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Review of the Analysis of Supplemental Treatment Approaches of Low-Activity Waste at the Hanford Nuclear Reservation

Review #1

Committee on Supplemental Treatment of
Low-Activity Waste at the Hanford Nuclear Reservation

Nuclear and Radiation Studies Board

Division on Earth and Life Studies

A Consensus Study Report of
The National Academies of
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[1]Deceased on March 31, 2018.

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Preface

The scale and complexity of the radioactive and hazardous waste disposal problem at the Hanford Nuclear Reservation is well known. The U.S. Department of Energy's Office of Environmental Management (DOE-EM) has called Hanford the most challenging cleanup task in DOE's nuclear complex.

DOE's current plan for treating the nearly 56 million gallons of radioactive and heterogeneous waste in 177 large tanks is to separate it into two waste streams: a high-level waste (HLW) stream that will have less than 10 percent of the volume but more than 90 percent of the radioactivity and a low-activity waste (LAW) stream that will have more than 90 percent of the volume but less than 10 percent of the radioactivity. Once the under-construction Waste Treatment and Immobilization Plant (WTP) becomes operational, it will vitrify the HLW stream and at least one-third to perhaps one-half of the LAW stream. The excess LAW that still needs to be treated is called supplemental low-activity waste (SLAW). DOE, the Washington State Department of Ecology, and the Environmental Protection Agency—the three parties under the legally binding 1989 Tri-Party Agreement—have yet to agree on the SLAW treatment method.

The use of a technology other than vitrification for *any* LAW is controversial for use at Hanford—though it has been adopted at other DOE-EM sites—and such use is at least initially opposed by the State of Washington, key Tribal Nations, and many Hanford stakeholders. In Section 3134 of the FY 2017 National Defense Authorization Act, Congress directed DOE to contract with a Federally Funded Research and Development Center (FFRDC) to analyze at least three potential technologies for treating the SLAW—vitrification, grouting, and fluidized bed steam reforming—and to report on its findings. It further directed DOE to contract with the National Academies of Sciences, Engineering, and Medicine to undertake a concurrent, independent, peer review of the FFRDC report, not only when the report is complete, but also at certain points during the effort. Congress also expressly required the FFRDC and the National Academies review committee to solicit and consider stakeholder input at every step of the process.

DOE appointed the Savannah River National Laboratory (SRNL) as the FFRDC to lead this study, and then SRNL assembled a team of experts from SRNL and other national laboratories to perform the analysis. The National Academies appointed our committee to conduct the overlapping review. This first committee report begins an iterative exchange between the FFRDC team and the review committee which—together with stakeholder comments—is intended to lead to a report on which DOE can rely in reaching a decision on the management of SLAW.

The FFRDC team has presented its work to our review committee twice, once in an introductory meeting in Washington, DC, and once in a meeting describing the status of the FFRDC's analysis held in Richland, Washington. Our committee is most grateful for the time and effort that went into their presentations, as well as the presentations by other interested government agencies, stakeholders, and members of the public. Between the first and second meetings, as our review indicates, the FFRDC team has made considerable strides in structuring its work and developing its data. We all recognize, however, that much more remains to be done, and that a comprehensive and final committee evaluation must await the comprehensive and final FFRDC team report. We hope that the present review will provide a useful guide to the work that has been completed to date, and additional guidance as it progresses. Our committee will meet three more times in Washington State (the next time in late July), and we look forward to our continued dialogue with the FFRDC team, interested government representatives, Hanford stakeholders, and interested members of the public.

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Finally, we acknowledge with sadness the absence of one of our committee members, Milton Levenson, who died unexpectedly shortly after our second meeting. Milt was the senior member of the committee—he was serving actively at 95—both in age and engagement with the activities that gave rise to the committee's work. Milt, alone among all of those involved in this study, actually participated in the Manhattan Project. While Milt's wartime service did not involve Hanford, he was "present at the creation" in a way than none of us were. This in itself would have commanded our respect, but even more important was his distinguished post-war career with DOE and its predecessors, to say nothing of a post-retirement career of service as a consultant in many settings, very much including the National Academies of Sciences, Engineering, and Medicine. Milt's name and biographical sketch are included with this report because he contributed substantially with many important insights based on his extensive experience. What the biographical sketch cannot convey is the man's vitality and eagerness to share his insights and experience with his colleagues. Milt's passing leaves a gap in our committee that we can only partly fill. We will miss him very much.

John S. Applegate, *Chair*
Allen G. Croff, *Vice Chair*
Committee on Supplemental Treatment of
Low-Activity Waste at the Hanford Nuclear Reservation

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Linda Suttora, DOE-EM

The committee also thanks the presenters and speakers who gave high-quality presentations during the two public meetings as listed in Appendix C. In particular, the committee is pleased to note the several very informative presentations given by the contractors from Washington River Protection Solutions as well as by the team members of the Federally Funded Research and Development Center led by the Savannah River National Laboratory. In addition, the committee is grateful for other submitted public comments, which were useful in helping the committee better understand the public's concerns and views.

The committee is grateful for the outstanding assistance provided by the National Academies of Sciences, Engineering, and Medicine staff in preparing the report. The chair and vice chair are also thankful for the time and energy devoted by the committee members.

REVIEWER ACKNOWLEDGMENTS

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report:

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Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by Michael L. Corradini, University of Wisconsin–Madison, and Robert J. Budnitz, Lawrence Berkeley National Laboratory. They were responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

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Summary

Section 3134 of the National Defense Authorization Act for Fiscal Year 2017 (P.L. 114-328) calls for a Federally Funded Research and Development Center (FFRDC) "to conduct an analysis of approaches for treating the portion of low-activity waste (LAW) at the Hanford Nuclear Reservation" intended for supplemental treatment.[1] The U.S. Department of Energy (DOE) has contracted with Savannah River National Laboratory (SRNL), an FFRDC, to provide the called-for analysis. SRNL then assembled a team of experts from SRNL and other national laboratories to perform the analysis. Section 3134 also calls for the National Academies of Sciences, Engineering, and Medicine (the National Academies) "to conduct a review of the analysis" performed by the FFRDC that is independent of and concurrent with the FFRDC's analysis "to improve [its] quality…." The complete text of the congressional mandate in Section 3134 is provided in Appendix A and the Statement of Task for the National Academies review is provided in Appendix B.

This review report, the first of four to be issued by the National Academies to address the congressional mandate, focuses on study charges 1-3 in the Statement of Task. The committee's comments in this review report are based on about 70 pages of draft working documents made publicly available on February 14, 2018; a set of about 140 slides produced by the FFRDC and presented at the public meeting on February 28-March 1, 2018, in Richland, Washington; and public presentations at that meeting and presentations at the first public meeting on December 12-13, 2017, in Washington, DC.

Crucially, the FFRDC's analysis is at an early stage, and much additional work remains to be done. Accordingly, this review provides the committee's observations about the publicly available work, as of March 1, 2018, and suggestions for the forthcoming analytic report by the FFRDC.[2] The committee's overarching task is to provide a concurrent, independent peer review of the ongoing FFRDC's analysis. The committee is neither charged to analyze the supplemental treatment approaches, nor to recommend any particular approach over another. Equally important, the committee notes what is not in the scope of the FFRDC's analysis and the committee's review, namely, tank waste management, high-level waste (HLW) processing and treatment, and the Waste Treatment and Immobilization Plant's design, construction, and operations. Indeed, the committee understands from the first public presentation by the FFRDC on December 12, 2017, that the FFRDC itself will not identify a preferred option for supplemental treatment, but instead will evaluate the treatment alternatives against the baseline as well as to one another.

RISK ASSESSMENT METHODOLOGIES

The FFRDC plans to use three types of risk assessment techniques in its analysis: probabilistic risk assessment (PRA), semi-quantitative expert elicitation, and qualitative hazards assessment. The committee suggests that the FFRDC specify and explain in its forthcoming report what type of PRA will be used, the parts of the supplemental LAW (SLAW) system to which it will be applied, and the basis for not applying it to other parts of the SLAW system, as well as the basis for selecting the risk analysis techniques applied

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[1]According to DOE, low-activity waste means the waste that remains after as much of the radionuclides as technically and economically practicable have been removed from the tank waste, and that when immobilized in waste forms, may be disposed as low-level waste in a near surface facility. Supplemental treatment refers to processing of the low-activity waste that is excess to that portion to be treated as part of the Waste Treatment and Immobilization Plant (WTP). See Chapter 1 for more details.

[2]Because the FFRDC's analysis is at such an early phase, the committee's review is necessarily preliminary and incomplete. The committee uses the terms *observations* and *suggestions*, rather than the more familiar consensus-study terms *findings* and *recommendations* to recognize the preliminary nature of this review.

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to other parts of this system. It will also be useful for the FFRDC to discuss which risks can be quantified and which can be analyzed using qualitative assessments, e.g., legal and regulatory risks. The FFRDC has stated that it will mostly use expert elicitation to help assess the supplemental treatment options and will have its team members serve as the elicitation's subject matter experts; however, the FFRDC has not fully described how it will carry out this elicitation. The committee also suggests that the FFRDC consider a complete set of risks associated with shipping waste forms off the Hanford Site. See Chapter 2 for additional details.

COST ESTIMATION

The core reference document for the FFRDC's cost-estimation analysis is the latest revision (Revision 8) of the River Protection Project System Plan produced by DOE's Office of River Protection in consultation with the Washington State Department of Ecology (this document is often referred to as System Plan 8). The cost estimation figures based on System Plan 8 are not detailed or precise enough for decision-making. The committee notes that the FFRDC plans to use cost data from analogous treatment facilities at other sites, as well as data from System Plan 8. The committee suggests that the FFRDC team in its forthcoming analysis discuss how order of magnitude (which is significantly uncertain) cost estimates could be useful to decision-makers. See Chapter 2 for additional details.

SCHEDULE ASSESSMENTS

Schedule assessments can involve the examination of timelines for completing tasks such as processing and treatment of SLAW waste streams. The committee suggests that the FFRDC's forthcoming analysis examine the important interrelationships among technical and schedule risks as well as safety and costs. In particular, a better understanding of scheduling risks could include considering an incremental approach that would have the SLAW treatment choice be made after the Waste Treatment and Immobilization Plant (WTP) at Hanford is operational, keeping in mind the WTP's start date, in order to take advantage of the additional knowledge gained from experience with the actual operation of the waste transport, pre-treatment, and treatment technologies and facilities. It is also worth considering performance of a sensitivity analysis of the likely downtimes or failures of essential equipment as well as of the potential for using modular equipment that could be switched out in the event of equipment breakdown. See Chapter 2 for additional details.

REGULATORY COMPLIANCE ASSESSMENT

Significant disagreements about fundamental aspects of the regulatory environment could render any SLAW treatment options highly uncertain. One important uncertainty is departure from the widely assumed use of vitrification for producing glass waste forms unless the alternatives are shown to be "as good as glass," a standard that is widely repeated but not formally adopted or defined by state or federal governments. As to the disposal site, there also appears to be a time-of-compliance disagreement between DOE's Order 435.1, which has a compliance period of 1,000 years, and the Washington State Department of Ecology's assessment, which focuses on the time when the calculated dose will reach its peak—as much as several thousand years after disposal depending on the waste form. Resolution of this disagreement might affect the selection of the final treatment technology. It is unclear whether there are parallel differences concerning the point of compliance.

The committee suggests that the FFRDC's analysis discuss what would be required for the non-vitrified waste forms being assessed to be considered "as good as glass" in the context of the current state of technology for waste forms other than glass from a technical and human health risk perspective. Concerning stakeholders' acceptance of non-vitrified waste forms, the committee recognizes that an additional evaluation of the applicable regulations that would be used to determine legal compliance of alternative

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waste forms would be useful. The committee also suggests that the FFRDC's analysis discuss how consideration of pre-treatment processing alternatives to remove radionuclides such as technetium-99 and iodine-129 could expand on-site and off-site disposal options, taking into account compliance with applicable laws and regulations, and the extent to which various treatment (immobilization) options affect the need for pre-treatment to remove key radionuclides. See Chapter 2 for additional details.

WASTE CONDITIONING AND SUPPLEMENTAL TREATMENT APPROACHES

The FFRDC's draft working documents and presentations discuss the three primary supplemental treatment technologies: vitrification, grouting, and fluidized bed steam reforming. The FFRDC has not identified any other primary SLAW treatment technology, and the committee is not yet aware of any other primary technologies that are sufficiently developed or likely of success to warrant detailed analysis. The committee offers the following observations about these three technologies:

- Vitrification, while a known technology, is still technologically challenging and thus technologically risky, especially when applied to complex and heterogeneous chemical mixtures and to the large scale of waste processing at Hanford, both of which exceed parameters encountered elsewhere.
- The grouting treatment approach would require high-quality constituent materials that could become less available or more expensive at the time when the SLAW treatment plant would become operational (in several years) and during the decades' long duration of operations.
- In the fluidized bed steam reforming process (FBSR), the Integrated Waste Treatment Unit at Idaho National Laboratory may not be a very useful model for steam reforming at Hanford because it has yet to work at scale and has experienced several technical and management problems since 2012, though as the FFRDC notes, experience at some commercial facilities might be applicable. Also, the source of high-quality coal for the coking process in FBSR might pose a supply chain concern.

