U.S. Nuclear Waste Technical Review Board

A Report to The U.S. Congress and The Secretary of Energy

Board Activities for the Period January 1, 2022 - December 31, 2024

September 2025

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

September 2025

The Honorable Mike Johnson
Speaker
United States House of Representatives
Washington, DC 20515

The Honorable Charles E. Grassley
President Pro Tempore
United States Senate
Washington, DC 20510

The Honorable Chris Wright
Secretary
U.S. Department of Energy
Washington, DC 20585

Dear Speaker Johnson, Senator Grassley, and Secretary Wright:

Congress created the U.S. Nuclear Waste Technical Review Board in the Nuclear Waste Policy Amendments Act of 1987 (NWPAA) (Public Law 100-203) to evaluate the technical and scientific validity of activities undertaken by the Secretary of Energy to implement the Nuclear Waste Policy Act, as amended. In accordance with provisions of the NWPAA directing the Board to report its findings and recommendations to Congress and the Secretary of Energy, the Board submits the enclosed *Report to the U.S. Congress and the Secretary of Energy*, which summarizes Board activities, conclusions, and recommendations for the period, January 1, 2022, through December 31, 2024.

During the period covered by the Report, the Board focused its efforts on evaluation of Department of Energy's activities related to packaging, storage, and transportation of spent nuclear fuel and high-level radioactive waste, and plans for interim storage and geologic disposal of those materials.

The Board hopes that Congress and the Secretary will find the information in this Report useful and looks forward to continuing its ongoing technical and scientific review of DOE activities related to nuclear waste management and disposal.

Sincerely,

Peter Swift
Chair

Telephone: 703-235-4473 Fax: 703-235-4494 www.nwtrb.gov

U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD

Note 1: This list reflects the Board members serving as of December 31, 2024.

Note 2: See Appendix A for a listing of all Board members during the period of this report.

U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD STAFF

Executive Staff

Daniel Ogg	*Executive Director*
Neysa Slater-Chandler	*Director of Administration*

Senior Professional Staff

Christopher R. Burk	*Director of External Affairs*
Hundal Jung	*Materials Engineering, Corrosion*
Bret W. Leslie	*Geoscience*
Chandrika Manepally	*Hydrogeology*

Professional Staff

Yoonjo Lee	*Nuclear Engineering, Corrosion*
Eugenio-Felipe Santillan	*Geoscience*

Administrative & Support Staff

Davonya S. Barnes	*Information Technology Systems Specialist*
Jayson S. Bright	*Systems Administrator*
Kimberly Brown	*Human Resources Specialist*
Sara Davis	*Financial Manager*

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EXECUTIVE SUMMARY

The U.S. Nuclear Waste Technical Review Board (Board) was established by Congress in the Nuclear Waste Policy Amendments Act of 1987 (Public Law 100-203). Pursuant to the Act, the Board is charged with evaluating the technical and scientific validity of activities undertaken by the U.S. Department of Energy (DOE) related to the management and disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW). The Board reports the results of its independent reviews and evaluations, along with its findings, conclusions, and recommendations, to Congress and to the Secretary of Energy.

Between January 1, 2022, and December 31, 2024, the period of Board activities summarized in this report, the Board focused its efforts on evaluation of DOE's activities related to packaging, storage, and transportation of SNF and HLW, and plans for interim storage and geologic disposal of those materials. Also, the Board continued to explore crosscutting issues associated with DOE efforts to develop an integrated waste management system. Figure ES-1 depicts a timeline of activities the Board completed in the 2022 to 2024 reporting period, including correspondence to DOE (and DOE responses), Board reports to Congress and the Secretary of Energy, an online, interactive Table of Repository programs, and fact-finding meetings and public Board meetings with DOE.

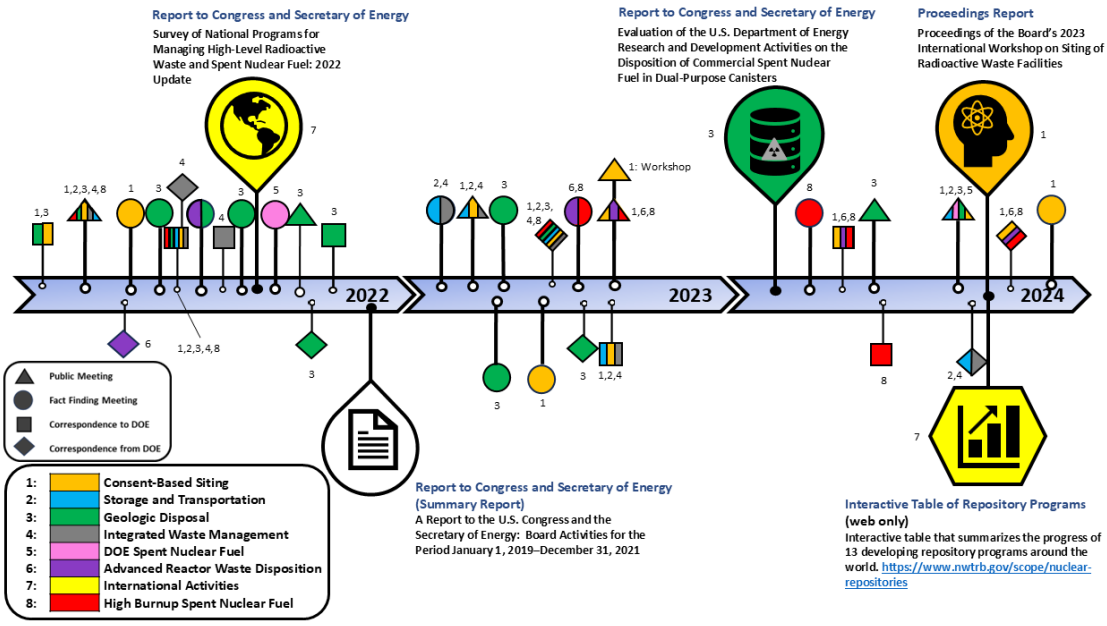

Figure ES-1. Timeline of Board activities, meetings, and correspondence from January 1, 2022, to December 31, 2024.
See legend at the bottom left: subject matters are color-coded, and shapes indicate a type of activity. Board reports are offset with large balloons; the large hexagon symbolizes the web-only interactive table; triangles symbolize public meetings; circles symbolize fact-finding meetings; squares symbolize correspondence to DOE, and diamonds symbolize correspondence from DOE, as indicated.

The Context of the Board's Review

The suspension of DOE's efforts on the Yucca Mountain, Nevada, repository program in 2010, and the issuance of DOE's 2013 strategy for managing and disposing of SNF and HLW, influenced DOE's activities during this reporting period. The 2013 strategy included a phased, adaptive, and consent-based approach to siting and implementing an integrated waste management and disposal system. DOE's 2013 strategy

> "endorses a waste management system containing a pilot interim storage facility; a larger, full-scale interim storage facility; and a geologic repository in a timeframe that demonstrates the federal commitment to addressing the nuclear waste issue, builds capability to implement a program to meet that commitment, and prioritizes the acceptance of fuel from shut-down reactors."

In its strategy, DOE acknowledged that full implementation required legislative changes but indicated that it was undertaking activities within existing congressional authorization to plan for the eventual transportation, storage, and disposal of SNF and HLW. These activities included research and development (R&D) on the suitability of various host rocks for a deep geologic repository. These non-site-specific geologic repository studies focused on disposal in a mined repository constructed in salt, clay/shale, or crystalline host rocks. The studies were intended to provide a basis for several evaluations, including an assessment to determine if the canisters used for SNF storage at nuclear power plant sites could be disposed of in these host rocks. DOE also indicated it was undertaking transportation evaluations to inform DOE's plans to accept commercial SNF from nuclear power plant sites.

DOE's strategy included initiatives for R&D on a deep borehole disposal concept as well as a commitment to develop plans for consent-based siting of both storage and disposal facilities, to be implemented when enabling legislation was in place. However, in 2017, the Administration of President Donald Trump terminated both initiatives. Therefore, DOE continued its efforts through 2021 to develop an integrated waste management system that was consistent with its 2013 strategy and existing legislative authority. Practically, this meant that DOE continued to conduct R&D on storage, packaging, transportation, and non-site-specific geologic disposal options for both commercial and DOE SNF and HLW and developing the system capabilities and infrastructure for future transportation of the waste.

Congress included $27.5 million in appropriations for fiscal year 2021 that was directed to be used for consolidated interim storage efforts. In 2021, the Administration of President Joseph Biden refocused the interim storage effort, and DOE began to develop a consent-based siting process for siting federal interim storage facilities for storing commercial SNF. Congress also directed DOE to continue site preparation activities at shutdown commercial nuclear power plant sites that store SNF and to undertake the preparations to coordinate transportation of the SNF. By 2024, DOE completed the planning phase of the consent-based siting process and was working on capacity-building. In 2024, in response to passage of the ADVANCE [Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy] Act, DOE began to review and reprioritize its disposal, storage, and transportation R&D activities.

