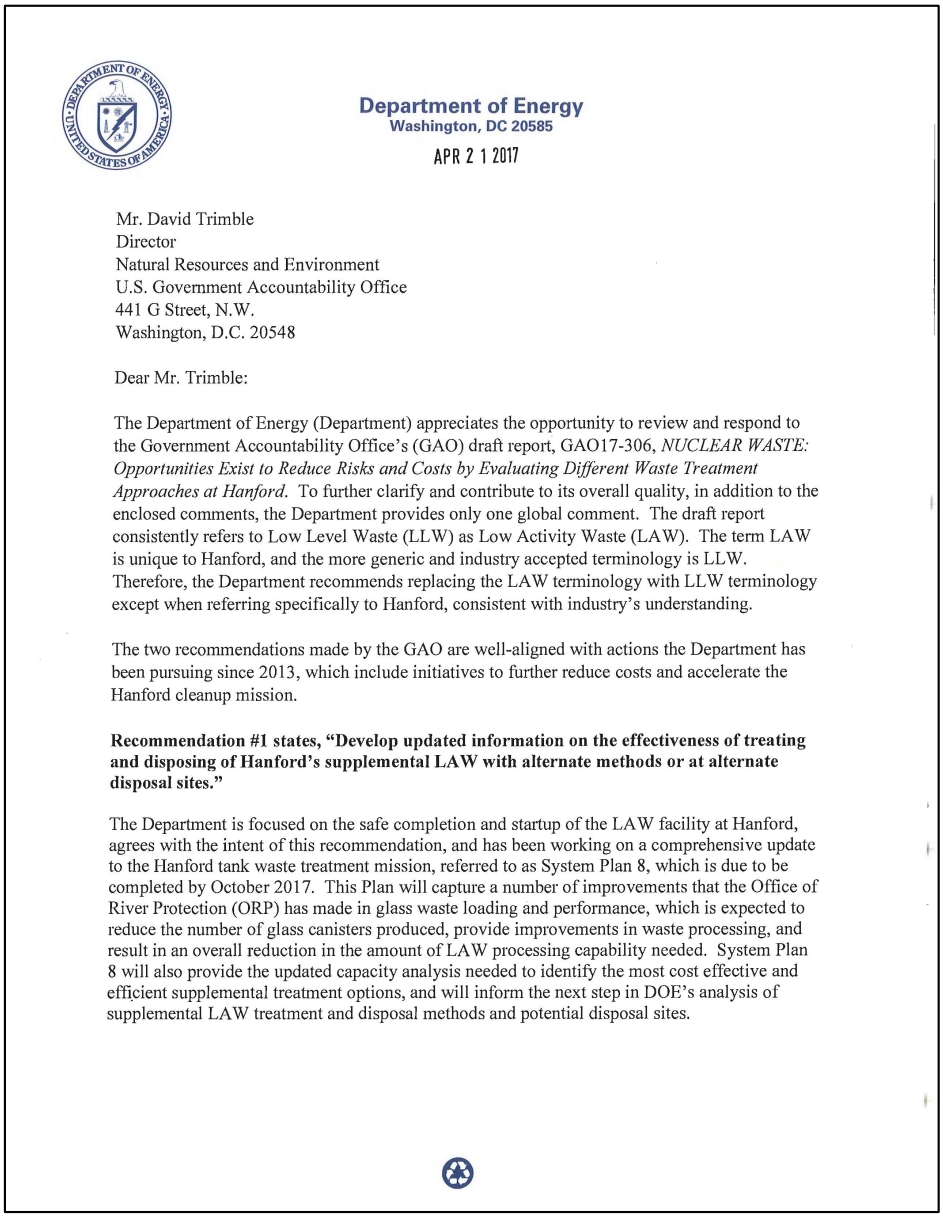
[26]At the Hanford Site, waste contained in single-shell tanks will be transferred to double-shell tanks prior to waste treatment.

[27]Savannah River Remediation LLC, *Liquid Waste System Plan Revision 20*, SRR-LWP-2009-00001 (Aiken, SC: March 2016).

requirements.[28] One expert also noted that containerized grout substantially increases the cost of treatment, compared with large grout disposal units.

[28]*DOE Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland.* Also see, Department of Energy, Office of River Protection, *Assessment of Low-Activity Waste Treatment and Disposal Scenarios for the River Protection Project* (Richland, WA: Apr. 14, 2003). Containerized grout has met requirements at West Valley, which grouted its waste into containers before shipping the grouted containers to the Nevada National Security site. According to an official at the Nevada National Security Site, the grout was determined to meet the site's waste acceptance criteria and was disposed of on site without special instruction.