The committee suggests that the FFRDC include its assessment of the potential problems and technical challenges of each of these treatment technologies as well as the potential barriers to acceptance of any of these technologies and the resulting waste forms for disposal sites under consideration.

The FFRDC's working documents and presentations indicate that there are opportunities for better SLAW treatment performance by making certain upstream flowsheet changes for conditioning (pre-treatment) of SLAW. The committee suggests that it would be useful for the FFRDC to identify promising upstream technologies or processes and use them to perform a sensitivity analysis on their effect on treatment flowsheets. Consideration can be given to removal of particular radionuclides of concern, such as technetium-99, iodine-129, and strontium-90, as well as methods of blending tank wastes. The analysis would benefit by having clear explanations of the reasons for such pre-treatment, for example, to remove certain radionuclides and other hazardous chemicals to meet waste acceptance criteria at certain disposal sites or to produce a releasable effluent. The committee also suggests that the team could usefully consider, at least briefly, whether certain *combinations* of immobilization technologies could confer particular advantages. See Chapter 3 for more details.

KEY INFORMATION AND DATA SOURCES BEING USED

The FFRDC has stated that its analysis will rely substantially on the One System Integrated Flowsheet and System Plan 8. This flowsheet and plan have numerous assumptions and uncertainties. The committee suggests that the FFRDC explicitly identify, discuss, and document the underlying assumptions that could impact its analysis. The committee also suggests that the team, if it has not yet done so, obtains and analyzes credible existing studies and data on long-term waste form performance to inform analysis of the "as good as glass" issue. See Chapter 4 for more details.

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Comments Received from Stakeholders and Interested Members of the Public

The committee appreciates the many informed presentations and comments received from stakeholders and members of the public during its public meetings. A major underlying theme of the comments appears to be safety, especially in safely processing the wastes, protecting the public (including future generations), and protecting the Columbia River and the surrounding environment. Several stakeholder and public commenters noted that, in their view, vitrification is the "agreed-to" treatment option for high-level waste and LAW, and that SLAW treatment should meet the concept of "good as glass," which has been interpreted in different ways. Some commenters stated that the peoples living on the land and fishing the rivers in the Hanford region for several thousand years do not look at timelines in the same way as DOE and emphasized that their priority is safe access to their traditional foods. See Chapter 5 for more details.

General Comments

The committee suggests that the FFRDC's forthcoming analytic report include:

- An accessible organizational structure of the analytic approach that presents clear choices and their consequences to decision-makers, with the recognition that the FFRDC will not select a preferred supplemental treatment option.
- A complete and consistent set of supplemental treatment alternatives specifying clearly whether just the major three supplemental treatment approaches are being assessed or whether there are any variations on these three to consider, including the processing, transportation, and disposal options in each alternative. Likewise, the committee suggests that the FFRDC consider identifying and describing opportunities to improve the performance, cost, and rate of implementation of the alternatives through pre-treatment to disposal, even if some are strictly speaking outside of the scope of the SLAW facility.
- Lines of inquiry to include, among other issues:
  - Safety (including nuclear safety, chemical safety, and physical safety of workers and the public)
  - Technical readiness of each option
  - Waste form performance for each option
  - Secondary wastes and effluents produced for each option
  - Cost of each option
  - Schedule of each option
  - Overall regulatory compliance
- A characterization of uncertainties for each line of inquiry.
- The use of appropriate assessment methodologies implemented using best practices for the comparisons within the lines of inquiry.

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1

Introduction

In 1943, as part of the Manhattan Project, the Hanford Nuclear Reservation was established with the mission to produce plutonium for nuclear weapons. During 45 years of operations, the Hanford Site produced about 67 metric tonnes of plutonium—approximately two-thirds of the nation's stockpile. Production processes generated radioactive and other hazardous wastes and resulted in airborne, surface, subsurface, and groundwater contamination. Presently, 177 underground tanks contain collectively about 210 million liters (about 56 million gallons) of waste. The chemically complex and diverse waste is difficult to manage and dispose of safely because of several factors, including: use of a variety of methods for plutonium extraction from irradiated nuclear fuel, mixing of wastes among tanks from transfers to optimize tank utilization, prior efforts to neutralize or otherwise alter the waste, recovery of cesium-137 and strontium-90, and addition of materials to the tanks from auxiliary processes (Peterson et al., 2018).

PROPOSED TREATMENT PLAN FOR THE HANFORD NUCLEAR RESERVATION'S TANK WASTE

The U.S. Department of Energy's Office of Environmental Management (DOE-EM) is responsible for managing and cleaning up the waste and contamination under a legally binding Tri-Party Agreement (TPA) with the Washington State Department of Ecology and the U.S. Environmental Protection Agency. Over the past three decades, expenditures have been more than $19 billion on several different treatment strategies for the tank waste (GAO, 2017). DOE-EM has estimated that that the waste treatment will require an additional four to five decades at a cost of more than $50 billion.

To process the tank waste for disposal, DOE-EM has been constructing at Hanford the Waste Treatment and Immobilization Plant (WTP). The plan is to retrieve the waste from the tanks to produce two waste streams, high-level waste (HLW) and low-activity waste (LAW), by removing several specific radionuclides that contribute most of the radioactivity. DOE-EM estimates that the HLW will contain more than 90 percent of the radioactivity and less than 10 percent of the volume of the total waste while LAW will consist of less than 10 percent of the radioactivity and more than 90 percent of the volume. The WTP will use vitrification, or immobilization in glass waste forms, to treat both the high- and low-activity fractions of the HLW feed material. The high-activity fraction is slated for disposal in a deep geological repository at a site to be determined. The low-activity waste is intended to be disposed in near-surface facilities, which can include the Integrated Disposal Facility (IDF) at Hanford. The WTP is designed to have the capacity to vitrify at least one-third and perhaps up to one-half of the LAW in tandem with all of the HLW; indeed, concurrent vitrification of this fraction of the LAW is essential to maintaining the throughput of the overall HLW vitrification process.

To treat the remaining portion of the LAW while keeping the HLW treatment on track, DOE-EM wants to increase LAW treatment capacity by building an additional facility for "supplemental treatment." As currently envisioned, the supplemental low-activity waste (SLAW) would be similar in composition to the WTP's LAW stream. DOE-EM has yet to formally select a supplemental treatment approach. While many stakeholders have assumed vitrification will be used, DOE is considering one or more of the following approaches:

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1. Vitrification, to produce glass waste forms, either using Joule-heated melters, which are to be used in the WTP, or bulk vitrification;
2. Grouting, to produce cementitious waste forms; or
3. Fluidized-bed steam reforming, which can produce a calcine powder or a monolithic crystalline ceramic waste form.

Additional treatment approaches might also be identified and considered, although no sufficiently mature or demonstrated technologies have yet been identified. However, to implement the three currently identified approaches, additional waste conditioning (pre-treatment) might be needed, for example, to remove certain radionuclides, or adjust the composition of the waste to make it suitable for treatment.

CONGRESSIONAL MANDATE TO ANALYZE AND REVIEW THE ANALYSIS OF SUPPLEMENTAL TREATMENT APPROACHES

Under the TPA, by April 2015 DOE-EM was to have negotiated with the Washington State Department of Ecology to select a mutually acceptable supplemental treatment approach. To date, these negotiations have been unsuccessful. Consequently, to speed the negotiations, Congress has directed DOE-EM to obtain an analysis of supplemental treatment approaches. This directive is in Section 3134 of the National Defense Authorization Act of Fiscal Year 2017 (Sec. 3134). Sec. 3134 (see Appendix A) requires DOE to contract with a Federally Funded Research and Development Center (FFRDC) to perform this analysis. An FFRDC "is an activity sponsored under a broad charter by a Government agency (or agencies) for purpose of performing, analyzing, integrating, and/or managing basic or applied research and/or development, and that receives 70 percent or more of its financial support from the Government" (FAR 2.101).

In parallel, DOE was directed to contract with the National Academies of Sciences, Engineering, and Medicine (the National Academies) to conduct a concurrent, iterative review of the FFRDC report as it develops, so that the review results can inform and improve the FFRDC's work. DOE contracted with Savannah River National Laboratory (SRNL), an FFRDC, and then SRNL formed a team of experts from SRNL and other national laboratories. The charge to the FFRDC team from Sec. 3134 is shown in Appendix A. The Statement of Task is provided in Appendix B.

STUDY PROCESS

In this first review, the National Academies committee (the committee)[1] discusses its observations of the FFRDC's publicly available work, as of February 28-March 1, 2018, the dates of the public meeting in Richland, Washington, when the FFRDC team presented its progress on its analysis to the committee, as well as to stakeholders and the interested public. Also, the committee received briefings and publicly available presentation slides from the FFRDC team during the first introductory meeting on December 12-13, 2017, in Washington, DC.[2] The webcast videos of these two public meetings are archived and available for viewing.[3] Moreover, the committee has reviewed a set of draft working documents, which in this review report will be called the "FFRDC's draft report," which is dated February 14, 2018, and has been made publicly available.[4] Table 1-1 lists the contents of the draft report; when referencing information in the draft

[1]For clarity, to the extent possible, this review report uses the nomenclature of *team* for the FFRDC's investigators, the *committee* for the National Academies committee, the *draft report* for the FFRDC team's work, and the *review* or *review report* for the committee's work.

[2]For this public meeting's presentations, see http://dels.nas.edu/Past-Events/Meeting-Supplemental-Treatment/DELS-NRSB-17-02/9656.

[3]For the first public meeting's video recording, see https://livestream.com/NASEM/DELS-NRSB; and for the second public meeting's video recording, see http://www.tvworldwide.com/events/nas/180228/.

[4]For the FFRDC's draft report, see http://dels.nas.edu/resources/static-assets/nrsb/miscellaneous/FFRDCTeam-WorkingDraft.pdf.

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report, this review report will refer to the document number and document's page number. Table 1-2 lists the FFRDC's presentations from the second public meeting; when referencing particular presentations, this review report will refer to the presentation number.[5] The FFRDC's draft report and presentations from the second public meeting are the two references of the FFRDC's work being considered by the committee in this review.

During the public meetings, the committee received briefings from several other presenters, as listed in Appendix C. Chapter 5 of this review provides a summary of the views from government agencies, Tribal Nations, other stakeholders, and interested members of the public. These views were expressed during the public meetings by oral presentations and written submissions; in addition, the National Academies have received comments submitted via e-mail and mail, which are available in the Public Access File. Sec. 3134 specifies that "the National Academies of Sciences, Engineering, and Medicine shall provide an opportunity for public comment, with sufficient notice, to inform and improve the quality of the review." Also, Sec. 3134 highlights the necessity of consultation with the State of Washington and an opportunity for it to comment on the FFRDC's draft report and the committee's review of that report. It is planned that the FFRDC's draft report will be completed during the summer and that its final draft report will be completed in the fall of 2018.

TABLE 1-1 List of Draft Working Documents in the FFRDC's Draft Report, Dated February 14, 2018

Document No.	Title
0	Cover letter by FFRDC Team Leader, Bill Bates
1	Description of Baseline Process for LAW Immobilization and Supplemental LAW Immobilization at the Hanford Site
2	NDAA 3134 Supplemental LAW Treatment Alternatives Analysis Approach
3	Approach to Assessment of "Other" Technologies NDAA 3134 Supplemental LAW Treatment
4	Vitrification
5	Grout Treatment for Hanford Supplemental Low-Activity Waste
6	Fluidized Bed Steam Reforming for Hanford Supplemental LAW Treatment
7	Cost Estimate Methodology and Basis Hanford Supplemental Low-Activity Waste Evaluation
8	NDAA Study Scope: Feed to Be Processed Through Supplemental LAW

TABLE 1-2 List of the FFRDC's Presentations, Shown on February 28-March 1, 2018

Presentation No.	Title
1	NDAA 3134 Supplemental Low-Activity Waste FFRDC Team Study Overview
2	WTP Baseline Process and Supplemental LAW Feed Vector Overview
3	NDAA 3134 Supplemental Low-Activity Waste FFRDC Team Study Overview: Vitrification
4	Grout Flowsheets and Waste Forms
5	Fluidized Bed Steam Reforming for Hanford Supplemental LAW—Process Description, Wasteforms, and Preliminary TRL Estimates
6	NDAA 3134 Supplemental Low-Activity Waste FFRDC Approach to "Other Options"
7	Disposal Facilities Overview, Waste Acceptance Criteria, and Transportation
8	NDAA 3134 Supplemental Low-Activity Waste FFRDC Analysis Approach and Methodology
9	Cost Estimating Methodology
10	Summary and Next Steps

[5]For the FFRDC's presentations at the second public meeting, see http://dels.nas.edu/Past-Events/Meeting-Supplemental-Treatment/DELS-NRSB-17-02/9769.