Geologic Disposal

Relative to geologic disposal, the Board focused its evaluation of DOE activities on two critical technical areas: non-site-specific (generic) disposal R&D activities, including the initiation of a review and reprioritization of geologic R&D activities that began in 2024, and disposal of SNF in dual-purpose canisters.

Non-site-specific (generic) disposal R&D activities

DOE's non-site-specific disposal R&D focuses on geologic disposal concepts in three potential host rocks—crystalline, salt, and argillite—and crosscutting investigations that utilize laboratory, field (e.g., underground research laboratories [URLs]), and modeling studies. Until passage of the ADVANCE Act, DOE's goals had been to provide a sound technical basis for developing alternative, viable disposal options for SNF (e.g., disposal in dual-purpose storage and transportation canisters) and HLW, to increase confidence in the robustness of non-site-specific disposal concepts, to develop tools (e.g., the Geologic Disposal Safety Assessment framework [GDSA]) needed to support disposal concept implementation, and to utilize international experience to inform the U.S. program. During the reporting period, the Board reviewed DOE's R&D activities on argillaceous and crystalline host rocks, including the development of the GDSA applied to those host rocks, clay-based engineered barriers, and DOE's post–ADVANCE Act review and reprioritization of its disposal R&D program.

In 2022, the Board reviewed DOE's R&D activities to develop models and generate experimental data for understanding and predicting the long-term performance of geologic repositories in argillaceous host rocks and that of clay-based engineered barriers. The Board found that DOE has a technically valid approach to developing its modeling capability that will enable it to evaluate the post-closure performance of a potential SNF and HLW repository in an argillaceous host rock, but the Board also found that DOE had not clearly articulated the progress of its R&D towards achieving its program objectives and addressing technical gaps. The Board found that further analysis by DOE is needed to clarify the relative importance of the bentonite buffer on the performance of a repository in an argillaceous host rock. The Board recognized that DOE has been working on effective public and stakeholder engagement in other areas of the national waste management program (i.e., consent-based siting activities), but the Board found insufficient integration between DOE activities related to consent-based siting of federal consolidated interim storage facilities and those related to geologic disposal. The Board commended DOE for exploring how URLs can play an important role in public outreach and communication and attracting the next generation of waste disposal scientists and engineers. Based on these findings, the Board made five recommendations to improve DOE's non-site-specific disposal R&D program (see pages 8–9).

In 2023, the Board reviewed DOE's R&D on potential disposal of SNF and HLW in crystalline rock formations and corrosion of commercial SNF after disposal. The Board noted that DOE is using state-of-the-art modeling approaches and methods of analysis for evaluating and predicting long-term repository performance in crystalline host rock. The Board observed that DOE's focus on international collaborations has been effective in

advancing DOE's state of knowledge related to nuclear waste disposal. The Board encouraged DOE to build on past collaborations to leverage advances in geophysical characterization techniques and tools from other industries. The Board reviewed DOE's development of a Fuel Matrix Degradation Model (FMDM) to model the corrosion of commercial SNF under various repository conditions. The Board noted it is essential that the program define "good enough" for the models in the FMDM to avoid unnecessary effort for limited benefit.

In August 2024, DOE provided a program update, including efforts to reprioritize the DOE Office of Nuclear Energy's storage, transportation, and disposal R&D activities to adjust to the expected impacts of the ADVANCE Act and to change its focus from generic R&D to reducing risk and liabilities. The Board noted that the key to accurate estimates of liabilities and life-cycle costs is the number of facilities for storage and disposal, their assumed start dates for operations, and the technical bases underlying the analyses and assumptions. The Board noted that another key cost consideration is the potential need to repackage commercial SNF in dual-purpose (storage and transportation) canisters (DPCs) to facilitate disposal of the SNF.

Disposal of SNF in dual-purpose canisters

In February 2024, the Board released a report on DOE's activities related to the disposition of commercial SNF stored in U.S. Nuclear Regulatory Commission (NRC)-approved dry-storage casks at independent spent fuel storage installations (ISFSIs). For several years, DOE has been conducting R&D, including studies on consequences of nuclear criticality in a repository and options for future packaging of SNF, to help determine the feasibility of repository disposal of commercial SNF in DPCs—canisters designed with the dual purpose of storage and transportation of SNF but not with consideration of disposal. The Board observed that a decision by DOE on the disposability of SNF in DPCs would have a substantial impact on how SNF is stored, transported, and disposed of, and may require interim storage of SNF for many decades to hundreds of years, depending on the availability of a repository that can accept DPCs.

The Board found that DOE had not fully analyzed, in an integrated manner, all the key aspects of the alternative approaches for managing commercial SNF such that a meaningful comparison of the alternatives could be made. The Board identified that DOE had not addressed the implications for the design, construction, and operation of a geological repository for disposing of SNF in large DPCs versus disposing of SNF repackaged into smaller canisters, with a particular focus on waste package degradation, thermal management, post-closure criticality, and the engineering aspects of waste package emplacement in various host rock types. The Board found that sufficient work had been completed to define the path forward regarding analyzing hypothesized post-closure criticality events that could occur in a repository, but the Board also found that some of the DOE-sponsored evaluations of post-closure criticality may be based on assumptions that are not fully supportable, and some of the codes used in the criticality consequence analyses may not be appropriate. The Board found that a set of criteria needs to be developed for use in assessing the various options for modifying the fuel assemblies and baskets for DPCs to be

loaded in the future and in prioritizing R&D activities. Based on these findings, the Board made three recommendations to improve DOE's DPC R&D (see pages 14, 16–17).

Packaging, Storage, and Transportation of SNF and HLW

The Board focused its evaluation of DOE activities in five important technical areas related to packaging, storage, and transportation: management of SNF under DOE's control, packaging and transportation of SNF and HLW, advanced reactor waste disposition including the impact of advanced nuclear fuels and accident tolerant fuels, long-term dry storage and transportation of high burnup commercial SNF, and dry storage canister corrosion.

Management of DOE SNF

In 2017, the Board released a comprehensive report on management and disposal of SNF managed at DOE sites (DOE SNF). Following release of this report, Congress specifically appropriated funds to DOE to address Board recommendations on management of DOE SNF. DOE has been sponsoring and conducting technology development activities to develop a technical basis for extended dry storage of aluminum-clad spent nuclear fuel (ASNF). These efforts have been guided by DOE's Spent Nuclear Fuel Working Group (SNFWG). The Board staff observed SNFWG meetings throughout the reporting period, and members of the Board held a fact-finding meeting with DOE and national laboratory staff in 2022 to assess DOE's progress relative to the Board's recommendations. In 2023, the Board toured DOE SNF facilities at the Idaho National Laboratory (INL) and discussed the development of an integrated SNF management plan for the Idaho site. In 2024, the Board toured SNF-related facilities at the Savannah River Site (SRS) and held a public meeting focused on DOE's management and plans for disposal of DOE SNF. The meeting addressed ASNF technology development activities and SNF management activities at SRS, including SNF storage, the accelerated basin de-inventory project, and management alternatives for stored SNF after completion of the de-inventory project. The Board also heard about SNF management activities at the INL, including the Idaho Road-Ready SNF Demonstration.

Packaging and transportation of SNF and HLW

DOE's R&D activities to evaluate the future removal of commercial SNF from commercial nuclear power plant sites include site visits to perform transportation infrastructure evaluations, preparing initial site-specific de-inventory reports, and developing railcars. Among DOE's proposed activities is the Package Performance Demonstration (now called the Package Performance Project), which, if funded, would entail physical demonstrations of an SNF transportation cask in hypothetical accident scenarios. DOE is developing a test plan for this demonstration, and its main purposes are to demonstrate to the public the robustness of SNF rail casks and to gather technical data related to validating package performance.

In a public meeting in 2023, the Board reviewed DOE activities in three major cross-cutting areas—transportation preparations, storage design and regulatory considerations, and systems analysis tools and integration. The Board found that incorporating public feedback in the early development of a Package Performance Study (now called the Package Performance Project) is important and that DOE had not yet received broad public feedback on its

proposed study. The Board found that DOE-sponsored site evaluations provide a good opportunity for DOE to meet with onsite staff and discuss technical details, including SNF condition, anomalies, and canister loading maps. The Board found that DOE can enhance its integrated waste management system by engaging early with the NRC regarding the need for amendments and exemptions to the transportation Certificates of Compliance (CoC) for SNF canisters that do not currently meet the CoC requirements. The Board also found that there may be technical difficulties with meeting the NRC requirements for SNF storage following the transportation of SNF. Based on these findings, the Board made four recommendations to improve DOE's activities related to packaging and transportation of SNF and HLW (see pages 23–24). In 2025, the Board commended DOE for addressing the Board's recommendation to engage the public early in developing the Package Performance Project.