Appendix V: Comments from the Department of Energy



Department of Energy
Washington, DC 20585

APR 2 1 2017

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

Dear Mr. Trimble:

The Department of Energy (Department) appreciates the opportunity to review and respond to the Government Accountability Office's (GAO) draft report, GAO17-306, *NUCLEAR WASTE: Opportunities Exist to Reduce Risks and Costs by Evaluating Different Waste Treatment Approaches at Hanford.* To further clarify and contribute to its overall quality, in addition to the enclosed comments, the Department provides only one global comment. The draft report consistently refers to Low Level Waste (LLW) as Low Activity Waste (LAW). The term LAW is unique to Hanford, and the more generic and industry accepted terminology is LLW. Therefore, the Department recommends replacing the LAW terminology with LLW terminology except when referring specifically to Hanford, consistent with industry's understanding.

The two recommendations made by the GAO are well-aligned with actions the Department has been pursuing since 2013, which include initiatives to further reduce costs and accelerate the Hanford cleanup mission.

Recommendation #1 states, "Develop updated information on the effectiveness of treating and disposing of Hanford's supplemental LAW with alternate methods or at alternate disposal sites."

The Department is focused on the safe completion and startup of the LAW facility at Hanford, agrees with the intent of this recommendation, and has been working on a comprehensive update to the Hanford tank waste treatment mission, referred to as System Plan 8, which is due to be completed by October 2017. This Plan will capture a number of improvements that the Office of River Protection (ORP) has made in glass waste loading and performance, which is expected to reduce the number of glass canisters produced, provide improvements in waste processing, and result in an overall reduction in the amount of LAW processing capability needed. System Plan 8 will also provide the updated capacity analysis needed to identify the most cost effective and efficient supplemental treatment options, and will inform the next step in DOE's analysis of supplemental LAW treatment and disposal methods and potential disposal sites.

Recommendation #2 states, "Have an independent entity develop updated information on the lifecycle costs of treating and disposing of Hanford's supplemental LAW with alternate methods or at alternate disposal sites."

The Department agrees with the intent of this recommendation, and has already commissioned a team of National Laboratory experts to conduct an independent review of supplemental LAW treatment options, and to have that review independently peer reviewed by the National Academy of Sciences. This review includes a cost benefit analysis for treatment and disposal alternatives.

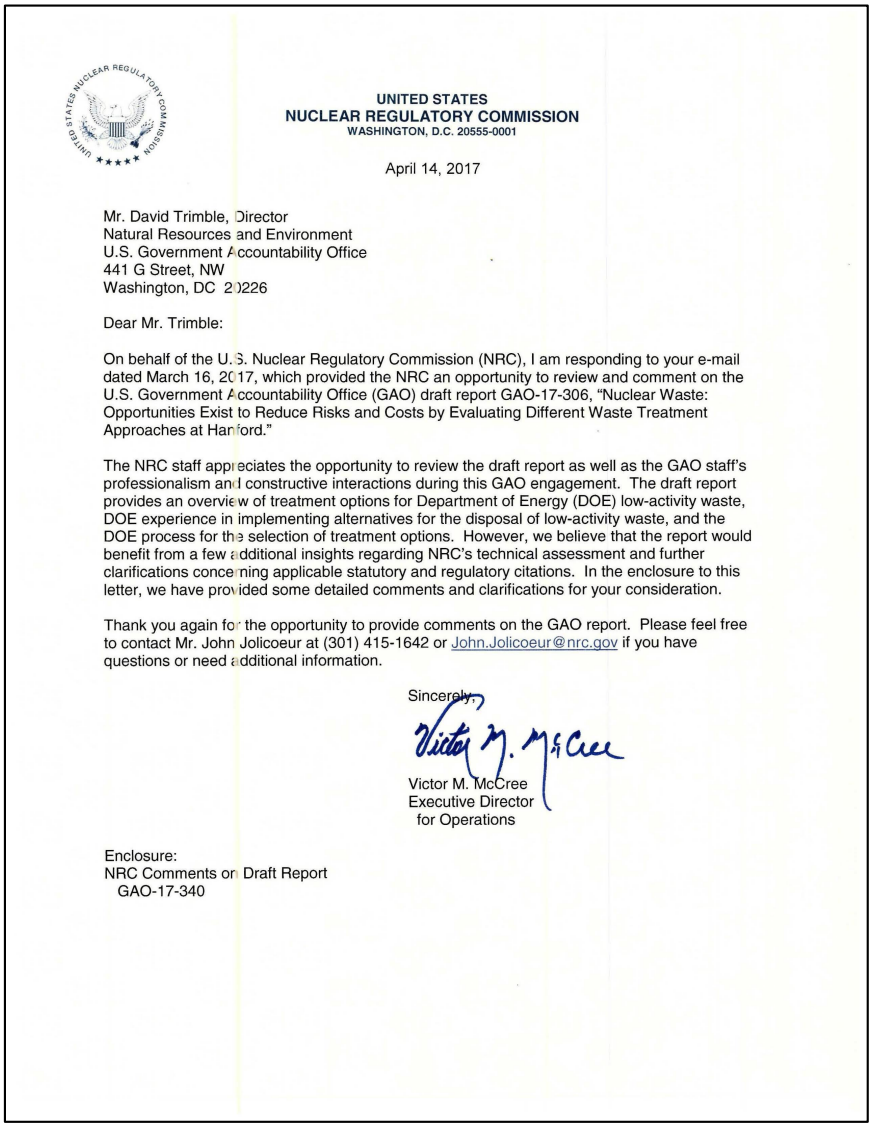
Again, thank you the opportunity to provide additional factual accuracy comments. If you have questions please feel free to contact me or Ms. Stacy Charboneau, Associate Principal Deputy Assistant Secretary, Field Operations, at 202-586-3077.