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Table 1-3 shows the current schedule for the FFRDC's work, the committee's review, the public meetings, and the briefings to stakeholders. While this schedule is subject to change, it is designed to allow adequate time for the FFRDC and the committee to do their work in the iterative fashion described in the Statement of Task, and for regulators, stakeholders, and the public to provide comments. The next public meeting at Richland, Washington, is scheduled for July 23-24, 2018.

Importantly, as Sec. 3134 makes clear, the committee's overarching task is to provide a concurrent, independent peer review of the ongoing FFRDC's analysis. The committee is neither charged to analyze the supplemental treatment approaches, nor charged to recommend any particular approach over another. Indeed, the committee understands from the first public presentation by the FFRDC on December 12, 2017, that the FFRDC itself will not identify a preferred option for supplemental treatment, but instead will evaluate the treatment alternatives against the baseline as well as to one another. Equally important, the committee notes what is *not* in the scope of the FFRDC's analysis and the committee's review, namely, tank waste management, HLW processing and treatment, and the WTP's design, construction, and operations.

To perform its peer review task, the committee is composed of 14 experts whose expertise spans the issues relevant for reviewing the FFRDC's analysis, including risk assessments, cost estimation, cost-benefit analysis, waste processing, supplemental treatment approaches, legal and regulatory requirements, and large scale nuclear construction projects. A majority of the members have prior experience in studying cleanup activities at the Hanford Nuclear Reservation, as well as other DOE-EM sites. Appendix D contains relevant biographical information about the committee members' qualifications and experiences. The committee could find it necessary to perform additional fact finding, for example, by receiving briefings from experts outside the FFRDC team about aspects of the supplemental conditioning, treatment, or analysis approaches. This additional fact finding could elucidate issues that have arisen or will arise during the presentations at the public meetings. Any information learned by the committee during additional fact finding will be made available in the study's Public Access File.

The committee appreciates that the FFRDC has been responsive by sending its draft working documents for timely review and has shown significant progress since the first public meeting in mid-December 2017. Because the FFRDC's analysis is at an early stage, much additional work remains to be done, and the FFRDC stated at the second public meeting that it intends to address this work in its forthcoming report.

TABLE 1-3 Planned Schedule of Forthcoming Public Meetings, the FFRDC's Reports, and Committee's Reviews

Timing	Activities
April-June 2018	Committee's first review report is prepared and published. The FFRDC receives this review report to take into account during its continued work on the analysis.
July 2018	The FFRDC sends complete draft analytic report to the committee. Convene public meeting in Richland, Washington; the FFRDC presents its work.
August-September 2018	Committee's second review report is prepared and published. The FFRDC receives this review report to take into account during its work on its final report.
October 2018	The FFRDC sends final analytic report to the committee. Convene public meeting in Richland, Washington; the FFRDC presents its final report.
November-December 2018	Committee's third review report is prepared and published.
January-March 2019	Period for review and comments by stakeholders and the interested public on the FFRDC's final report and committee's review report.
March 2019	Convene public meeting in Richland, Washington, for committee to receive final stakeholders' and public's comments.
April-May 2019	Committee's final review report is prepared and published.
June-July 2019	Final briefings to Congress, DOE, and other stakeholders.

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REVIEW REPORT ORGANIZATION

The remainder of this review report is structured in the order of the charges in the Statement of Task (see Appendix B) as follows:

- Chapter 2 provides the committee's review of the technical quality and completeness of the methods used to conduct the risk, cost-benefit, schedule, and regulatory compliance assessments and their implementation.
- Chapter 3 discusses the committee's review of the waste conditioning and supplemental treatment approaches considered in the FFRDC's draft assessments.
- Chapter 4 describes the committee's review of key information and data used in the FFRDC's draft report and presentations.
- Chapter 5 summarizes comments and input received from stakeholders and interested members of the public as well as the committee's observations of these comments.

The structure of each subsequent chapter is first to summarize key points that the FFRDC has in its draft report and presentations for each topic or charge to the committee. These key points can also consider issues raised by stakeholders and interested members of the public. Second, after these summaries of key points, the committee makes observations about points of clarification and information it anticipates that the FFRDC will provide in the future. Third, the committee provides some suggestions for consideration by the FFRDC to help the FFRDC's analysis. Please note that because the FFRDC's work at this stage is still draft and not yet complete, the committee does not make definitive recommendations. The committee anticipates that such recommendations would follow after it receives the FFRDC's complete draft analysis, expected in July 2018.

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Committee's Review of the FFRDC's Draft Methodologies

The first charge in the committee's Statement of Task (see Appendix B) is to evaluate the technical quality and completeness of the methods used by the Federally Funded Research and Development Center (FFRDC) team to conduct the risk, cost estimation, schedule, and regulatory compliance assessments and their implementation.

RISK ASSESSMENT

Key Points in the FFRDC's Work

In Document 2, the FFRDC describes three risk assessment methods that it is planning to apply to its analysis: probabilistic risk assessment (PRA), semi-quantitative risk assessment, and qualitative hazards analysis. As to PRA, the FFRDC notes the U.S. Nuclear Regulatory Commission's defines its purpose as being "to estimate risk by computing real numbers to determine what can go wrong, how likely is it, and what are its consequences. Thus, PRA provides insights into the strengths and weaknesses of the design and operation of a nuclear power plant" (USNRC, 2018). Document 2, p. 2, mentions that PRA "usually involves a very structured, systematic, and quantitative analysis explicitly accounting for uncertainties through probabilistic methods. In comparison, semi-quantitative methods are intermediate between a fully numerical PRA and a textual, qualitative risk assessment." Semi-quantitative methods "provide a structured approach to ranking risks with numeric scores, frequently using expert input versus mathematical models." The FFRDC describes qualitative hazards assessment methods as producing "non-numerical estimates of risk, and may use a risk matrix to organize levels of impact and likelihood, and prioritize or rank risks for future action."

While the FFRDC states in Document 2, p. 2, that each of these risk assessment methods is being applied in different areas, the FFRDC highlights (Document 2, p. 3) that it will apply, for its main risk assessment method, an expert elicitation technique to perform the semi-quantitative analysis and specifically will use Expert Choice® software[1] to collect the elicitation input and help the team perform its analysis. Also, the FFRDC team members, who are experts from multiple U.S. Department of Energy (DOE) national laboratories, will comprise the subject matter experts needed to carry out the expert elicitation and that a subject matter expert in risk analysis will support the expert elicitation's development and implementation.

In Document 2, pp. 3, 5-6, the FFRDC discusses that it has defined or will use pre-defined lines of inquiry (LOIs), such as safety and waste form performance, in its expert elicitation. Each LOI has criteria associated with it. For example, the LOI for safety includes nuclear safety, chemical safety, accident/hazards analysis, and hazards requiring controls. Each criterion will have a metric from one to five to allow the experts to rank whether a treatment technology has low to high confidence for meeting that criterion.

[1]For the Expert Choice® software's website, see https://expertchoice.com.

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Committee's Observations

The committee notes that Congress has provided guidance about specific risk assessment methods in the congressional conference committee's report on Sec. 3134. That conference report states that an amendment to the act removed the requirement that the FFRDC should use a specific risk assessment approach. But the conferees drew attention to Section 3161 of the National Defense Authorization Act for Fiscal Year 2013, which specifically calls for "probabilistic or quantitative risk assessment if sufficient data exist." The conference report further points out that the Sec. 3134 conferees "expect that, to the extent practicable and appropriate, the analysis shall be conducted using state-of-the-art assessment practices such as probabilistic risk assessment" (Congress, 2016). The committee also notes that DOE published in 2013 a standard on "Development of Probabilistic Risk Assessments for Nuclear Safety Applications"; this publication was based on the standards, guides, and best practices used across a number of industries and was designed to be used to complement qualitative and deterministic methods for developing hazard assessments, hazard controls, and safety management programs (DOE, 2013).

Based on the committee's review of Document 2, it is unclear to the committee how lines of inquiry and associated criteria are determined and defined. Also, the expert elicitation technique and where exactly it will be applied in the analysis are not fully described. During May 1-3, 2018, two committee members and the study director observed the expert elicitation session that used the Analytic Hierarchy Process (Saaty, 2008) for pairwise comparison among criteria and options. Expert Choice® software was used to record these expert assessments and allowed the experts to perform some sensitivity analyses. During the public meeting in July 2018, the observers will give a summary of their observations. The full committee will review the results of this elicitation that the committee anticipates will be described in the forthcoming FFRDC report.

The committee noted some gaps in the draft risk assessment methodology, as described in Document 2 and Presentation 8, as well as Presentation 7, which mentions issues related to transportation of wastes off site. For instance, the committee notes that in the FFRDC's consideration of shipping waste forms outside of Washington State, some additional risks were not explicitly mentioned, in particular, the possibility of transportation accidents would lead to consideration of health risks to populations near the accident sites. In addition, in the transportation routing, several state boundaries would have to be crossed and would introduce programmatic risks (for example, legal or political opposition) into the evaluation.

While tank waste management is not within the scope of the FFRDC's analysis, tank failure is a primary concern given the fact that in recent years DOE had discovered water intrusion in several tanks and leaks from a couple of tanks (GAO, 2014). The committee stresses the likely increased risk of tank failure if there is no or delayed action on waste processing. The longer the treatment process will take, the longer the waste remains in tanks whose useful life expectancy is finite; the 149 single-shell tanks were built between 1943 and 1964 (NRC, 2006a). The committee also notes that this concern could be relevant for the FFRDC's analysis if the throughputs of competing supplemental low-activity waste (SLAW) treatment approaches and the expected lives of the various tanks being sequenced for a particular treatment are significantly different. As to potential changes in throughput, Document 8 discusses the baseline assumptions for feed material to be processed in SLAW treatment:

> Changes in the required throughput of Supplemental LAW could occur if the schedule for completion of LAW immobilization changes from the current assumption of 40 years after the start of HLW process (to allow the LAW mission end to coincide with HLW mission end). It is noted that acceleration of the mission is not simply a matter of building [a] bigger immobilization facility; tank farm operations would need to be scaled similarly to allow retrieval of waste to meet the processing needs of the larger facility. (Document 8, p. 2)

This would appear to indicate that the FFRDC will assume that all treatment alternatives will have the same lifetime (40 years after the start of high-level waste [HLW] treatment) for the purpose of performing its analyses, but it is unclear whether the FFRDC's analysis will consider the benefits of higher throughput

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with respect to the expected lives of the tanks and the impacts on SLAW operations of having to quickly empty an unexpectedly failed tank. The risks of the present configuration of the waste material, including the need to transport the waste a substantial distance from the tanks to the Waste Treatment and Immobilization Plant (WTP), are relevant to DOE's overall management decisions. However, they do not affect the choice among the primary options, except inasmuch as the difference in duration of treatment is relevant to the integrity of the tanks that are past their expected useful life. The committee notes that consideration of *new* tank construction is beyond the scope of this study.

Committee's Suggestions

While the FFRDC has provided useful information about its proposed analytic techniques, the FFRDC has not discussed specifically how and where it will apply PRA techniques. Also in light of congressional interest in application of PRA, to the extent practicable, the committee suggests that the FFRDC discuss in its forthcoming report what type of PRA will be used, the sources of uncertainties in risk assessment data, the parts of the SLAW system to which it will be applied, and the basis for not applying it to other parts of the SLAW system, as well as the basis for selecting the risk analysis techniques applied to other parts of this system and to other risks such as schedule, technology, and cost. It will also be useful for the FFRDC to discuss which risks can be quantified and which can be analyzed using qualitative assessments, e.g., legal and regulatory risks.

The FFRDC has not fully described in detail how it will perform the expert elicitation and on what parts of the SLAW system. While as noted above, the committee had three observers at the May 1-3, 2018, expert elicitation session, the committee still believes that it is useful for the team to give a full description of the elicitation process to be used in its forthcoming report.

As to understanding lines of inquiry, the committee suggests that the forthcoming analytic report discuss more fully how lines of inquiry and associated criteria are determined and defined. It would be useful for the results in the FFRDC analytic report to summarize, compare, and contrast relevant results from previous reports concerning supplemental treatment.

The committee, in addition, suggests that the FFRDC take into consideration the additional health risks and high-level legal issues that could challenge transportation of wastes off-site. While the committee notes that political risks will be an important consideration for DOE, the committee understands that there is little, beyond identifying such risks, that can be done within the FFRDC's scope.

COST ESTIMATION

Key Points in the FFRDC's Work

Document 7 and Presentation 9 outline the FFRDC's preliminary considerations for the estimation of costs. Notably, the FFRDC intends to provide a Class 5 planning estimate, which is useful at the concept screening phase of a project to develop an order-of-magnitude estimate. To make the cost estimates, the FFRDC can draw on expert judgment, expert opinion, and specific analog projects (DOE, 2011a). Document 7, p. 2, notes that such estimates "have the least project definition available (from 0 to 2 percent) and therefore have very wide accuracy ranges. They are the fastest of the five types of estimates to complete, but they are also the least accurate." For its cost estimates, the FFRDC mentions that it will make use of cost data of similar processes and analogous facilities that were designed, developed, and deployed at other sites.