Advanced reactor waste disposition

For fiscal year 2022, Congress earmarked $5 million for DOE to conduct R&D for advanced reactor SNF disposition as it relates to tri-structural isotropic and metal-fueled advanced reactors. DOE will need sufficient data from an advanced reactor applicant describing the characteristics of both the initial fuel and the discharged SNF and HLW and operations (e.g., storage canister design and what constitutes "failed fuel"), to allow DOE to determine whether to enter a contract with the applicant for disposal of their SNF and HLW. The Board found that DOE has initiated an effort to assess the potential impacts of various advanced nuclear fuels on storing, transporting, and disposing of SNF and HLW by requesting data from advanced reactor vendors. The Board also found that DOE is developing a strategy to identify knowledge gaps. The Board commended DOE for initiating this assessment and strongly endorsed the effort. The Board also held a fact-finding meeting with DOE on its efforts related to advanced nuclear fuels including accident tolerant fuels.

Long-term dry storage and transportation of high burnup commercial SNF

An increasing quantity of SNF discharged from current commercial nuclear reactors and upcoming advanced reactors will be fuel that is utilized for longer times, achieving higher burnups. In 2021, the Board released a comprehensive evaluation of DOE's research program to examine the performance of commercial high burnup SNF during extended storage and transportation that included 13 recommendations. During this reporting period, the Board assessed DOE's efforts to address the recommendations by holding a fact-finding meeting and receiving a presentation in a public meeting. The Board concluded that DOE had satisfactorily addressed nine of the recommendations. The remaining open recommendations related to SNF drying and the technical basis for DOE's assumption that the information developed for a limited number of types of high burnup fuels bounds the behavior of the many other types that have not been tested or modeled. The Board provided suggestions to DOE on how the related open Board recommendations can be closed (see pages 28–32).

Dry storage canister corrosion

For several years, DOE had been conducting R&D to address chloride-induced stress corrosion cracking (CISCC) of welded stainless steel canisters, an aging-related degradation

mechanism, during extended storage of SNF. In 2022, the Board commended DOE for R&D on CISCC and encouraged DOE to continue its efforts but found that DOE had not fully considered one area of focus regarding localized corrosion mechanisms. The Board also noted several positive aspects of DOE's activities, including collaborating with industry on the Hanford Lead Canister project, integration efforts across DOE programs, and DOE's storage and transportation 5-year R&D plan. The Board noted that the overall risk of SNF canister degradation is best informed by combining the results of a realistic assessment of the consequences of canister penetration with the results of a more thorough assessment of the probability of breaching an SNF dry cask storage system. Based on these findings, the Board made two recommendations to improve DOE's R&D on dry-storage canister corrosion (see pages 32–33).

Integrated SNF and HLW Management and Disposal System

Through the Consolidated Appropriations Acts of 2021, 2022, and 2023, DOE was congressionally directed to move forward under existing authority to identify a site, using a consent-based siting approach, for a federal consolidated interim storage facility (CISF) for storing commercial SNF. In 2024, DOE approved Critical Decision-0 (Approve Mission Need) for the Federal Consolidated Interim Storage Facility project, formally establishing the project. The Board noted that DOE was already facing some significant challenges early in the process and that development of DOE's consent-based siting process could be informed by the details and lessons learned from the consent-based siting programs in other countries. In another important cross-cutting area, DOE is developing several decision-support tools to assist in developing and managing an integrated waste management system.

Consent-based siting

As DOE reinitiated an effort to site one or more federal facilities for the temporary, consolidated storage of commercial SNF, the Board commended DOE for undertaking efforts to develop a consent-based approach and process that is well-aligned with the recommendations in the Board's 2021 report, titled *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward*. The Board supported DOE's commitment to transparency, openness, and effectively engaging stakeholders.

The Board found that effectively meeting public information needs is an important component of consent-based siting, and for interested parties to be informed and empowered in the siting process, they need consistent and timely access to scientific and technical information. The Board also found that communication of complex scientific and technical information is a crucial part of consent-based siting efforts and noted that DOE is contemplating various efforts to disseminate such information. The Board commended DOE for its plan to support its future risk communication efforts with social science expertise and for incorporating a wide range of social and behavioral science disciplines into its consent-based siting efforts. The Board also found that for successful siting programs in Sweden and other countries, different evaluation approaches, methodologies, and metrics have been

employed to help assess the effectiveness of consent-based siting efforts, and some of those approaches are transferrable to DOE's efforts. The Board made five recommendations to help improve DOE's activities related to consent-based siting (see pages 35, 37–39).

In August 2023, the Board held an International Workshop on Siting of Radioactive Waste Facilities to provide individual speakers from DOE and several countries with the opportunity to candidly share their viewpoints, insights, and lessons learned regarding the siting of radioactive waste storage and disposal facilities. The Board's workshop proceedings, published September 2024, summarize the presentations, discussions, key themes, and takeaways. Despite important differences between countries and organizations, there are many points of commonality and lessons learned (including failures and success factors) that may be transferable from countries that have well-developed programs for SNF and HLW disposal to those that are not as far along. Four general success factors are gaining public trust through public engagement and communication, mutual learning and listening, being prepared for a long process, and having a well-defined process that is both technically and socially acceptable.

System tools for an integrated waste management system

During the reporting period, DOE continued developing several decision-support tools, including the Next Generation System Analysis Model (NGSAM) and Stakeholder Tool for Assessing Radioactive Transportation (START), to assist in developing and managing an integrated waste management system. In 2022, the Board commended DOE for advancing development of NGSAM and expanding its capabilities to model individual elements of DOE SNF. The Board noted that NGSAM capabilities did not address various packaging/repackaging options, such as disposal of DPCs. The Board found value in expanding NGSAM capabilities and analyses to more completely address possible integrated waste management system options in support of consent-based siting activities. In 2023, the Board found that there were additional opportunities for developing and using START as a training tool and to improve DOE's outreach to other agencies. Based on these findings, the Board made two recommendations to improve DOE's development and application of system tools (see page 42-43).

International Activities

A broader goal of the Board, to monitor and be informed by activities in other countries related to programs for the management and disposal of radioactive waste, was advanced by visiting nuclear-waste-related facilities in two countries, publishing resources on national nuclear waste programs, participating in an international nuclear waste organization's activities, and interacting with foreign nuclear waste experts. Members of the Board and staff traveled to Switzerland in October 2022 to visit the site of the proposed Swiss geologic repository, to meet with representatives of national nuclear waste organizations, and to tour the Zwilag SNF interim storage facility and the Mont Terri URL. Members of the Board and staff traveled to Ontario, Canada, in October 2023 to meet with the Nuclear Waste Management Organization (NWMO), the Canadian implementer, to tour NWMO's disposal technology demonstration facility, to visit South Bruce, a potential repository host community, and to tour NWMO's associated rock core storage facility and local information

center. In July 2022, the Board released a report that provides an update to the Board's survey of 13 international waste disposal programs and provides useful technical and scientific information as well as major milestones reached by each program. In September 2024, the Board also released an online, interactive Table of Repository Programs on the Board's website that summarizes the progress in developing repository programs around the world for disposal of SNF and HLW. Board staff participated in four meetings of the Nuclear Energy Agency's Integration Group for the Safety Case (IGSC) and attended an IGSC workshop in New Jersey on extended storage and transportation of SNF. During the reporting period, the Board received presentations from experts from Canada, Finland, Spain, Sweden, and Switzerland and met locally with representatives of the Australian, Canadian, Finnish, and French nuclear waste disposal programs when they were visiting the United States.

PREFACE

Congress established the U.S. Nuclear Waste Technical Review Board as part of the Nuclear Waste Policy Amendments Act of 1987 to "evaluate the technical and scientific validity" of the actions taken by the Secretary of Energy to implement the Nuclear Waste Policy Act.

This report provides a summary of the activities carried out by the Board between January 1, 2022, and December 31, 2024. Among these activities are observations, findings, conclusions, and recommendations recorded by the Board in its letters and reports. This report records the views of the Board at the time they were published. The format of observations, findings, conclusions, and recommendations recorded in this report matches those in each cited letter and report.

BOARD ACTIVITIES

The Board and Its Mission

The U.S. Nuclear Waste Technical Review Board (Board) was established by Congress in Title V of the Nuclear Waste Policy Amendments Act of 1987 (NWPAA), P.L. No. 100-203. The Board's mandate is to "evaluate the technical and scientific validity of activities undertaken" by the U.S. Secretary of Energy to implement the Nuclear Waste Policy Act of 1982 (NWPA), P.L. No. 97-425, as amended. Among other things, Congress charged the Board with evaluating the U.S. Department of Energy's (DOE's) site characterization activities, and activities relating to packaging and transporting high-level radioactive waste (HLW) and spent nuclear fuel (SNF).