Sincerely,

Susan M. Cange
Acting Assistant Secretary
for Environmental Management

Enclosure

Appendix VI: Comments from the U.S. Nuclear Regulatory Commission



UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

April 14, 2017

Mr. David Trimble, Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20226

Dear Mr. Trimble:

On behalf of the U.S. Nuclear Regulatory Commission (NRC), I am responding to your e-mail dated March 16, 2017, which provided the NRC an opportunity to review and comment on the U.S. Government Accountability Office (GAO) draft report GAO-17-306, "Nuclear Waste: Opportunities Exist to Reduce Risks and Costs by Evaluating Different Waste Treatment Approaches at Hanford."

The NRC staff appreciates the opportunity to review the draft report as well as the GAO staff's professionalism and constructive interactions during this GAO engagement. The draft report provides an overview of treatment options for Department of Energy (DOE) low-activity waste, DOE experience in implementing alternatives for the disposal of low-activity waste, and the DOE process for the selection of treatment options. However, we believe that the report would benefit from a few additional insights regarding NRC's technical assessment and further clarifications concerning applicable statutory and regulatory citations. In the enclosure to this letter, we have provided some detailed comments and clarifications for your consideration.

Thank you again for the opportunity to provide comments on the GAO report. Please feel free to contact Mr. John Jolicoeur at (301) 415-1642 or John.Jolicoeur@nrc.gov if you have questions or need additional information.

Sincerely,

Victor M. McCree
Executive Director
for Operations

Enclosure:
NRC Comments on Draft Report
GAO-17-340

Appendix VII: GAO Contacts and Staff Acknowledgments

GAO Contacts

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

Timothy M. Persons, (202) 512-6412 or personst@gao.gov

Staff Acknowledgments

In addition to the individuals named above, Nathan Anderson, Assistant Director; Charlotte E. Hinkle; Richard Johnson; Amanda K. Kolling; Jeffrey Larson; and Katrina Pekar-Carpenter made key contributions to this report. Also contributing to this report were Mark Braza, Ellen Fried, Andrew Stavisky, Sara Sullivan, and Jack Wang.

Appendix VIII: Accessible Data

Agency Comment Letters

Accessible Text for Appendix V: Comments from the Department of Energy

Page 1

Department of Energy

Washington, DC 20585

APR 21 2017

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Natural Resources and Environment

U.S. Government Accountability Office

441 G Street, N.W.

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Page 2

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Sincerely,

Susan M. Cange

Acting Assistant Secretary for Environmental Management

Enclosure

Accessible Text for Appendix VI: Comments from the U.S. Nuclear Regulatory Commission

UNITED STATES

NUCLEAR REGULATORY COMMISSION

WASHINGTON, D.C. 20555-0001

April 14, 2017

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Natural Resources and Environment

U.S. Government Accountability Office

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Washington, DC 20226

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Executive Director for Operations

Enclosure:

NRC Comments or Draft Report GA0-17-340

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