In its draft report and presentations, the FFRDC team states that it is using the One System Integrated Flowsheet (Cree et al., 2017) to estimate feed vectors for the notional supplemental treatment approaches. As to cost estimation, the FFRDC team mentions in Document 1, p. 1, that this flowsheet will be used "to determine the scale of the facilities during cost estimation." The other primary basis of the FFRDC's ongoing analysis is the River Protection Project System Plan's Revision 8, often referred to as "System Plan 8" (ORP, 2017). The foreword to System Plan 8 states that the plan "is a computer modeling exercise, which

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evaluates a set of 11 technical scenarios and provides rough cost and schedule estimates" and is "not intended as a decision document or budget document." But it "will aid discussions with regulators and other stakeholders" (ORP, 2017).

Committee's Observations

While System Plan 8 states that its cost estimation figures are not detailed or precise enough for decision-making, the information in System Plan 8 is still useful for the FFRDC's analysis, even if this would only produce order-of-magnitude estimates. The committee notes that it is too early to conclude that cost estimation cannot be adequately based on the data available to the FFRDC. Also, the committee recognizes that the FFRDC will obtain other useful cost data from similar processes and analogous facilities.

Committee's Suggestions

The committee suggests that the FFRDC team in its forthcoming analysis discuss how order of magnitude (which is significantly uncertain) cost estimates could be useful to decision-makers including analysis of how the quality and uncertainty in the cost estimates affect their usefulness to decision-makers. Also, the committee suggests that the team consider use of DOE's "Cost Estimating Guide" because it provides guidance on methods and procedures that are to be used in programs at DOE for preparing cost estimates (DOE, 2011a).

SCHEDULE ASSESSMENT

Key Points in the FFRDC's Work

On the assessment of the anticipated schedules for supplemental treatment approaches, including the time needed to complete necessary construction and to begin treatment operations, Presentation 8 states that the team will assess the time needed to implement each treatment technology by comparing against the current DOE's Office of Environmental Management baseline liability profile and by evaluating each treatment option's opportunities to improve the schedule. In addition, the team will review previous scheduling estimates for each disposition technology. This presentation specifies two questions the team is considering:

- Can the disposition technology accelerate the baseline schedule?
- How likely is meeting the estimated schedule?

In Presentation 8, the team, in addition, outlines its considerations of technological complexity and process risks. The team mentions that an assessment of technological complexity will include evaluating "the level of difficulty in operating and maintaining required facilities and unit operations for each disposition technology" to include:

- Number and type of unit operations
- Expected life of processing equipment
- Secondary waste generation/disposition
- Packaging operations
- Ability to handle process upsets (such as off-spec products)

The team notes that considerations of process risks will include whether the process would fail to make acceptable immobilized product by having the product out of specification. Another process risk is whether the throughput is met. The presentation also mentions generation of excessive secondary wastes as a process risk.

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Committee's Observations

The schedule for completion of waste treatment is estimated to take at least four to five decades based on System Plan 8. Most of the scenarios for tank waste treatment in System Plan 8—which are driven by initial assumptions defining each scenario—extend to the 2060s, and two scenarios project tank waste treatment to be finished in 2079 and 2081 (ORP, 2017). The committee notes that the issue areas of technological complexity and process risks are not explicitly linked in Presentation 8 to evaluation of scheduling risks. Given the complexities involved in the treatment scenarios and the technical challenges involved in treating 177 tanks filled with approximately 56 million gallons of hazardous and radioactive wastes, the committee observes that assessments of the impact of technological complexity and process risks are useful to more fully understand schedule risks.

Presentation 8 does not include in the schedule risk the potential that some materials and specialized components needed for certain SLAW treatment options could become less available or more expensive. For example, fly ash is proposed to be used for the grouting approach. Although there are many stockpiles of fly ash, a byproduct of coal-fired generation of electricity, not all fly ash is suitable for the grouting approach. Thus high quality fly ash might become scarce if coal-fired plants become less available. To minimize this aspect of scheduling risk, alternative materials such as calcined clay and natural pozzolans can be considered. Early warnings of changes of availability of materials can be obtained by connecting with industry associations such as the Portland Cement Association and the American Coal Ash Association.

The committee also notes the importance of receiving continuous funding at needed levels to meet the planned schedule. It is well known that budgets can have significant impacts on schedule performance. Schedules can be accelerated or delayed depending on the budgetary assumptions and actual receipt of funds to manage a project.

Committee's Suggestions

While the committee views the proposed scheduling evaluation as a good starting point, the committee suggests that the FFRDC's assessments of process risks at unit operation and system level (specifically the interactions among the units), as well as overall technological complexity connect to its assessment of the risks to achieving the SLAW treatment schedule for the various treatment approaches. Given the importance of schedule as a reason for commissioning the FFRDC study and the increasing danger of tank leakage over time, schedule risk must be a central consideration.

The committee notes that additional considerations could result in better estimates of schedule risks, by adequately understanding the interplay between technical and schedule risks. Such considerations could include considering an incremental approach that would have the SLAW choice be made after the WTP is operational, keeping in mind the WTP's start date, and performing a sensitivity analysis of the optimistic assumption of 70 percent availability for the feed material into the SLAW facility. That is, it is worth considering performance of a sensitivity analysis of the likely downtimes or failures of essential equipment as well as of the potential for using modular equipment that could be switched out in the event of equipment breakdown.

While schedules can be accelerated or delayed depending on the budgetary assumptions and actual receipt of funds to manage a project, the FFRDC team should consider whether it would be helpful to acknowledge the existence of such risks and their impacts on its analysis, so that DOE can take them into account in its decision-making.

REGULATORY COMPLIANCE ASSESSMENT

Key Points in the FFRDC's Work

In Presentation 8, the FFRDC notes the draft status of the Integrated Disposal Facility's (IDF's) waste acceptance criteria (WAC) and indicates that the draft criteria are mostly comparable to the WAC at the

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Waste Control Specialists (WCSs) disposal site in Texas. The IDF's draft criteria are based on disposal of vitrified LAW and still being reviewed by DOE as of April 2018. In Presentation 8, the FFRDC mentions that it will conduct a mini-performance assessment to compare alternative waste forms and to assess whether a waste form will meet long-term performance objectives. That assessment will account for differing release mechanisms for various radionuclides from each waste form and the rates of transport to groundwater.

Committee's Observations

The committee observed, during the most recent public meeting, that significant disagreements were expressed about fundamental aspects of the regulatory environment, which could make the feasibility of some alternatives highly uncertain. One important disagreement is that two of the treatment approaches depart from the widely assumed use of vitrification as a waste form. Although the State of Washington appears to accept the HLW-LAW-SLAW waste products as the appropriate regulatory-treatment structure, it does not accept deviation from what it believes is an agreement to use vitrification for SLAW, unless the alternative is "as good as glass." This difference introduces uncertainty into the acceptability and potential timelines for alternatives to vitrification technologies. Although this may not be readily quantifiable by the FFRDC analytic report, the committee notes this issue as well as the consequences (delays, waste disposition elsewhere, etc.) of rejection of an alternative to vitrification technologies.

As to other features that would help with compliance assessments and other analyses of SLAW treatment alternatives and their implementation, the committee notes that the FFRDC has not specified comparable alternatives (starting with the same feed vector, accounting for all effluents and wastes and including pre-treatment) that will be analyzed from the numerous options identified in various parts of their draft report.

Similarly, there appears to be a time-of-compliance disagreement between DOE and the Washington State Department of Ecology. DOE's Order 435.1 concerning waste disposal has a compliance period of 1,000 years while the Washington State Department of Ecology focuses on the time when the calculated dose will reach its peak, which is projected to be several thousand years after waste disposal (Smith, 2018). However, at the recent public meeting, the Washington River Protection Solutions presentation on the performance assessment of the IDF showed graphs with dose estimate calculations to 10,000 years and with a broad peak in calculated doses occurring over several thousand years (Lee, 2018). Resolution of this disagreement might well affect the selection of the final treatment technology.

The committee understands that the results of the FFRDC's performance assessment of the disposal facility could also help with the identification of potential regulatory obstacles that might affect the need for or desirability of SLAW feed processing. Sec. 3134 specifically called for the FFRDC to examine "further processing [conditioning] of the low-activity waste to remove long-lived radioactive constituents, particularly technetium-99 and iodine-129, for immobilization with high-level waste" and to assess compliance with applicable laws and regulations under this and the other treatment options being evaluated. Removal of technetium-99 and iodine-129 could significantly affect the disposal options and even open consideration of other sites for disposal.

Committee's Suggestions

The committee suggests that the FFRDC's analysis discuss whether the non-vitrified waste forms being assessed could be considered "as good as glass," because this standard is a de facto element of the decision-making environment at Hanford. The committee also suggests that the FFRDC's analysis discuss how consideration of processing alternatives to remove technetium-99 and iodine-129 could affect disposal options, taking into account compliance with applicable laws and regulations. In addition, the committee suggests that the FFRDC's analysis discuss differences in requirements concerning time-of-compliance, and the impacts of various assumptions on lines of inquiry such as cost, schedule, and risk.

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Finally, in this chapter, the committee suggests that the FFRDC's analysis report define the flowsheets that would be compared from the waste receipt tank showing the steps of blending, conditioning, treatment, transportation, and disposal. Also, the committee would like to know the material balances for the key radionuclides in each flowsheet.

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3

Committee's Review of the FFRDC's Draft Assessment of Waste Conditioning and Supplemental Treatment Approaches

The committee's second charge in the Statement of Task is to evaluate the technical quality and completeness of waste conditioning and supplemental treatment approaches considered in the Federally Funded Research and Development Center's (FFRDC's) assessments, including any approaches not identified by the U.S. Department of Energy's Office of Environmental Management (DOE-EM).

THREE PRIMARY SUPPLEMENTAL TREATMENT TECHNOLOGIES

Key Points in the FFRDC's Work

In Documents 4, 5, and 6 and Presentations 3, 4, and 5, the FFRDC discusses the three primary supplemental treatment technologies, vitrification, grouting, and fluidized bed steam reforming, and the FFRDC does not identify any other primary supplemental low-activity waste (SLAW) treatment technology.

Vitrification

In Document 4 and Presentation 3, the FFRDC describes two vitrification methods: "traditional" Joule-heated ceramic-lined melter and in-container, or bulk vitrification. (Joule-heating passes an electric current through a mixture of glass forming materials and waste; the internal resistance of these materials results in the electrical energy being dissipated as heat, thereby melting the material to form glass.) The Joule-heating method has two options: one that "mimics" the flowsheet for the immobilized LAW (ILAW) treatment system within the Waste Treatment and Immobilization Plant (WTP) (Document 4, p. 1), and another that uses the ILAW system design but with two next generation melters rather than the four melters planned for the ILAW system. The next generation melters would have increased throughput as compared to the WTP's melters because of larger surface area and thicker refractory liners. The next generation melters would be able to operate at higher temperatures due to the increase in the refractory material's resistance to heat. In addition, the next generation melter system would be expected to use simultaneously both of its pour spouts as compared to the ILAW melters' capacity to only use one pour spout at a time. Thus, the draft flowsheet for this advanced system projects that two next generation melters can meet the production rate of four WTP LAW melters (Document 4, p. 3). For either the current or next-generation melters, it could be possible to increase throughput using improved glass formulation as has occurred in the Savannah River Site's HLW melter during its operating life (e.g., Kruger et al., 2013).

The method of bulk vitrification is also known as in-container vitrification because dried feed material and glass forming chemicals are added to a melt container. Heating is provided through Inconel electrodes that transfer the electrical current through the molten glass pool which is heated through resistance effects.

In Presentation 3, the FFRDC provides its estimates, as of the end of February 2018, for the technology readiness levels (TRLs) for the vitrification options. For all flowsheets, the waste feed system is rated as a *high* TRL because of common commercial equipment that would be used. But the batching and blending systems for the glass forming chemicals are rated as TRL *medium* because they would be more complicated at Hanford's proposed SLAW system than most dry material blending and transfer operations that have

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been demonstrated elsewhere. It is assumed that SLAW vitrification facility construction (if this approach is selected) would begin after LAW vitrification was initiated and would thus likely then have a *high* TRL rating if the LAW vitrification works successfully. As to the next generation melters, the TRL is assessed as *medium* due to the need to incorporate modifications that have yet to be demonstrated. As to in-container vitrification, the TRL is rated as *medium* because it has been demonstrated only in limited testing.

Grouting

Document 5, p. 1, notes that grouting technology has a long track record of transforming radioactive aqueous liquid and sludge waste into solid waste forms, and it has been used to encapsulate radioactive particulate matter and debris. Grouting for radioactive waste treatment can use hydraulic cements or acid-based cements. For details on the cementitious grouts that can be used, see Document 5. The FFRDC notes also that there are several advantages to using grout technology to treat and condition radioactive waste, including relatively inexpensive cementitious materials, low-cost processing at ambient temperatures, multiple demonstrated remote processing options, capability of incorporating slag cement to reduce the mobility of toxic heavy metals, suitability for a wide-range of aqueous compositions, alkaline chemistry to reduce the solubility of many radionuclides, flexible formulations to accommodate various waste feeds, and limited secondary waste volume (Document 5, p. 1).