The Board is an independent federal agency within the Executive Branch. Members of the eleven-person Board serve part-time and are appointed by the President from a list of nominees prepared by the National Academy of Sciences. For the period covered by this report, the members of the Board who served included: Dr. Peter Swift (Chair); Dr. Jean M. Bahr (former Chair); Dr. Richelle Allen-King; Dr. Ronald G. Ballinger; Mr. Lake Barrett; Dr. Steven M. Becker; Mr. Allen G. Croff; Dr. Teresa Fryberger; Dr. Miles Greiner; Dr. Tissa H. Illangasekare; Dr. Silvia Jurisson; Dr. Kenneth Lee Peddicord; Dr. Nathan Siu (former Chair); Dr. Seth Tuler; Dr. Paul J. Turinsky; Dr. Scott Tyler; and Dr. Brian Woods.[1] Appendix A contains biographies of each member.

The Board is required to report its findings, conclusions, and recommendations to Congress and the Secretary of Energy. This report summarizes the Board's activities beginning on January 1, 2022, and ending on December 31, 2024.[2] Figure 1 presents a timeline of Board activities, meetings, and correspondence during this timeframe. The Board's website, www.nwtrb.gov, contains all the correspondence, reports, and meeting materials.[3] In addition, the Board began streaming its meetings over the Internet starting in June 2017. Those webcasts are archived on the Board's website. The Board's strategic plan is also on the website and is reproduced in Appendix B. Appendix C lists and describes all the Board's reports since its inception, and these reports are archived on the Board's website. Appendix D lists, for this reporting period, each of the meetings and their topics. Appendix E lists and

[1] Dr. Jean M. Bahr, Chair, was replaced by a newly appointed Chair, Dr. Nathan Siu, in December 2022. Dr. Paul J. Turinsky resigned in May 2024. Dr. Steven M. Becker, Dr. Kenneth Lee Peddicord, Mr. Allen G. Croff, and Dr. Tissa H. Illangasekare were replaced by new Board members in September 2024. Dr. Peter Swift was designated as Chair in September 2024. Dr. Ronald G. Ballinger resigned from the Board in January 2025. Mr. Lake Barrett resigned from the Board in May 2025. The appointments of Drs. Richelle Allen-King, Miles Greiner, Silvia Jurisson, Nathan Siu, Seth Tuler, Scott Tyler, and Brian Woods were terminated in July 2025.

[2] This report does not discuss the Board's 2021 summary report to Congress and the Secretary of Energy (NWTRB 2022a) that summarized Board activities that occurred from January 1, 2019, until December 31, 2021.

[3] The website also contains factsheets that the Board developed solely to provide information on, and increase understanding of, technical issues related to the management and disposal of SNF and HLW.

reproduces the correspondence to and from DOE during the period of January 1, 2022, to December 31, 2024.

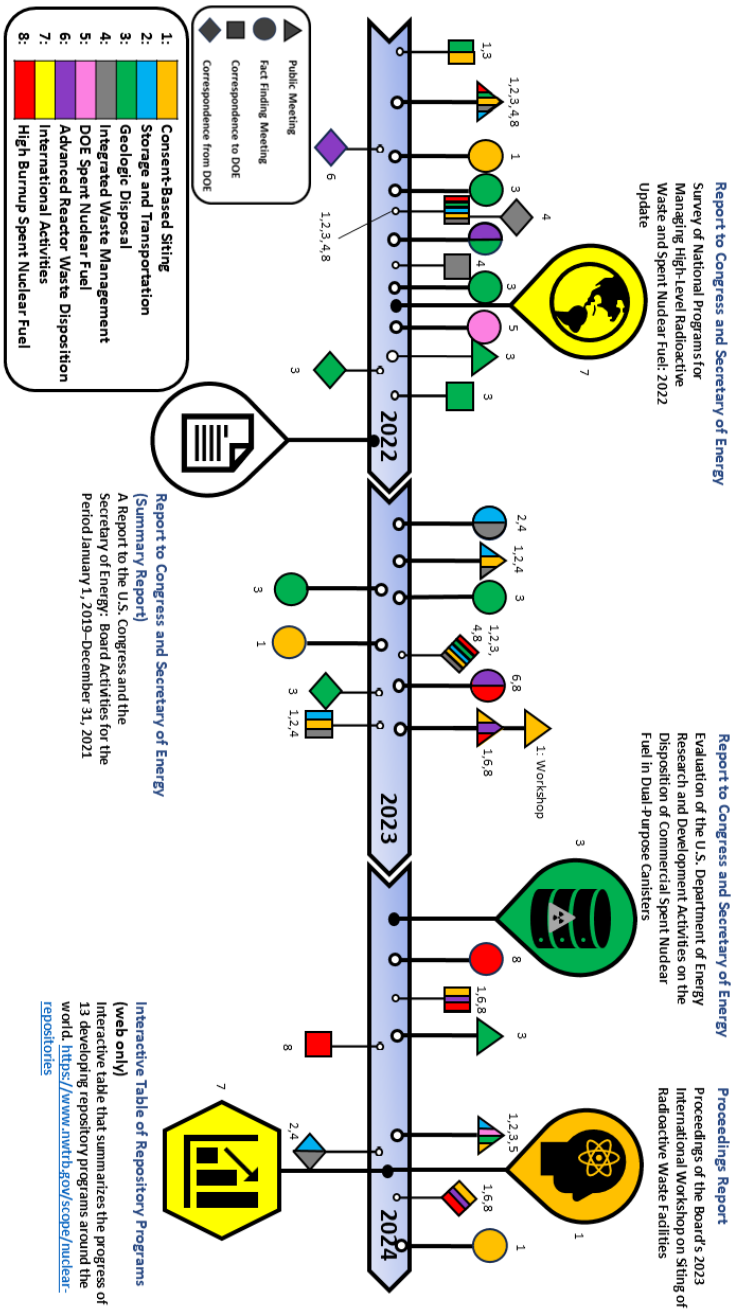

Figure 1. Timeline of Board activities, meetings, and correspondence from January 1, 2022, to December 31, 2024.
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Developments in Nuclear Waste Management

In passing the NWPAA in 1987, Congress instructed DOE to limit its efforts to characterize a site for a deep-mined geologic repository to Yucca Mountain in Nevada. Since then, the Secretary of Energy nominated the site, Congress approved the site, and in 2008, DOE applied for a construction authorization to the U.S. Nuclear Regulatory Commission (NRC). In 2010, Congress halted appropriations for the project. DOE suspended its Yucca Mountain program in 2010, and NRC suspended its licensing proceeding in 2011. Details on those developments and other developments through 2015, such as the Blue Ribbon Commission on America's Nuclear Future (BRC), are available in the Board's previous summary report (NWTRB 2022a). DOE's activities during this reporting period have been influenced by the BRC report (BRC 2012) and DOE's response to the report (DOE 2013).

The BRC recommendations had several key elements related to the NWPA (BRC 2012):

- "A new consent-based approach to siting future nuclear waste management facilities.
- A new organization dedicated solely to implementing the waste management program and empowered with the authority and resources to succeed.
- Access to the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management.
- Prompt efforts to develop one or more geologic disposal facilities.
- Prompt efforts to develop one or more consolidated storage facilities.
- Prompt efforts to prepare for the eventual large-scale transport of spent nuclear fuel and high-level waste to consolidated storage and disposal facilities when such facilities become available."

DOE responded to the BRC's report in *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste* (DOE 2013). Although many details of implementation were left to future discussions with lawmakers and other interested and affected parties, it included two major outcomes (DOE 2013):

> "The Administration endorses the key principles that underpin the BRC's recommendations. The BRC's report and recommendations provide a starting point for this Strategy, which translates many of the BRC's principles into an actionable framework within which the Administration and Congress can build a national program for the management and disposal of the nation's used nuclear fuel and high-level radioactive waste. . . .
>
> . . . [T]his Strategy endorses a waste management system containing a pilot interim storage facility; a larger, full-scale interim storage facility; and a geologic repository in a timeframe that demonstrates the federal commitment to addressing the nuclear waste issue, builds capability to implement a

> program to meet that commitment, and prioritizes the acceptance of fuel from shut-down reactors."

DOE has continued to pursue two key initiatives from its *Strategy* report, each of which has been considered by the BRC. The first key initiative being pursued by DOE is consent-based siting of nuclear waste storage and disposal facilities. In a *Federal Register* notice (DOE 2015c), DOE stated that it was implementing:

> "[A] consent-based siting process to establish an integrated waste management system to transport, store, and dispose of commercial spent nuclear fuel and high-level defense radioactive waste. In a consent-based siting approach, DOE will work with communities, tribal governments and states across the country that express interest in hosting any of the facilities identified as part of an integrated waste management system."

Evaluating options for transportation of SNF from shut-down reactors was the subject of DOE's second initiative. In 2013, DOE began evaluating "the inventory, transportation interface, and shipping status of used nuclear fuel at shut-down reactor sites" (DOE 2013). In 2015, DOE awarded a contract to design and develop a prototype 12-axle railcar that would meet the Association of American Railroads' standard for transport of SNF and HLW. DOE's prototype transport cask car, called the "Atlas railcar," was designed for transport of commercial SNF. In 2020, DOE began a similar development effort for an 8-axle prototype transport cask car, called the "Fortis railcar."

The *Strategy* (DOE 2013) noted that DOE was undertaking activities within existing congressional authorization to plan for the eventual transportation, storage, and disposal of SNF. DOE's activities included conducting research and development (R&D) on the suitability of various geologic environments for a repository. These non-site-specific studies focused on disposal in a mined geologic repository constructed in salt, clay/shale, and crystalline host rocks.

In 2017, the Administration of President Donald Trump redirected budget priorities and changed DOE's program direction. DOE terminated the consent-based siting effort and worked on a deep borehole disposal initiative. Instead, DOE continued its efforts to develop an integrated waste management system that was consistent with the *Strategy* (DOE 2013). This meant that DOE conducted R&D on storage, packaging, transportation, and non-site-specific geologic disposal options for both commercial and defense SNF and HLW.

In 2020, the Administration of President Donald Trump requested funding "dedicated to performing activities that would lay the groundwork necessary to ensure near-term deployment of interim storage to ensure safe and effective consolidation and temporary storage of nuclear waste." Congress appropriated $20 million that was directed to be used for interim storage. In 2021, the Administration of President Joseph Biden refocused the interim storage effort and DOE began to develop a consent-based siting process for siting one or more federal interim storage facilities.

The Consolidated Appropriations Act of 2022 provided DOE with $5 million for advanced reactor used fuel disposition R&D to address used fuel from tri-structural isotropic (TRISO)-fueled and metal-fueled advanced reactors. In 2024, President Joseph Biden signed into law the ADVANCE [Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy] Act, which takes substantial steps in helping to expedite development and deployment of advanced nuclear reactor technologies. A key provision of the Act addresses nuclear fuel cycle and nuclear waste management and requires DOE to biennially report to Congress on SNF and HLW inventory and status, liabilities, and recent actions taken regarding interim storage and technology developments for storage and transportation. In 2024, in response to the ADVANCE Act, DOE began a systematic review and reprioritization effort of its current storage, transportation, and disposal R&D program.

Fulfilling its obligations under the NWPA as amended, the Board maintained a "watching brief" over technical and scientific aspects of these initiatives.

Board Review: Disposal in a Mined Geologic Repository

In this reporting period, DOE continued to develop and evaluate different disposal concepts that would apply across the inventory of commercial and DOE SNF and HLW. DOE's disposal R&D was intended to provide a sound technical basis for multiple viable disposal options in the U.S., to increase confidence in the robustness of generic disposal concepts, to develop the science and engineering tools needed to support disposal concept implementation, and to utilize international experience and develop the U.S. program. DOE's non-site-specific disposal research program included host-rock (argillite, crystalline, and salt) studies and cross-cutting investigations (Figure 2). DOE has relied heavily on its international collaborations in disposal research (Figure 2), especially from underground research laboratories (URLs), to obtain data and gain understanding of the characteristics and processes that may occur in repositories sited in the three host rocks. A key aspect of DOE's disposal R&D program has been the development of the Geologic Disposal Safety Assessment (GDSA) (Figure 2) software framework that evaluates post-closure repository performance in various host rock types. During this reporting period, the Board's efforts focused on an overall assessment of DOE's non-site-specific disposal R&D program and DOE's evaluation of disposition of commercial SNF in dual-purpose canisters (DPCs)—canisters designed with the dual purpose of storage and transportation of SNF but not with consideration of disposal. In 2024, as DOE began a review and reprioritization effort of its R&D portfolio, the Board focused on understanding DOE's technical basis for the reprioritization from generic R&D to reducing risk and liabilities.

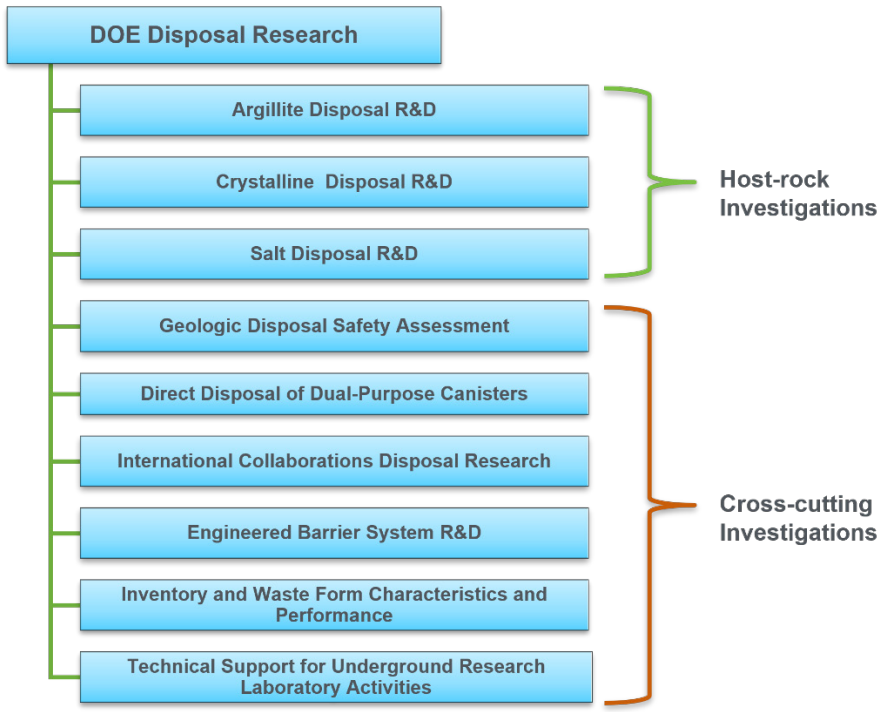


Figure 2. DOE disposal research investigations.
Note: Revised from (Gunter 2020). The "Technical Support for Underground Activities Program Area" is focused on domestic URLs.

Non-site-specific disposal R&D

DOE's roadmap for its generic (i.e., non-site-specific) disposal R&D focused on disposal R&D concepts in three potential host rocks—crystalline, salt, and argillite (Sevougian 2019)—and identified the need to better understand and model high temperature processes associated with the disposal of DPCs (Figure 3). In Figure 3, the horizontal green, blue, magenta, and red lines depict the approximate waste package thermal power limit, at emplacement, for the different disposal host rocks that are described in the text boxes. The points A, B, C, and D depict that a waste package containing a DPC with 32 assemblies having a burnup of 40 GWd/MTU would require <50 years, 50 years, 150 years, and >200 years, respectively, of aging prior to emplacement in a repository in the described unsaturated hard rock, salt, argillite, and saturated hard rock repository.

DOE began to develop higher temperature disposal concepts that would accommodate disposal of DPCs. Since its initial Disposal Research R&D 5-Year Plan (Sassani 2020), DOE has been producing updates to the 5-Year R&D Plan. In 2023, DOE released the second update to the R&D 5-Year Plan, and four focus areas were identified for the next five years, including GDSA capabilities development and demonstration, international collaboration and URLs, engineered barrier system representations, and evaluation of potential disposal of DPCs. With passage of the ADVANCE Act in July 2024, DOE began to review and reprioritize its disposal, storage, and transportation R&D activities, moving away from generic activities to applied activities that could reduce DOE's liabilities for managing, storing, transporting, and disposing of SNF and HLW.

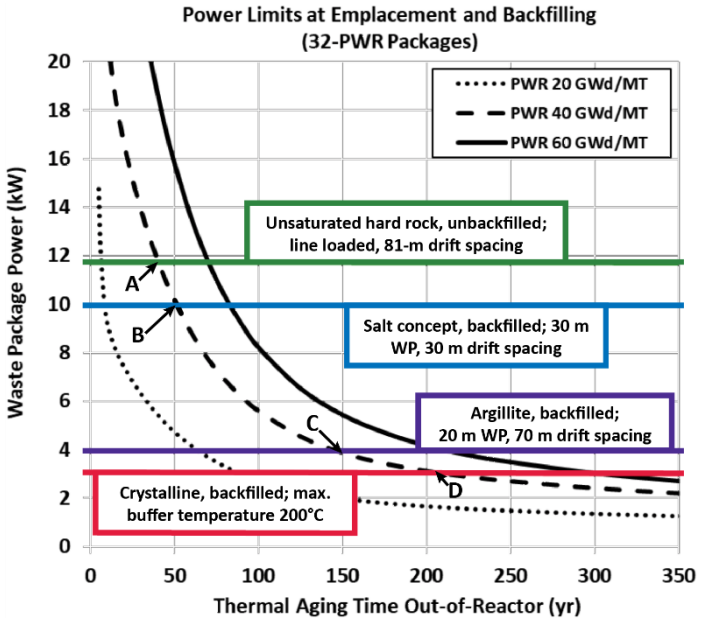


Figure 3. Thermal power versus age for a waste package containing a DPC with 32 assemblies of pressurized water reactor SNF. Note: Figure taken from (Hardin 2020) and revised for clarity.