In Document 5 and Presentation 4, the FFRDC specifically calls attention to some demonstrations and successful applications of grout technology for waste form encapsulation. At the Savannah River Site, since 1991, more than 17 million gallons of liquid decontaminated tank waste (i.e., LAW) have been grouted and disposed in near-surface concrete vaults on site. The grouted material is known locally as Saltstone. At the West Valley Demonstration Project, the supernate tank waste in more than 19,000 square bins holding 71 gallons each were grouted and then shipped to the Nevada National Security Site (NNSS). At the Oak Ridge Reservation, an in situ grouting disposal method was used and aqueous tank low-level waste were also grouted and shipped to NNSS.

Document 5 and Presentation 4 mention that the FFRDC team will consider in its analysis: (1) keeping technetium-99 and iodine-129 in the grouted waste forms, (2) removing these radionuclides, (3) pre-treatment for removal of strontium-90 to lower the transportation costs, (4) pre-treatment for organics in the waste to meet waste classification and treatment standards, and (5) disposal on-site at IDF or off-site at the WCS facility, taking into account the waste acceptance criteria at these facilities.

Fluidized Bed Steam Reforming

Document 6, p. 2, defines fluidized bed steam reforming (FBSR) as a process that uses superheated steam to crack and oxidize organic chemicals in order to generate more free radical chemicals that can accelerate decomposition of hydrocarbons and reactions with other solids and gaseous chemicals. The end products (p. 5) are mineralized waste forms such as nepheline, carnegieite, and sodalite that can incorporate non-volatile and semi-volatile waste chemicals and radionuclides in the mineral structure or inside "cages." Document 6, p. 1, notes that FBSR "has been researched, developed, and used commercially for over two decades for processing low level radioactive wastes." In particular, it notes the experience of the commercial Studsvik Processing Facility that began operations in the late 1990s for treating radioactive wastes in ion-exchange resins, as well as the small-scale testing at Idaho National Laboratory (INL) for treating liquid, highly acidic, radioactive sodium bearing waste. This testing provides the basis for the full-scale Integrated Waste Treatment Unit (IWTU) for treating up to 900,000 gallons of sodium-bearing waste in tanks at INL. Document 6, pp. 1-2, notes that the IWTU is presently in non-radioactive startup operations to be readied for beginning radioactive waste treatment although this is occurring after modification of the facility over a period of years to address operational problems. Presentation 5 mentions that some key components of a potential SLAW treatment system for Hanford have already been demonstrated at the Engineering Scale Test Demonstration Fluidized Bed Steam Reformer at the Hazen Research Inc. facility in Golden, Colorado.

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Presentation 5 outlines two options for potential application of FBSR for SLAW treatment at Hanford. The first option would use two Denitration Mineralizing Reformer (DMR) vessels to create a dry granular solid product. The DMR "contains a bed of particles that are the right size and density to be continually fluidized [circulated within a vessel] by a superheated flow of steam that enters the bottom of the vessel" (Document 5, p. 2). This option would use a 500,000 gallon waste holding tank upstream of the SLAW treatment system, but a ≈1,000,000 gallon additional delay tank plus two 250,000 gallon waste feed/mix tank capacity would be needed for the first approximately three years of SLAW treatment to accommodate the high initial feed rates calculated by the One System Integrated Flowsheet and then the throughput would decrease afterwards. The two identical DMRs would have shared waste staging, mixing, and feed systems. Option 2 would use two DMR systems to produce a solid monolith product to eliminate dust and provide for more compression strength. This option would have the same waste feed, FBSR, off-gas, and product handling systems as in Option 1 and would have two completely identical product monolith systems.

The FFRDC's estimate of the FBSR's TRL is that technology maturation is needed for some operations. Presentation 5 lists some advantages as (1) the use of moderate temperatures and pyrolysis in the DMR to destroy organics and nitrous oxides, (2) production of a durable, mineralized waste form, (3) the capability to retain radionuclides, halogens, and hazardous metals with efficient loading in the waste forms, and (4) no liquid secondary wastes and thus no volume increase. But some disadvantages, which the FFRDC notes might be resolved with applied research and development, are (1) that it is a complex, integrated thermal process, (2) the need for design details specific to Hanford SLAW, and (3) the need for integrated pilot-scale demonstration of that design.

Committee's Observations and Suggestions

The committee understands that the FFRDC has focused on the three primary technologies listed in Sec. 3134 as the technologies to analyze. Based on the FFRDC's draft report and presentations, the committee is not aware of any other primary technologies that are sufficiently developed or likely of success to warrant detailed analysis.

Regarding each of the three primary treatment technologies, the committee suggests that the FFRDC clarify the relationship between the low-medium-high TRL levels used in the FFRDC report to the traditional nine-level TRL scale (DOE, 2011b) and the reason the traditional scale was not used. The committee suggests that the FFRDC give its assessment of the potential problems and technical challenges of each of these treatment technologies as well as the potential barriers to acceptance of any of these technologies and the resulting waste forms for disposal sites under consideration.

In general, the committee notes that the relevant consideration in analyzing the human health risks from various treatment options is the performance of the entire disposal system (natural and engineered components), not just the waste form per se and that leaching measures need to account for containers. The committee offers the following observations concerning each of the three primary technologies.

Vitrification

Vitrification, while a known and successful technology, is still technologically challenging, and thus technologically risky, especially when applied to variable feed mixtures, and at the unprecedented scale envisioned for Hanford. To reckon a sense of the larger scale, consider that the first-of-a-kind LAW melter for Hanford that was assembled last year has a capacity that is five times bigger than the Defense Waste Processing Facility (DWPF) melter at the Savannah River Site (Cary, 2017). Notably, the DWPF at Savannah River has operated successfully since 1996; only two melters have been used so far, the second of which lasted nearly 13 years. Nonetheless, the Hanford LAW melters are significantly larger.

Previous analysis by several researchers at national laboratories has underscored the variability of the LAW at Hanford. "The composition of the LAW will vary from tank to tank because of the variability in types and sources of wastes stored in the individual tanks and the processes used to separate the wastes into

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HLW and LAW fractions" (PNNL and SRNL, 2013). These challenges point to potential benefits of blending of the tank waste. Notably, the FFRDC mentions that "it should be expected that tanks that would challenge the treatment technology would not be selected for individual treatment (i.e., the waste would be blended as needed to meet the specified limits for Supplemental LAW)" (Document 1, p. 10).

Grouting

The grouting treatment approach would require high quality constituent materials. Another consideration is the potential of various chemicals in some parts of the heterogeneous SLAW feed being possible impediments to use of grouting as a treatment method. The committee suggests that the FFRDC evaluate whether this is an impediment. As mentioned previously, some, or even most, of these materials could become less available or more expensive at the time when the SLAW plant would become operational (in several years) and during the decades' long time of operations. For instance, while there are many stockpiles of fly ash, not all fly ash is suitable for use in cementitious systems; some fly ash is incompatible with admixtures; some will cause premature setting; and some is too variable. As a byproduct material, fly ash is subject to quality variations that are beyond the control of DOE. The alternatives to fly ash, slag cement, and other constituents need to be tested. Some potential alternatives are calcined clay and natural pozzolans. Consideration also needs to be given to what happens if a grouting batch fails to set, as well as the effect (if any) of alternatives on the leaching properties of the resulting grout.

Fluidized Bed Steam Reforming

The IWTU at INL may not be a useful model because it has yet to operate successfully and has experienced several technical problems since 2012 (DOE-OIG, 2016; Trevellyan, 2017). The waste treatment challenge at Idaho is much smaller than at Hanford—approximately 900,000 gallons versus 56 million (a greater than 60× scale-up)—and the waste composition at Idaho is more homogeneous and well characterized as compared to Hanford's wastes. The committee also notes that while the FFRDC does mention commercial, large-scale industrial experience in this technology, it would be useful to understand this experience in more depth in order to find out if it is more applicable to Hanford especially in terms of technological maturity and scalability. Also of note is that high-quality coal is used in the FBSR process; thus, there might be a supply chain concern about the source of such coal if likely to come from outside the United States.

IDENTIFICATION AND ANALYSIS OF OTHER PRE-TREATMENT AND TREATMENT TECHNOLOGIES

Key Points in the FFRDC's Work

In Document 3 and Presentation 6, the FFRDC presents a preliminary identification of "other" options for review. Presentation 6, in particular, lists in a table a dozen options; nine of those are conditioning (pretreatment) options and the additional three consist of immobilization options (treatment). In Presentation 6, the FFRDC also states that it will perform a literature review of these other options and that the review will look at the "rationale for the options' earlier disposition (e.g., screened out, or further consideration recommended)." Presentation 8 discusses that the team will assess "subsequent development or evaluation of the technology option (since its previous evaluation)." Moreover, the FFRDC will "evaluate the current relevance of the option to:

- Scope of the study,
- Potential benefits to the supplemental treatment mission, and
- Likelihood that benefits could be realized if pursued."

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Committee's Suggestions

Because it was not clear to the committee whether the FFRDC considers these technologies to be major alternatives to the three major SLAW options, or variations within one or more of these three, the committee suggests that the FFRDC clarify whether there are other major alternatives or a variation of or supplement to one of the major three baseline SLAW approaches. Clarity in this regard will both highlight opportunities to vary the major approaches to optimize operations or output, and assist decision-makers in their assessment of the alternatives provided.

COMMON ISSUES FOR THE SUPPLEMENTAL TREATMENT APPROACHES

Committee's Observations

The committee notes that DOE may find that the development of two treatment approaches, instead of just one, would be useful as a hedge against technological or programmatic risks. For example, if vitrification is chosen as the main approach, it might be useful to develop grouting or another approach on a smaller scale in order to mitigate and diversify risk, because then there would be a backup approach. (The analogy is imperfect, but the Manhattan Project itself followed multi-track approaches to its novel engineering challenges: a two-track approach [uranium-235 and plutonium] for the designs of the weapons, and a three-track approach [thermal diffusion, gaseous diffusion, and electromagnetic separation] for uranium enrichment.) Viable alternatives could be especially important if supplemental LAW becomes a rate-limiting step.

Variability in volume, composition, and timing of the feed vector is a pervasive concern in design, according to the FFRDC's draft report and presentations. Upstream waste blending (which could occur in the SLAW facility, the tank farm, or facilities associated with the WTP) could potentially address the variation and result in a more reliable, more effective production process. The committee understands that much of the uncertainty is traceable to the limited or complete absence of successful experience with the technologies and processes. The SLAW treatment is planned to be connected to other components of the HLW and LAW portions of the WTP, and thus a comprehensive plan is the preferred management approach. Indeed, for this reason, comprehensiveness has been DOE's consistent approach to planning for waste treatment at Hanford. Given the novelty, complexity, and the many and substantial uncertainties surrounding the waste and the treatment technologies, there might be opportunities to stage decisions and construction so as to (a) learn from the results of actual operations (e.g., "direct feed" LAW vitrification), (b) revisit primary technologies if upstream/previous aspects of the project do not operate as expected, or (c) other key variables (e.g., funding or regulatory environment) change fundamentally. This is an adaptive management approach.

Committee's Suggestions

The committee suggests that the team could usefully consider, at least briefly, whether certain *combinations* of primary treatment technologies could confer particular advantages.

FURTHER "UPSTREAM" TECHNOLOGIES

Committee's Observations

In addition to considering variations in the principal SLAW alternatives themselves, consideration can be given to "upstream" opportunities that can optimize these alternatives. Notably, the FFRDC's draft report and presentations identify several opportunities that may improve SLAW treatment or disposal by making certain upstream changes part of the conditioning (pre-treatment) of SLAW. Without expanding

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the FFRDC's scope, the committee believes that it would be useful to identify a limited number of promising upstream technologies or processes and use them to do a sensitivity analysis on the FFRDC report's ultimate findings. Consideration can be given to removal of particular elements of concern, especially technetium and iodine and maybe strontium, and blending of tank wastes. This consideration would benefit from laying out clearly the reasons for such pre-treatment, for example, to remove certain radionuclides and other hazardous chemicals to meet waste acceptance criteria at certain disposal sites.

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4

Committee's Review of the Information and Data Used by the FFRDC

The committee's third charge in the Statement of Task is to evaluate the technical quality and completeness of key information and data used in the Federally Funded Research and Development Center's (FFRDC's) assessments.

KEY POINTS IN THE FFRDC'S WORK

The FFRDC team lists in its draft report and presentations many references and other documents that appear relevant to the analysis of the various supplemental treatment approaches, risks, cost estimation, cost-benefit analysis, and regulatory compliance, among other issues germane to the study. Notably, the FFRDC's draft report and the presentations mention two key documents that form the starting point of their analysis:

> Cree, L.W., J.M. Colby, M.S. Fountain, D.W. Nelson, V.C. Nguyen, K.A. Anderson, M.D. Britton, S. Paudel, and M.E. Stone. 2017. "One System River Protection Project Integrated Flowsheet," RPP-RPT-57991, Rev. 2, 24590-WTP-RPT-MGT-14-023, Washington River Protection Solutions (WRPS) One System, Richland, Washington.

This is often referred to as the One System Integrated Flowsheet. The FFRDC is using spreadsheets and computer modeling simulations based on this WRPS document to calculate feed rates and compositions as a function of time.

> Office of River Protection. 2017. "River Protection Project System Plan," U.S. Department of Energy, Richland, Washington, ORP-11242, Rev. 8, October 2017.

As mentioned previously, this is often referred to as System Plan 8.

COMMITTEE'S OBSERVATIONS

Because the analysis and assessments are in the earliest stages of selection and implementation, it is certain that the FFRDC will need to gather additional data to perform a detailed analysis. In particular, the committee notes that it appears from the listed references in the draft report that the FFRDC might not have collected many references on the previous work done on waste forms. Much of the emphasis of the FFRDC's listed references is on the three treatment technologies—with very limited comments on the resulting waste forms and their performance characteristics. Several such references are listed in the 2011 National Research Council report *Waste Forms Technology and Performance* (NRC, 2011).

As mentioned previously about System Plan 8, while SLAW treatment is included in System Plan 8, this plan is intended to provide the basis for discussion among the parties in the Tri-Party Agreement. Also, System Plan 8 is not intended to be used for decision-making and budgeting purposes, but it can be used to develop rough cost estimates. While the U.S. Department of Energy (DOE) has stated that System Plan 8

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is a planning document, "DOE believes further analysis is needed that focuses on how the assumptions and conditions interact with one another to impact the costs and the hypothetical completion dates of the RPP [River Protection Project] mission" (DOE, 2017).

COMMITTEE'S SUGGESTIONS

The committee encourages the FFRDC to explicitly identify and check the underlying assumptions in the One System Integrated Flowsheet and System Plan 8 that impact its analysis. The committee also suggests that the team, if it has not yet done so, obtains and analyzes credible existing studies and data on long-term waste form performance.

The committee recommends the following documents that address topics relevant to the FFRDC's attention:

National Research Council. 1994. *Building Consensus Through Risk Assessment and Management of the Department of Energy's Environmental Remediation Program*. Washington, DC: National Academy Press.

National Research Council. 2005. *Risk and Decisions About Disposition of Transuranic and High-Level Radioactive Waste.* Washington, DC: The National Academies Press.

National Research Council. 2006b. *Improving the Regulation and Management of Low-Activity Radioactive Wastes*. Washington, DC: The National Academies Press.

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5

Stakeholders' and Public Comments

Sec. 3134 requires that "the National Academies of Sciences, Engineering, and Medicine shall provide an opportunity for public comment, with sufficient notice, to inform and improve the quality of the review." The committee's review has benefited from stakeholders' and public comments received during the public meetings on December 12-13, 2017, in Washington, DC, and on February 28-March 1, 2018, in Richland, Washington, as well as those received via e-mail and mail. All comments are documented and made available in the project's Public Access File.[1] Interested members of the public and stakeholders can communicate their views through e-mail, mail, brief presentations at the public meetings, the project's Web submission form, and social media. Please note that all input received by the committee, including any names and e-mail addresses included in the input, will be made available in the Public Access File for the project and may be quoted in whole or in part in the committee's report(s).

Before the most recent public meeting, outreach to the public and stakeholders was done via Twitter using the hashtag #Hanfordstudy, Eventbrite registration, the Hanford-Info listserv, which reached more than 1,400 contacts, and the Nuclear and Radiation Studies Board's listserv, which reached a few hundred contacts. The National Academies media office also sent notifications to local news media and press about the public meeting. In addition, the study director contacted several key stakeholders via e-mail, including the Washington State Department of Ecology, the Region 10 Office of the Environmental Protection Agency, the State of Oregon Department of Energy, the Hanford Advisory Board, the Hanford Communities, the Tri-Cities Washington Economic Development Council (TRIDEC), and the Tribal Nations in the region. All of these stakeholders, except for some of the Tribal Nations, presented to the committee at the public meeting. The committee recognizes the informative presentation by Matthew Johnson of the Confederated Tribes of the Umatilla Indian Reservation and understands that the Yakama Nation was not able to present due to its leadership's attendance at another event. The committee will reissue invitations to the Yakama and other Tribal Nations to present during the next public meeting on July 23-24, 2018.

Overarching comments by the stakeholders and interested members of the public relating to the cleanup project at the Hanford Nuclear Reservation were:

- The cleanup of the Hanford site should be cost-effective, in compliance, and use best available technologies.
- Our goal is to get the site cleaned up. If a tank fails, this will be costly.
- We have been looking at the tank waste for half a century.
- Moving waste from the tanks must be high priority. This is important to our community. The tanks are deteriorating. We do not have time to lose.
- The health of tribal people and their culture is based on the ability to access and safely use the tribes' traditional foods from the Hanford region.

Some of the comments focused on the Columbia River:

- The Columbia River must be protected.

[1]See http://www8.nationalacademies.org/cp/ManageRequest.aspx?key=49905.

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- While you were here, I hope you had a chance to walk its banks. It is the economic and ecological heart of the region, and the ancestral and modern-day home to tribes.
- This river's importance to our state, our region, our identity is not debatable.
- We want to bicycle along the river and not be contaminated in the process.
- The Columbia River is at risk for generations to come.

Some other comments specifically related to the waste treatment technologies. The concept of "good as glass" was cited repeatedly and ardently by many speakers, although not by all. Other comments included:

- The U.S. Department of Energy (DOE) needs to recognize vitrification as the baseline starting point for treatment of high-level waste (HLW) and low-activity waste (LAW); it is not helpful to act as if we start with a blank slate.
- DOE needs to stop pushing vitrification as a "Cadillac" technology.
- The design of the waste treatment system is inadequate for immense tanks containing highly variable waste that has a composition that is still changing. The tank chemistry is more complex than anybody in this room understands. Textbook chemistry does not apply at Hanford.
- The cited studies of grouting are almost all from more than a decade ago or older.
- We keep hearing that grout technology has improved. We have not seen the research and credible scientific evidence verified in the real world.
- Immobilized LAW decisions need to be evaluated against the background of existing contamination.
- Previously disposed legacy waste has already impacted groundwater and will continue to contribute to the overall site risk burden.
- A commenter representing a European technology firm (Knauf Insulation) stated that this company has developed and demonstrated a new melting technology that represents a very flexible and efficient option for stabilization of wastes and that the technology is capable of vitrification for LAWs. He requested that this melting technology be evaluated with respect to treating LAWs.

Finally, some comments opened up potential new lines of inquiry:

- Some commenters were not as concerned about the form of the waste if it could meet disposal criteria at sites outside Washington State and thus be shipped elsewhere.
- Investigate where DOE is unnecessarily following regulations that are not really relevant. DOE might be implementing complex and costly immobilization technologies based on definitions, not on actual chemical and/or physical properties of the wastes.
- Investigate processes to remove technetium. The technology is here today to scavenge the technetium.
- Investigate the cost of removing technetium and iodine versus the cost of grout and/or vitrification.
- There is an apt opportunity to modify or elaborate the current definition of HLW, which has driven the whole treatment plan by classifying essentially all tank waste as HLW.
- As to further waste reclassification, 137 of the tanks would likely contain transuranic (TRU) waste.
- Investigate cold processes. At a thermal facility, accidents are possible. Cold processes are much safer to workers and to the public.

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COMMITTEE'S OBSERVATIONS

The committee appreciates the many informed presentations and public comments received from stakeholders and members of the public during its public meetings. A major underlying theme of the comments appears to be safety, especially in safely processing the wastes, protecting people (including future generations), and protecting the Columbia River and the surrounding environment. The Hanford region has sophisticated and engaged state regulators, Tribal Nations, and other stakeholder groups. The views and preferences of all of these groups will unavoidably be a significant element, in formal legal terms and political acceptance, of the selection of supplemental treatment of low-activity waste. For example, several, but not all, stakeholders have underscored their view that vitrification is their preferred waste treatment approach and that any other waste treatment method needs to produce waste forms as "good as glass." In addition, peoples who have been living on the land and fishing the rivers in the Hanford region for several thousand years do not look at timelines in the same way as DOE. People from these cultures have emphasized that a priority for them is safe access to their traditional foods.

In the upcoming public meetings, the committee would like to learn more about the basis for the disparate claims on grouting technology, as well as about the basis of the views on "good as glass." The committee notes Box 8.1 in the 2011 National Research Council report *Waste Forms Technology and Performance*, which discusses some possible approaches to "demonstrate that an alternative waste form is as good as glass." Concerning stakeholders' acceptance of non-vitrified waste forms, the committee recognizes that an additional evaluation of the applicable regulations that would accept legal compliance would be useful. Also, in a subsequent report, the committee will review the Federally Funded Research and Development Center's (FFRDC's) analysis of the other options that it has identified as well as new options as they arise, e.g., the potential use of water cleanup technologies applied at Fukushima Daiichi and the Knauf concept. In closing the committee reminds readers that Section 3134 of the FY2017 National Defense Authorization Act (see Appendix A) requires the FFRDC to perform a cross-technology evaluation to include vitrification, grouting, fluidized bed steam reforming, and any other treatment technologies that DOE or the FFRDC will identify.

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Appendix A

Section 3134 of the Fiscal Year 2017 National Defense Authorization Act

SEC. 3134. ANALYSIS OF APPROACHES FOR SUPPLEMENTAL TREATMENT OF LOW-ACTIVITY WASTE AT HANFORD NUCLEAR RESERVATION.

(a) IN GENERAL.—Not later than 60 days after the date of the enactment of this Act, the Secretary of Energy shall enter into an arrangement with a federally funded research and development center to conduct an analysis of approaches for treating the portion of low-activity waste at the Hanford Nuclear Reservation, Richland, Washington, that, as of such date of enactment, is intended for supplemental treatment.

(b) ELEMENTS.—The analysis required by subsection (a) shall include the following:

(1) An analysis of, at a minimum, the following approaches for treating the low-activity waste described in subsection (a):

(A) Further processing of the low-activity waste to remove long-lived radioactive constituents, particularly technetium-99 and iodine-129, for immobilization with high level waste.

(B) Vitrification, grouting, and steam reforming, and other alternative approaches identified by the Department of Energy for immobilizing the low-activity waste.

(2) An analysis of the following:

(A) The risks of the approaches described in paragraph (1) relating to treatment and final disposition.

(B) The benefits and costs of such approaches.

(C) Anticipated schedules for such approaches, including the time needed to complete necessary construction and to begin treatment operations.

(D) The compliance of such approaches with applicable technical standards associated with and contained in regulations prescribed pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (42 U.S.C. 9601 et seq.), the Solid Waste Disposal Act (42 U.S.C. 6901 et seq.) (commonly referred to as the "Resource Conservation and Recovery Act of 1976"), the Federal Water Pollution Control Act (33 U.S.C. 1251 et seq.) (commonly referred to as the "Clean Water Act"), and the Clean Air Act (42 U.S.C. 7401 et seq.).

(E) Any obstacles that would inhibit the ability of the Department of Energy to pursue such approaches.

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(c) REVIEW OF ANALYSIS.—

(1) IN GENERAL.—Concurrent with entering into an arrangement with a federally funded research and development center under subsection (a), the Secretary shall enter into an arrangement with the National Academies of Sciences, Engineering, and Medicine to conduct a review of the analysis conducted by the federally funded research and development center.

(2) METHOD OF REVIEW.—The review required by paragraph (1) shall be conducted concurrent with the analysis required by subsection (a), and in a manner that is parallel to that analysis, so that the results of the review may be used to improve the quality of the analysis.

(3) PUBLIC REVIEW.—In conducting the review required paragraph (1), the National Academies of Sciences, Engineering, and Medicine shall provide an opportunity for public comment, with sufficient notice, to inform and improve the quality of the review.

(d) CONSULTATION WITH STATE.—Prior to the submission in accordance with subsection (e)(2) of the analysis required by subsection (a) and the review of the analysis required by subsection (c), the federally funded research and development center and the National Academies of Sciences, Engineering, and Medicine shall provide to the State of Washington—

(1) the analysis and review in draft form; and

(2) an opportunity to comment on the analysis and review for a period of not less than 60 days.

(e) SUBMISSION TO CONGRESS.—

(1) BRIEFINGS ON PROGRESS.—Not later than 180 days after the date of the enactment of this Act, and every 180 days thereafter until the materials described in paragraph (2) are submitted in accordance with that paragraph, the Secretary shall provide to the congressional defense committees a briefing on the progress being made on the analysis required by subsection (a) and the review of the analysis required by subsection (c).

(2) COMPLETED ANALYSIS AND REVIEW.—Not later than two years after the date of the enactment of this Act, the Secretary shall submit to the congressional defense committees the analysis required by subsection (a), the review of the analysis required by subsection (c), any comments of the State of Washington under subsection (d)(2), and any comments of the Secretary on the analysis or the review of the analysis.