During the reporting period, the Board reviewed DOE's R&D activities on argillaceous and crystalline host rocks, including the development of the GDSA applied to those host rocks and corrosion of commercial SNF after disposal, clay-based engineered barriers, and DOE's post–ADVANCE Act review and reprioritization of its disposal R&D program. The Board held three public meetings, conducted three fact-finding meetings, sent four letters to DOE, and received two letters from DOE.

The Board's January 7, 2022, letter to DOE on the Board's November 2021 public meeting on the GDSA, which included four findings and recommendations, was summarized in the Board's last summary report (NWTRB 2022a). DOE responded to the Board's letter in September 2022 (DOE 2022a) and stated that it continues to ensure the GDSA capability is applicable to disposal in a variety of host rocks and includes the features, events, and processes most relevant to the generic R&D program. DOE stated that drawing conclusions about the relative performance of generic disposal concepts at this point is premature given the nature of such generic reference cases in this conceptual stage, which is focused on demonstrating the GDSA capabilities. In response to the Board's recommendation for DOE to develop the GDSA further in the near term to assess the performance of different engineered barriers and disposal options, DOE stated further R&D on detailed engineered barrier design/evaluation/selection would likely occur within a program in the site-selection stage. DOE agreed that peer review is important to the development and credibility of the complex set of tools required for probabilistic performance assessment.

In September 2022, the Board held a public meeting that focused on a review of DOE's efforts to develop models and generate experimental data for understanding and predicting the long-term performance of geologic repositories in argillaceous host rocks and clay-based engineered barriers, such as bentonite buffer and backfill. A focus of DOE's R&D efforts at that time was on understanding bentonite behavior when subjected to high temperatures. DOE representatives summarized R&D on clay-based engineered barriers, numerical model development to assess the long-term integrity of argillaceous host rocks, and information on how the process-level models of argillaceous host rock and engineered barrier system behavior are integrated into the GDSA framework. Non-DOE experts, including one from Spain, described the technical challenges related to conducting laboratory experiments at high temperatures as well as technical issues in characterizing argillaceous formations and key technical gaps. The Board was encouraged by ongoing DOE efforts to collaborate with and leverage experience from disposal programs in other countries. DOE's progress on addressing technical gaps and R&D tasks was unclear to the Board based on reports and information presented at the fact-finding and public meetings. The Board noted that DOE used the GDSA framework to assess repository performance for the argillite reference case, but DOE had not evaluated repository performance for alternative scenarios, e.g., scenarios wherein the bentonite buffer is either absent or is replaced with a buffer made of crushed host rock. The Board also noted several technical and programmatic issues related to the disposal R&D program and DOE's current efforts to employ a consent-based approach to siting one or more federal consolidated interim storage facilities. The Board commended DOE for exploring how URLs can play an important role in public outreach and communication and attracting and training the next generation of waste disposal scientists and engineers. After examining the information gathered at an earlier fact-finding meeting and presented at the public meeting, the Board sent DOE a letter (Bahr 2022a) containing its findings and recommendations, as follows:

- *The Board finds that DOE has a technically valid approach to developing its modeling capability that will enable it to evaluate the post-closure performance of a potential SNF and HLW repository in an argillaceous host rock.*

- *The Board encourages DOE to continue its R&D efforts related to argillaceous host rocks and clay-based engineered barriers, including leveraging the experience of disposal programs in other countries.*

- *The Board finds that DOE has not clearly articulated the progress of its R&D activities related to argillaceous host rocks and clay-based engineered barriers toward achieving its program objectives and addressing the technical gaps.*

- *The Board recommends that DOE assess the overall progress of its R&D activities relative to achieving the stated objectives and addressing the identified technical gaps and how each R&D task contributed to understanding processes in the natural and engineered barrier systems and to developing DOE's argillite reference case. This self-assessment could also serve as a tool for knowledge management and for clear and effective communication on its disposal options, including disposal in argillaceous rocks. Ongoing and future assessments could help refine the focus of DOE's R&D activities documented in the disposal R&D 5-year plan.*

- *The Board finds that additional analysis is required to clarify the relative importance of the bentonite buffer on the performance of a repository in an argillaceous host rock.*

- *The Board recommends that DOE assess the performance of argillite repositories with no buffer or with a crushed host rock buffer.*

- *The Board finds insufficient integration between DOE activities related to consent-based siting of federal consolidated interim storage facilities and those related to geologic disposal.*

- *The Board recommends integration of DOE activities related to consent-based siting of federal consolidated interim storage facilities and those related to geologic disposal to enable effective public and stakeholder engagement.*

- *The Board commends DOE for recognizing the importance of URLs in training the next generation of scientists and engineers.*

- *The Board recommends that DOE further consider how URLs and other DOE facilities could play a role in public information and community engagement efforts and in training programs. As DOE proceeds with its consent-based siting process for federal consolidated interim storage facilities, systematic consideration should be given to how URLs and other facilities might contribute. This should include systematically reviewing and learning from the experiences by other countries.*

DOE responded to the Board's letter in August 2023 (DOE 2023a) and stated that the disposal R&D program maintains awareness of activities focused on consent-based siting for consolidated interim storage, both in the U.S. program and in international nuclear waste management efforts. DOE at that time was also considering how consent-based siting could be adapted for siting deep geologic repositories in the future. However, because Congress

had not authorized DOE to pursue consent-based siting for disposal, the primary focus for DOE remained on federal consolidated interim storage. DOE also stated that the use and leveraging of URLs both internationally and at the U.S. Waste Isolation Pilot Plant facility are fundamental aspects of the U.S. geologic disposal R&D program. DOE stated that it was in the beginning stages of evaluating the potential uses of a U.S. URL for geologic disposal R&D as well as for public outreach. DOE stated that it was adjusting how features, events, and processes for each generic repository concept are integrated with the R&D efforts and defining the technical bases for each concept such that additional analyses of barrier function/reliance would be facilitated.

In May 2024, the Board held a public meeting in Knoxville, Tennessee, to review DOE's R&D activities related to non-site-specific disposal of radioactive waste in crystalline host rocks and corrosion of commercial SNF after disposal. To prepare for the public meeting, the Board and DOE participated in two fact-finding meetings in April. In the May public meeting, the Board heard presentations from DOE that focused on assessing the performance of a repository in crystalline host rock using the GDSA framework. National laboratory staff also presented research activities related to disposal in crystalline host rocks, including site characterization, physical and chemical processes, buffer behavior, conditions in the engineered barrier system, and the integration of process models into the GDSA framework. Experts from Canada and Finland described crystalline rock site characterization and the status and lessons learned from the Finnish crystalline rock geologic repository program. Additionally, DOE described ongoing work developing a Fuel Matrix Degradation Model (FMDM) to model the corrosion of commercial SNF under various repository conditions that could be included in the GDSA.

Regarding corrosion of commercial SNF after disposal, the presentations included information on modeling the degradation rate of commercial SNF, process model coupling and implementation within the GDSA framework, international collaborations that DOE was engaged with, and a strategic approach to fill the knowledge gaps that were identified for waste form degradation. The Board also heard presentations addressing the FMDM, surrogate models, and electrochemical testing used to obtain the data needed for model implementation.

Based on the information presented and discussed at the fact-finding meetings and the public meeting, the Board sent a letter to DOE (Swift 2025a) and commended DOE for its leadership and participation in international collaborative research projects on geologic disposal. The Board noted that DOE is using state-of-the-art modeling approaches and methods of analysis for evaluating and predicting long-term repository performance in crystalline host rock. The Board observed that DOE's focus on international collaborations has been effective in advancing DOE's state of knowledge related to nuclear waste disposal. The Board encouraged DOE to build on past collaborations to leverage advances in geophysical characterization techniques and tools from other industries. The Board noted that given the overall uncertainties in the system characteristics and performance, and in particular in the FMDM, it is essential that the program defines what is "good enough" for the models in the FMDM to avoid unnecessary effort for limited benefit.

In August 2024, the Board held a public meeting that included a DOE Office of Nuclear Energy (DOE-NE) program update that addressed an effort to reprioritize its storage, transportation, and disposal R&D activities. DOE stated that the ADVANCE Act is expected to lead to changes in priorities from generic R&D to more focus on reducing risk and liabilities. DOE stated it would be refocusing its program using a risk-informed approach, including developing a risk register, and that future R&D would have to have a clear programmatic need that reduces risk and liabilities. The Board noted that a key to accurate estimates of liabilities and life-cycle costs is the number of facilities for storage and disposal, their assumed start dates for operations, and the technical bases underlying the analyses and assumptions (Swift 2025b). The Board noted that another key cost consideration is the potential need to repackage commercial SNF in DPCs to facilitate disposal of the SNF. The Board encouraged DOE to provide additional details on its revised integrated waste management program and to address the assumptions, analyses, and technical bases, and how DOE has addressed relevant Board recommendations in developing the revised program (Swift 2025b).

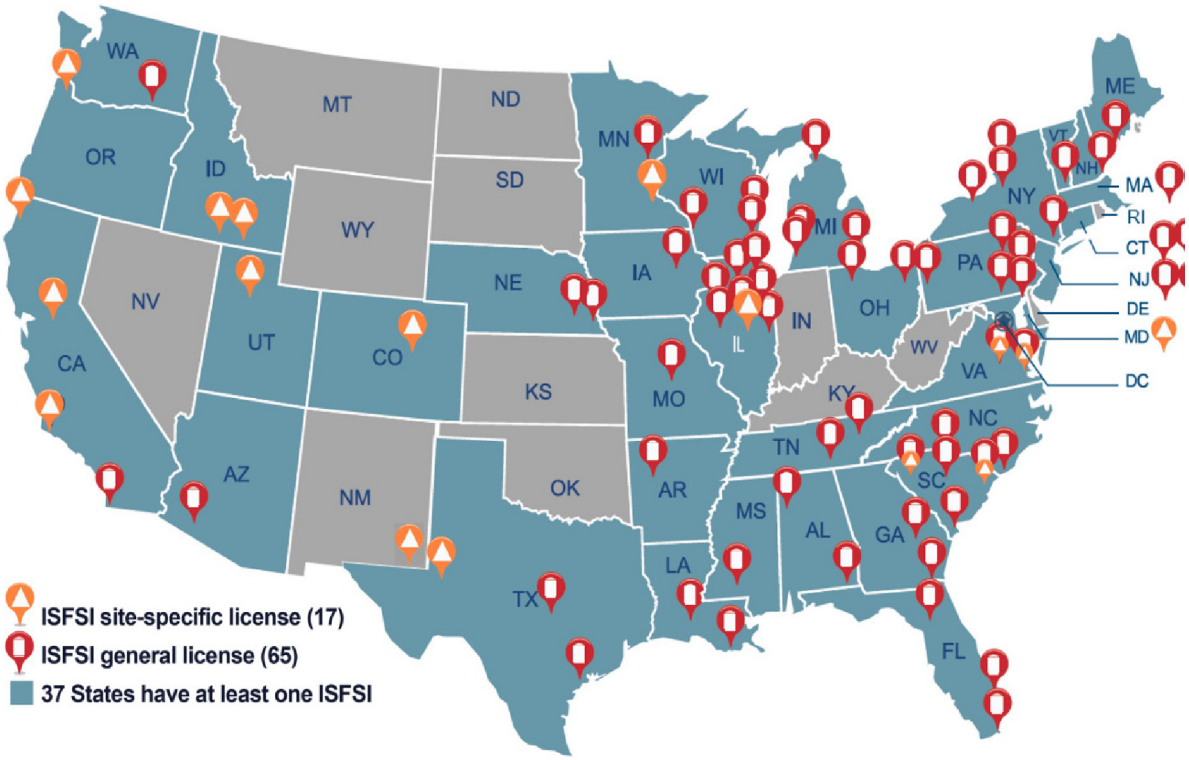
During the reporting period, members of the Board staff also attended three meetings and toured a DOE facility related to DOE's non-site-specific disposal R&D:

- Thirteenth U.S./German Workshop on Salt Repository Research, Design and Operation, held in New Mexico in October 2023, to obtain information on U.S. and international R&D activities relevant to salt repositories.
- Tour of the Yucca Mountain, Nevada, repository site in November 2023 to obtain information on DOE's potential use of the site to host URL experiments.
- DOE's Spent Fuel and Waste Science and Technology Annual Program Review Meetings held in 2022, 2023, and 2024, to obtain updates on DOE's activities.
- Integration Group for the Safety Case (IGSC), Safety Case Symposium 2024, *Moving towards the construction of a safe deep geologic repository (DGR)—Getting real*, held in Budapest, Hungary, in October 2024 to obtain an update on the DOE-led international collaboration on sensitivity analyses in safety assessments for geologic disposal facilities.

Disposal of SNF in dual-purpose canisters

In the United States, commercial SNF is stored at over 70 sites across the country, including operating and decommissioned nuclear power plant sites. SNF continues to be generated at a rate of more than 2,200 metric tons of heavy metal per year. Much of the commercial SNF inventory has been stored inside dry-storage casks at independent spent fuel storage installations (ISFSIs) associated with nuclear power plants (Figure 4) because the spent fuel pools at the plants do not have the storage capacity to accommodate all the SNF discharged from the reactors. Figure 4 shows the ISFSIs for which licenses have been approved by the NRC as of June 2023. By June 2023, almost 4,000 dry-storage casks were in service. The number of DPCs is projected to increase to about 10,000 by 2080, when projections indicate

that all SNF discharged from power plants will have been transferred from spent fuel pools into dry storage.



ALABAMA
- Browns Ferry
- Farley

ARIZONA
- Palo Verde

ARKANSAS
- Arkansas Nuclear

CALIFORNIA
- Diablo Canyon
- Humboldt Bay
- Rancho Seco
- San Onofre

COLORADO
- Fort St. Vrain

CONNECTICUT
- Haddam Neck
- Millstone

FLORIDA
- Crystal River
- St. Lucie
- Turkey Point

GEORGIA
- Hatch
- Vogtle

IDAHO
- DOE: Three Mile Island 2 (Fuel Debris)
- DOE: Idaho Spent Fuel Facility *

ILLINOIS
- Braidwood
- Byron
- Clinton
- Dresden
- GEH Morris (Wet)
- LaSalle
- Quad Cities
- Zion

IOWA
- Duane Arnold

KANSAS
- Wolf Creek

LOUISIANA
- River Bend
- Waterford

MAINE
- Maine Yankee

MARYLAND
- Calvert Cliffs

MASSACHUSETTS
- Pilgrim
- Yankee Rowe

MICHIGAN
- Big Rock Point
- Cook
- Fermi 2
- Palisades

MINNESOTA
- Monticello
- Prairie Island

MISSISSIPPI
- Grand Gulf

MISSOURI
- Callaway

NEBRASKA
- Cooper
- Ft. Calhoun

NEW HAMPSHIRE
- Seabrook

NEW JERSEY
- Hope Creek
- Oyster Creek
- Salem

NEW MEXICO
- Holtec Consolidated Interim Storage Facility (CISF)*

NEW YORK
- FitzPatrick
- Ginna
- Indian Point
- Nine Mile Point

NORTH CAROLINA
- Brunswick
- McGuire

OHIO
- Davis-Besse
- Perry

OREGON
- Trojan

PENNSYLVANIA
- Beaver Valley
- Limerick
- Peach Bottom
- Susquehanna
- Three Mile Island

SOUTH CAROLINA
- Catawba
- Oconee
- Robinson
- Summer

TENNESSEE
- Sequoyah
- Watts Bar

TEXAS
- WCS Consolidated Inter Storage Facility (CISF)*
- Comanche Peak
- South Texas Project

UTAH
- Private Fuel Storage*

VERMONT
- Vermont Yankee

VIRGINIA
- North Anna
- Surry

WASHINGTON
- Columbia

WISCONSIN
- Kewaunee
- La Crosse
- Point Beach

* Facility licensed only, never built or operated.

Figure 4. U.S. locations of independent spent fuel storage installations. Modified after (NRC 2023).

Notes: The Colorado and Idaho locations are managed by DOE. The Waste Control Specialists (WCS) location in Texas and the Holtec location in New Mexico are proposed by commercial companies as consolidated interim storage facilities. The General Electric (GE) facility at Morris, Illinois, is a pool that was built as part of a commercial reprocessing facility. Only the pool was put into operation.

The design of most dry-storage casks involves large, welded canisters known as DPCs. Storage of SNF in DPCs and the trend toward larger DPCs will have significant implications on the later stages of the national SNF management and disposal system. Repackaging the SNF from DPCs into smaller waste packages that may be needed for disposal in a repository would be a major undertaking. If DOE chooses not to repackage SNF into smaller waste packages and decides to dispose of higher-heat load and large waste packages (see Figure 3), then it would need to develop the technical bases for new repository designs and operations that are beyond what was planned for the Yucca Mountain project and beyond what other countries are implementing.

DOE's R&D activities related to the feasibility of repository disposal of commercial SNF in DPCs (both currently loaded DPCs and future loaded DPCs) in overpacks[4] focused on three areas:

- The consequences of potential criticality events on the long-term performance of a geologic repository after closure;
- Potential filler materials that could be injected as liquids into existing DPCs, where they solidify and prevent groundwater ingress into breached DPCs and, thereby, reduce the probability for nuclear criticality (Figure 5); and
- Modifications to future DPCs so they remain subcritical in any repository setting.