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Appendix B

Statement of Task

The National Academies of Sciences, Engineering, and Medicine will review the analysis carried out by the U.S. Department of Energy's Office of Environmental Management (DOE-EM)-selected Federally Funded Research and Development Center (FFRDC) on approaches for supplemental treatment of low-activity waste at the Hanford Nuclear Reservation. The review will evaluate the technical quality and completeness of the following:

1. Methods used to conduct the risk, cost-benefit, schedule, and regulatory compliance assessments and their implementation;
2. Waste conditioning and supplemental treatment approaches considered in the assessments, including any approaches not identified by DOE-EM;
3. Other key information and data used in the assessments; and
4. Results of the assessments, including the formulation and presentation of conclusions and the characterization and treatment of uncertainties.

The review will be carried out concurrently with the FFRDC's analysis with opportunities for input from the Washington State Department of Ecology, other principal Hanford stakeholders, and members of the public. The study will produce up to four review reports with findings and recommendations. The first report will focus on study charges 1-3; the second report will focus on study charge 4; the third report will provide the committee's overall assessment; and the fourth report will provide a summary of public comments on the third committee report and the committee's views, if any, on these comments and whether they change any of the findings or recommendations in that report.

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Appendix C

Presentations at the Committee's Information-Gathering Meetings

Public Meeting #1: Washington, DC, December 12-13, 2017

Invited Presentations

- *Congressional Perspectives on the Tasking*, Jonathan Epstein, professional staff member, Senate Committee on Armed Services
- *Overview of the U.S. Department of Energy's Environmental Management (DOE-EM) Program and Perspective on the Committee's Tasking*, Betsy Connell, Director, EM Regulatory, Intergovernmental, and Stakeholder Affairs
- *DOE's Office of River Protection (DOE-ORP): Program Scope and Status*, Delmar Noyes, Assistant Manager Waste Immobilization and Treatment Plant Start-Up, Commissioning, and Integration, DOE-ORP
- *Presentations by members of the Federally Funded Research and Development Center (FFRDC) Team, led by the Savannah River National Laboratory (SRNL)*, Bill Bates, project leader, SRNL, with Michael Stone, SRNL, and Thomas Brouns, Pacific Northwest National Laboratory
- *Perspective Regarding Congressional Interests About Cleanup at the Hanford Site*, David Bearden, Congressional Research Service
- *Perspective from the U.S. Government Accountability Office's Reports on Treatment Options for Low-Activity Waste at the Hanford Site*, David Trimble and Nathan Anderson, U.S. Government Accountability Office
- *Independent Assessment of Challenges Concerning Cleanup at the Hanford Site*, Robert Alvarez, Senior Scholar, Institute of Policy Studies

Public Comments

- John Greeves, independent consultant
- Suzanne Dahl, Washington State Department of Ecology
- Geoff Fettus, Natural Resources Defense Council
- Ian Pegg, Vitreous State Laboratory, The Catholic University of America

Public Meeting #2: Richland, Washington, February 28-March 1, 2018
Invited Presentations

- *Introductory Remarks on DOE-ORP*, Jon Peschong, DOE-ORP

Presentations by Washington River Protection System's contractors

- *Introduction*, Jason Vitali
- *Hanford Low Activity Waste Historical Overview*, Dave Swanberg
- *System Plan 8 Baseline Case Supplemental Low-Activity Waste (SLAW) Sizing*, Jeremy Belsher
- *History of SLAW Treatment Reviews*, Dave Swanberg
- *History of SLAW Cost Comparison*, Dave Swanberg

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- *Advanced Glass Program*, John Vienna
- *Immobilized Low-Activity Waste (ILAW) Glass Testing Program Status*, Elvie Brown
- *Overview of the 2017 Integrated Disposal Facility (IDF) Performance Assessment for LAW*, Pat Lee
- *Radioactive Waste Test Bed Initiative*, Stephanie Doll
- *Cementitious Waste Form Formulation and Testing Status*, Dave Swanberg

FFRDC Team's presentations

- *Introduction to Study and Lines of Inquiry Table and Schedule Overview*, Bill Bates (SRNL)
- *Process Flowsheet Overview and Feed Vector Overview*, Michael Stone (SRNL)
- *Baseline and Vit Flowsheets and Preliminary Technical Readiness Levels (TRLs)*, Alex Cozzi (SRNL)
- *Grout Flowsheets and Waste Forms and Preliminary TRLs*, George Guthrie (Los Alamos National Laboratory)
- *Steam Reforming and Waste Forms and Preliminary TRLs*, Nicholas Soelberg (Idaho National Laboratory)
- *Technologies Considered and Not Included*, Thomas Brouns (Pacific Northwest National Laboratory)
- *Disposal Facilities Overview, Waste Acceptance Criteria, and Transportation*, John Cochran (Sandia National Laboratories)
- *Analytic Approach to Risk*, Thomas Brouns
- *Cost Estimating Methodology*, Frank Sinclair (SRNL)
- *Wrap Up*, Bill Bates

Stakeholders' Presentations

- Alex Smith, Washington State Department of Ecology
- Dave Bartus, U.S. Environmental Protection Agency Regional Office
- Ken Niles, State of Oregon Department of Energy
- Susan Leckband, Chair, Hanford Advisory Board
- David Reeploeg, Vice President, Tri-Cities Development Economic Council (TRIDEC)
- Pam Larsen, President, Hanford Communities
- Matthew Johnson, Confederated Tribes of the Umatilla Indian Reservation (CTUIR)

Public Comments

- Paul Flaherty, CHC Consulting LLC, who made an oral presentation and submitted a written comment on behalf of Knauf Insulation
- Vince Panesko, retired from the Hanford Site
- Don Alexander, retired from DOE

Submitted Written Comments at the Public Meeting

- John Vienna, Pacific Northwest National Laboratory
- John Williford, Chrysalis Technology Group, Ltd.
- Tom Carpenter, Hanford Challenge

Darryl Siemer, a consulting scientist who is retired from the Idaho National Laboratory, submitted a number of comments via e-mail to the National Academies.

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Appendix D

Biographical Sketches of the Committee

John S. Applegate, *Chair*, is the executive vice president for University Academic Affairs at Indiana University (IU) and the Walter W. Foskett Professor of Law in the IU Maurer School of Law. He has served as a vice president for IU since 2008. He teaches and has written extensively in the fields of environmental law, administrative law, regulation of chemicals and hazardous wastes, international environmental law, risk assessment, and the management of radioactive waste. He chaired the Fernald Citizens Advisory Board at the U.S. Department of Energy's (DOE's) Fernald facility in Ohio from 1993-1998 and he served on the DOE Environmental Management Advisory Board from 1994-2001. He has also served on several National Academies of Sciences, Engineering, and Medicine studies. A member of the American Law Institute, Professor Applegate has also taught at the University of Paris (Panthéon-Assas) and University of Erlangen-Nürnberg and has been a research fellow at Cardiff University. Before moving to Indiana, he was the James B. Helmer, Jr., Professor of Law at the University of Cincinnati's College of Law and was a visiting professor at the Vanderbilt University Law School. He was a judicial law clerk for the U.S. Court of Appeals for the Federal Circuit and an attorney in private practice in Washington, DC. He has served as a board member of the National Academies' Nuclear and Radiation Studies Board; he was chair of the National Academies' Workshop on Low-Level Radioactive Waste Management and Disposition; and he has served on several National Academies' committees. Professor Applegate received his BA in English from Haverford College in 1978 and his JD from Harvard Law School in 1981.

Allen G. Croff, *Vice Chair*, is an adjunct professor of nuclear and environmental engineering in the Department of Civil and Environmental Engineering at Vanderbilt University. He is also a member of the U.S. Nuclear Waste Technical Review Board, appointed to this position by the president in February 2015, and a Distinguished Emeritus Member of the National Council on Radiation Protection and Measurements. Mr. Croff has 29 years of technical and program management experience at Oak Ridge National Laboratory. He was subsequently vice-chairman of the Advisory Committee on Nuclear Waste in the U.S. Nuclear Regulatory Commission and a Senior Technical Advisor to the Blue Ribbon Commission on America's Nuclear Future. He has led or participated in numerous multidisciplinary national and international technical and review committees for the National Academies, the National Council on Radiation Protection and Measurements, the Nuclear Energy Research Advisory Committee, and the Nuclear Development Committee of the Nuclear Energy Agency. Mr. Croff's technical accomplishments include creating the ORIGEN2 computer code used worldwide to calculate the radioactive characteristics of nuclear materials for use in nuclear material and waste characterization, risk analyses, and nuclear fuel cycle analysis; developing and evaluating comprehensive, risk-based waste classification systems, including changing the boundary defining transuranic waste from 10 to 100 nCi/g; technical, economic, and systems analysis of current and advanced nuclear fuel/material cycles from uranium mining through waste disposal; conceiving, analyzing, and reviewing actinide partitioning-transmutation (P-T) concepts beginning with the first comprehensive analysis of P-T from 1976 to 1980 through subsequent cycles of renewed interest in the concept up to the present. Mr. Croff received a BS (1971) in chemical engineering from Michigan State University, a nuclear engineer degree (1974) from the Massachusetts Institute of Technology, and an MBA (1981) from the University of Tennessee.

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Margaret S.Y. Chu provides consulting services to domestic and international clients in nuclear waste management, nuclear fuel cycle analysis, nuclear security analysis, and research and development. Her entire career has been devoted to promoting safe nuclear energy and nuclear fuel cycle. She has extensive experience in successfully managing large, multidisciplinary projects and in negotiating with customers, regulators, and stakeholders. She has more than 20 years of experience serving at Sandia National Laboratories in several capacities, including as director of the Nuclear Waste Management Program Center, manager of the Environmental Risk Assessment and Waste Management Department, and deputy manager of the Waste Isolation Pilot Project (WIPP) and Technical Integration Department. In 2002, she was appointed by President George W. Bush as director of the U.S. Department of Energy's (DOE's) Office of Civilian Radioactive Waste Management, which is responsible for developing the nation's waste disposal system for spent nuclear fuel and high-level radioactive waste at Yucca Mountain. She has authored nearly 50 publications and has received numerous awards, including in 2005 the Secretary of Energy's Gold Award, DOE's highest honor, and Team Lead of the Lockheed Martin Nova Award (1998). She is a member of the National Academies' Nuclear and Radiation Studies Board, a member of the Advisory Committee of Reactor Safeguards at the U.S. Nuclear Regulatory Commission, and a member of the Nuclear Energy Advisory Committee at DOE. She is a member of the National Academy of Engineering (NAE). She holds a BS in chemistry from Purdue University and a PhD in physical (quantum) chemistry from the University of Minnesota.

Kenneth R. Czerwinski is a professor in the radiochemistry program at the University of Nevada, Las Vegas, and director of the radiochemistry PhD program. His current research is centered on understanding the chemical speciation and coordination of actinides and technetium compounds for exploratory and applied studies. His fundamental research focuses on coordination chemistry and evaluating electronic structure. By understanding radioelement-containing systems, one can determine relevant species, study their behavior, verify results, inform computational efforts, and incorporate the latest concepts into education. His current projects include speciation of actinides in spent fuel, chemical speciation of actinides in separations, nuclear forensics, and radioelement compounds and material synthesis. Dr. Czerwinski has been an associate professor in the Nuclear Engineering Department at the Massachusetts Institute of Technology and an associate research scientist for the Institut für Radiochemie Technische Universität München. He has been accorded the Presidential Early Career Award in Science and Engineering and was elected Fellow of the American Association for the Advancement of Science in 2012 for his distinguished contributions to actinide and fission product chemistry. Dr. Czerwinski obtained his BA from Knox College in Russian language and chemistry and his PhD in nuclear chemistry from the University of California, Berkeley.

Rachel J. Detwiler is principal engineer at Beton Consulting Engineers, LLC. Her areas of expertise are construction troubleshooting, concrete durability, transport properties, microstructure, and test methods for concrete and cement-based materials. Dr. Detwiler previously worked as an associate and senior engineer at Braun Intertec Corporation; a principal engineer at Construction Technology Laboratories; an assistant professor at the University of Toronto; and a design and materials engineer with ABAM Engineers, Inc. She is a fellow of the American Concrete Institute, where she served as chair of Committee 227 on Radioactive and Hazardous Waste Management and as a member of the Publications Committee. She is a member and past chair of Committee 234 on Silica Fume in Concrete and a member of Committee 201 on Durability of Concrete. She also served in an advisory role until 1986 for the initial development of a formulation of grout for the stabilization of radioactive and hazardous waste in underground storage tanks at the Savannah River Site. Dr. Detwiler has published more than 60 technical papers related to concrete microscopy, durability, and testing. Dr. Detwiler has served on several National Academies committees. Dr. Detwiler holds a BS in civil engineering, an MS in structural engineering, and a PhD in civil engineering materials from the University of California, Berkeley. She was also a postdoctoral fellow at the Institute for Building Materials at the Norges Tekniske Høgskole, Trondheim, Norway.

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Timothy A. DeVol is the Toshiba Professor of Nuclear Engineering and director of the Nuclear Environmental Engineering Sciences and Radioactive Waste Management Center at Clemson University. Dr. DeVol's primary teaching responsibilities are in the areas of radiation detection and measurement, environmental risk assessment, and introduction to nuclear engineering and radiological sciences. Dr. DeVol oversees the Accreditation Board for Engineering and Technology–Applied and Natural Science Accreditation Commission's accredited Environmental Health Physics educational program in the Environmental Engineering and Earth Sciences Department at Clemson University. Dr. DeVol's research interests are in the areas of radiological environmental measurements, environmental health physics, statistical methods, homeland security, nuclear forensics, and in situ and field portable analytical instrumentation for radioactive environmental contaminant quantification. Dr. DeVol has more than 60 refereed publications and more than 160 presentations in the field of detection of radioactive materials. He holds three U.S. patents on the development of methods and materials for the detection of radioactivity in the environment. Additionally, Dr. DeVol has helped to bring in more than $8 million in externally funded research, of which $4.5 million was directly attributed to him in his more than 20 years on the faculty at Clemson University. Dr. DeVol is also the recipient of the 2003 and 2011 Clemson University Innovation Award and the 2004 Elda E. Anderson Award from the Health Physics Society. He is a member of the American Nuclear Society, the Health Physics Society, and the Institute of Electrical and Electronics Engineering Society. Dr. DeVol is an American Board of Health Physics certified health physicist. He holds an MS and a PhD, in nuclear engineering from the University of Michigan, Ann Arbor, and a BS in engineering physics from The Ohio State University, Columbus.

Rodney C. Ewing is the Frank Stanton Professor in Nuclear Security and co-director of the Center for International Security and Cooperation in the Freeman Spogli Institute for International Studies and a professor in the Department of Geological Sciences in the School of Earth, Energy and Environmental Sciences at Stanford University. In addition, he is the Edward H. Kraus Distinguished University Professor Emeritus at the University of Michigan, where he was in three departments: Earth & Environmental Sciences, Nuclear Engineering & Radiological Sciences, and Materials Science and Engineering. He is also a Regents' Emeritus Professor at the University of New Mexico. His professional interests are in mineralogy and materials science and his research has focused on radiation effects in complex ceramic materials and the long-term durability of radioactive waste forms. He is a Fellow of the American Association for the Advancement of Science, the American Ceramic Society, The Geochemical Society, the Geological Society of America, the Mineralogical Society of America, and the Materials Research Society. He is a past president of the International Union of Materials Research Societies and the Mineralogical Society of America. In 2006, he was awarded the Lomonosov Great Gold Medal of the Russian Academy of Sciences and in 2007 he was awarded an Honorary Doctor of Université Pierre et Marie Curie. He is a member of the National Academy of Engineering (NAE). He received his MS and PhD in geology from Stanford University.

Craig S. Hansen is an independent business consultant with 27 years of executive and senior-level experience in facility/site management; business and product line management; executing large and complex nuclear plant manufacturing, construction, decommissioning, and nuclear reactor servicing contracts; and in successful leadership of complex technical projects facing a wide range of stakeholder challenges. Mr. Hansen has extensive experience with BWXT, formerly the nuclear technology business of the Babcock & Wilcox Company (B&W). His most recent service was as president and board member (2013-2014) at B&W's American Centrifuge Manufacturing LLC (ACM), where he was responsible for the management and operations of the American Centrifuge Technology and Manufacturing Center located in Oak Ridge, Tennessee, overseeing direction, management, and operation through bankruptcy and program re-alignment; managed a sophisticated technical manufacturing operation in a highly automated facility; and led product line diversification and demobilization due to government funding cuts. In B&W's nuclear manufacturing division (2008-2013), he was the vice president of nuclear equipment where he was responsible for B&W's global commercial nuclear equipment business along with U.S. and Canadian manufacturing sites, worldwide contracts, and product lines. From 2003 through 2008, Mr. Hansen organized and managed

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B&W's government relations team. As B&W's deputy site manager (2001-2003), he accelerated the cleanup and public relations at the U.S. Department of Energy Miamisburg Environmental Management Project (Mound Plant), a site on the National Priorities List since 1989 due to past disposal practices and releases to the environment. Prior to B&W, he worked on the Naval Nuclear Propulsion Program in Washington, DC, and Idaho (1988-2001) in a series of progressively responsible positions at the nuclear reactor headquarters and naval reactor site management. He also served as the first chairman of the U.S. Department of Commerce Civil Nuclear Trade Advisory Committee. Mr. Hansen has a BA from Eastern Washington University in operations management.

Milton Levenson[1] was an independent consultant with a long and successful 73 years in the nuclear energy and related fields. His work experience began at Oak Ridge National Laboratory in 1944, with most of it in nuclear reactor safety and fuel processing. He served as a research engineer at Oak Ridge from 1944 to 1948; during part of that time (1944-1946) he was also in the U.S. Army. In 1948, Mr. Levenson moved to Illinois to work at the Argonne National Laboratory, where he retired as an associate laboratory director in 1973. He then moved to the Electric Power Research Institute in Palo Alto, California, where he served as the first director of the nuclear power division, a post he held until 1980. From 1981 to 1988, Mr. Levenson served as an executive consultant to the Bechtel Power Corporation in San Francisco and became vice president of Bechtel International in 1984, a position he kept until 1989. In 1990, he began work as a private executive consultant. He is the author of more than 150 publications and presentations and holds three U.S. patents. Mr. Levenson was a Fellow of the American Institute of Chemical Engineering (AIChE) and received the Robert E. Wilson award from AIChE in 1975 for his contributions to nuclear chemical engineering. He was a member of the American Nuclear Society (ANS) for more than 50 years and was an ANS Fellow, the highest membership grade of ANS. He was elected the 29th president of ANS in 1983. He was also a recipient of a special ANS award for his work on the Source Term. He was elected to the National Academy of Engineering (NAE) in 1976 for his contributions to fast reactor technology, nuclear fuel reprocessing, and especially the first remote-handling completely closed fuel cycle plant. He served as a chair or committee member for several National Academies studies. Mr. Levenson earned a bachelor's degree in chemical engineering from the University of Minnesota in 1943.

Cathy Middlecamp is a professor at the Nelson Institute for Environmental Studies and the Integrated Liberal Studies Program (Howe Bascom Professor) at the University of Wisconsin–Madison. Since 2015, she has also served as the interim director for academics and research for the Office of Sustainability. On campus, statewide, and nationally she has been recognized for her excellence in teaching and service to a diverse group of students. From 2007 to 2016, she was the editor-in-chief for Chemistry in Context, a project of the American Chemical Society, and has served as the lead author for the chapters on nuclear energy, air quality, stratospheric ozone depletion, acid rain, and polymers. Other recognition from the American Chemical Society includes being elected as a Fellow (2009) and receiving national awards for incorporating sustainability into the chemistry curriculum (2011), for encouraging women in careers in the chemical sciences (2003), and for fostering diversity (2001). Over the past 20 years, Dr. Middlecamp has designed, supervised, and taught in a number of programs for students under-represented in the sciences, both collegiate and pre-collegiate. In addition, she has edited and contributed chapters to monographs on teaching and learning sustainability in the chemistry curriculum. Recognition from the American Association for the Advancement of Science includes being named a Fellow (2003) and being elected the chair of Section Q, Education (2015). Dr. Middlecamp graduated with distinction in all subjects and Phi Beta Kappa from Cornell University (1972), earned her PhD in chemistry from the University Wisconsin–Madison (1976), and holds a master's degree in education from the University of Wisconsin–Madison (1989).

[1]Deceased on March 31, 2018.

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Alfred P. Sattelberger retired in 2017 from the Argonne National Laboratory, where he most recently was the deputy lab director for Programs, a chief research officer, and a senior intelligence official. Prior to his appointment as an associate lab director at Argonne in 2006, he was a senior laboratory fellow and former head of the Chemistry Division and the Science and Technology Base Program Office at the Los Alamos National Laboratory (LANL). Dr. Sattelberger's research interests include actinide coordination and organometallic chemistry, technetium chemistry, homogeneous and heterogeneous catalysis, and nuclear energy. Before joining LANL in 1984, Dr. Sattelberger held a faculty appointment in the Chemistry Department at the University of Michigan. He is a former chair of the Inorganic Chemistry Division of the American Chemical Society (ACS) and the Chemistry Section of the American Association for the Advancement of Science (AAAS). He served as a member of the 1996 Environmental Management Science Program merit review panel. He was elected a Fellow of AAAS in 2002 in recognition of his scientific contributions to early transition metal and f-element chemistry, and was elected a Fellow of ACS in 2010. He has also served as a member of several National Academies committees examining radioactive waste management issues at the U.S. Department of Energy (DOE) and is currently the chair of the Nuclear Technology R&D Subcommittee of the DOE Nuclear Energy Advisory Committee. Dr. Sattelberger received a BA in chemistry at Rutgers College in 1970 and obtained a PhD in inorganic chemistry from Indiana University in 1975.

Barry E. Scheetz is recognized for his expertise in the chemistry of cementitious systems for waste forms and environmental remediation. He is a retired professor of materials, civil, and nuclear engineering at The Pennsylvania State University. His work includes environmental waste management programs such as the remediation of mine lands by the use of industrial by-products, focusing on large-volume usage of fly-ash-based cementitious grouts. Other programs include developments of radioactive waste forms based on vitrifiable hydroceramics and sodium zirconium phosphate structures. Dr. Scheetz received a national internship from the Argonne National Laboratory in 1972 and he was a National Academy of Sciences visiting scholar to China in 1989. He served as a member of the National Academies' Board on Radioactive Waste Management's Committees on Idaho National Engineering and Environmental Laboratory High-Level Waste Alternative Treatments, and Cesium Processing Alternatives for High-Level Waste at the Savannah River Site. Dr. Scheetz is the author of more than 240 scientific publications and holds 40 U.S. and world patents. He received a BS in chemical education from Bloomsburg State College and an MS in geochemistry and a PhD in geochemistry from The Pennsylvania State University.

Anne E. Smith is a managing director and the co-chair of the National Economic Research Associates, Inc.'s (NERA's) Global Environment Practice. Trained in economics, decision sciences, and mathematical modeling, she has applied this expertise to issues including air quality, climate change, contaminated sites, food safety, and nuclear waste management. She has also conducted training courses in health risk assessment and risk management for the staff of corporations and government agencies. In addition to her consulting activities, Dr. Smith has served on National Academies committees, the United Nations (UN) Economic Commission for Europe, the UN's Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP), and the U.S. Environmental Protection Agency's (EPA's) Board of Scientific Counselors. She is a member of many different professional societies, performs peer reviews for journal articles, and served on the Board of Directors of the Society for Benefit-Cost Analysis in 2013 and 2014. Prior to joining NERA, Dr. Smith was practice leader of Climate and Sustainability at Charles River Associates. She was also a vice president and a policy analysis practice leader at Decision Focus Incorporated and served as an economist in the Office of Policy Planning and Evaluation at EPA. Dr. Smith graduated summa cum laude from Duke University with a BA in economics and from Stanford University with an MA and a PhD in economics and a PhD minor in engineering-economic systems.

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Chris G. Whipple has 40 years of experience in managing risks to human health and the environment. The major emphases of his work have been radioactive wastes, hazardous air pollutants, and environmental mercury. He has served on numerous national committees addressing radioactive waste management, including committees of the National Academies, the U.S. Environmental Protection Agency, and the National Council on Radiation Protection and Measurements, of which he is a member. He was elected to membership in the National Academy of Engineering (NAE) in 2001. He has chaired the National Academies' Board on Radioactive Waste Management, as well as National Academies committees on the Review of the Hanford Site's Environmental Remediation Science and Technology Plan; Models in the Regulatory Decision Process; Medical Isotope Production Without Highly Enriched Uranium; and Understanding and Managing Risk in Security Systems for the Department of Energy Nuclear Weapons Complex. He also co-chaired the National Academies' Report Review Committee from 2008-2016. He was a charter member and second president of the Society for Risk Analysis and is a Fellow of the American Association for the Advancement of Science. He received a PhD and an MS in engineering science from the California Institute of Technology and a BS in engineering science from Purdue University. In 2004, he received Purdue's Distinguished Engineering Alumni Award.

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Appendix E

Acronyms and Abbreviations

DMR	Denitration Mineralizing Reformer
DOE	U.S. Department of Energy
DOE-EM	U.S. Department of Energy's Office of Environmental Management
DOE-ORP	U.S. Department of Energy's Office of River Protection
DWPF	Defense Waste Processing Facility
EPA	U.S. Environmental Protection Agency
FBSR	fluidized bed steam reforming
FFRDC	Federally Funded Research and Development Center
HLW	high-level waste
IDF	Integrated Disposal Facility
ILAW	immobilized low-activity waste
INL	Idaho National Laboratory
IWTU	Integrated Waste Treatment Unit
LAW	low-activity waste
LOI	line of inquiry
NNSS	Nevada National Security Site
PRA	probabilistic risk assessment
SLAW	supplemental low-activity waste
SRNL	Savannah River National Laboratory
TPA	Tri-Party Agreement
TRIDEC	Tri-Cities Washington Economic Development Council
TRL	technology readiness level
WAC	waste acceptance criteria
WCS	Waste Control Specialists
WRPS	Washington River Protection Solutions
WTP	Waste Treatment and Immobilization Plant

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