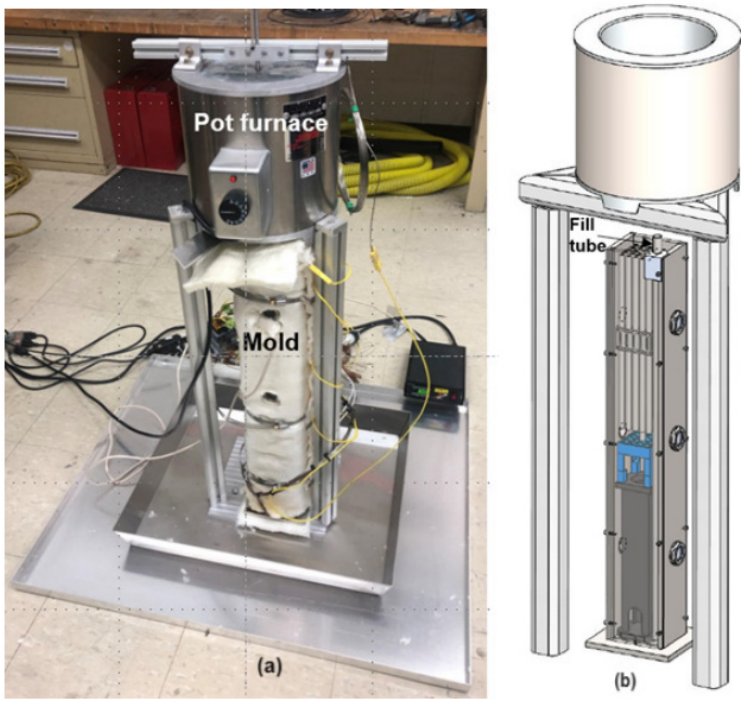


Figure 5. Canister filling test apparatus and drawing showing the pour test internals. (a) Test setup with pot furnace above the insulated mock-up mold. (b) Drawing of pot furnace on a stand and mold with 5 × 5 array of simulated fuel rods atop a stand representing a bottom spacer. The mold has internal dimensions of 68.6 cm × 7 cm × 8.6 cm. The simulated fuel rods are 30.5 cm long, and the stand is 57.8 cm tall. The fill tube runs along the front corner of the mold and is 1.42 cm in inner diameter. Source: (Fortner 2022)

[4] The Board uses the term "direct disposal" to capture the concept of repository disposal of commercial SNF in DPCs in disposal overpacks.

During the reporting period, the Board focused its review of DOE's R&D efforts to support the potential disposal of commercial SNF in DPCs. The Board held one public meeting that included updates related to DPC R&D activities, held two fact-finding meetings, sent one letter to DOE, received one letter from DOE, and released a technical report on a multi-year review of DOE's DPC R&D activities (Figure 1).

The Board's public meeting in March 2022 reviewed DPC R&D efforts among several other topics. DOE and laboratory staff updated the Board on DOE's assessment of the feasibility of direct disposal of commercial SNF in DPCs, including its assessment of post-closure criticality consequences. The Board heard about an independent technical review that was conducted on DOE's DPC direct disposal R&D program and how DOE was currently evaluating the observations from that review. The Board then held two fact-finding meetings, in May and June 2022, to gain more information on specific topics, including how DOE intends to respond to the independent technical review of its DPC disposal R&D.

Based on the information presented at the public meeting and the May 2022 fact-finding meeting, the Board sent DOE a letter (Bahr 2022b) containing its findings and recommendations, and those pertaining to DPCs are as follows:

- *The Board finds that additional analyses and quantitative information regarding the potential pros and cons of the DPC direct disposal option will be useful to decision-makers.*

- *To provide decision-makers with information about the pros and cons of direct disposal of DPCs versus repackaging of SNF assemblies currently in DPCs, the Board recommends that DOE complete quantitative assessments for both concepts spanning the waste management lifecycle. These assessments should include estimates of costs and radiation doses related to packaging (or repackaging) of SNF, transportation, interim storage, and repository operations, including the ramifications of disposal in alternative geological media.*

The Board's letter noted that if DOE decided to continue criticality consequence studies without simultaneously considering the probability for criticality to occur, then DOE would need to consider several questions and issues. Those questions are: How does criticality affect the performance of engineered barriers and host rock, particularly in environments such as a crystalline repository under saturated conditions, which has yet to be evaluated? Does the range of infiltration rates capture the full range of plausible infiltration rates for other settings where there also could be a thick unsaturated zone? The Board continued to review DOE's efforts to address the Board's questions and issues, which was the subject of the June 2022 fact-finding meeting, and reported its evaluation in a 2024 technical report. DOE responded to the Board's letter in July 2023 (DOE 2023b) and agreed with the Board that the recommended assessments would be useful to decision-makers and will be considered by DOE in the future.

In February 2024, the Board released a report focused on a multi-year review of DOE's DPC R&D activities, titled *Evaluation of the U.S. Department of Energy Research and Development Activities on the Disposition of Commercial Spent Nuclear Fuel in Dual-*

Purpose Canisters (NWTRB 2024a). The report described the historical context of how the nation's commercial SNF came to be stored in DPCs and examined three alternative approaches for managing commercial SNF: (1) storing SNF at ISFSIs indefinitely, (2) repackaging the SNF into smaller canisters before disposal, and (3) direct disposal of SNF in DPCs in a geologic repository.

The Board's 2024 report also summarized DOE's R&D activities related to the direct disposal of SNF in DPCs. The report recommended actions that could be taken to better assess and clarify the advantages and disadvantages of the different alternatives for managing commercial SNF. The report was intended to offer recommendations to DOE and to inform U.S. policymakers as they make the critical decisions that will be required in developing a national program for the management and disposal of SNF and HLW. Among the three alternative approaches, recent DOE R&D has been focused on direct disposal of SNF in DPCs, and thus the Board's review also focused on that option. The Board report focused on commercial SNF, but the Board noted that some of the issues related to storage and direct disposal or repackaging also apply to DOE SNF and other SNF that is stored at DOE sites.[5]

Overall, the Board observed that DOE has developed integrated waste management system tools (e.g., tools such as Next Generation System Analysis Model [NGSAM] and Performance Assessment of Strategy Options Model [PASO]) and tools to evaluate different repository concepts (e.g., the Geologic Disposal Safety Assessment [GDSA] framework), which could inform in-depth evaluation of the advantages and disadvantages of each alternative, but DOE had not yet conducted a fully comprehensive evaluation of the alternatives. Regarding criticality consequence analysis, where DOE examined hypothetical criticality events, the Board observed that the work DOE had completed to date can be characterized as preliminary but with the objective of gathering sufficient information so that the scope of future analyses can be defined with increased confidence. Regarding development and testing of DPC fillers, the Board encouraged DOE to continue with development and validation of computational capabilities that can be used for predicting canister filling and solidification of DPC fillers (both metal alloys and phosphate-based cements) for the range of canister designs and fuel loadings (Figure 5). The Board also observed that filler materials, especially metal/metal alloy fillers, can add significant weight to DPCs. Further, the Board observed that the use of fillers for DPCs and the facilities that would implement the technology would require approval by the NRC. Regarding the modification of DPCs to be loaded in the future, the Board observed that DOE was examining several options for modifying fuel assemblies and baskets for future DPCs to be loaded to reduce the probability of criticality after closure of a repository.

Based on reviews of DOE technical reports, fact-finding meetings with national laboratory and DOE personnel, and the presentations and discussions at Board public meetings, the Board made the following findings, conclusions, and recommendations in the report (NWTRB 2024a):

[5] The Board report, titled *Management and Disposal of U.S. Department of Energy Spent Nuclear Fuel* (NWTRB 2017) discusses issues related to the SNF stored at DOE sites.

- **Finding 1**: The Board finds that DOE has not fully analyzed, in an integrated manner, all the key aspects of the alternative approaches for managing commercial SNF such that a meaningful comparison of the alternatives can be made. Particular issues that need to be addressed include:

(1) The implications (time, effort, and cost) of identifying and finding a resolution for commercial SNF canisters approved by the NRC for storage, but which include contents not currently approved by the NRC for transportation.

(2) The implications for the design, construction, and operation of a geological repository of disposing of SNF in large DPCs versus disposing of SNF repackaged into smaller canisters, with a particular focus on waste package degradation, thermal management, postclosure criticality, and the engineering aspects of waste package emplacement in various rock types.

- ***Recommendation 1****: The Board recommends that DOE give higher priority to refining its systems analysis tools and completing comprehensive analyses that address issues (1) and (2) in Finding 1, as well as the other variables and complexities noted in this report. By doing so, decision-makers would be better informed of the pros and cons of the alternative approaches for implementing an integrated waste management system and better prepared to adopt one or a combination of alternative approaches that would be the most effective and efficient for the nationwide program.*

- **Finding 2a**: The Board finds that sufficient work has been completed to define the path forward regarding analyzing hypothesized postclosure criticality events. There is now sufficient information to determine going forward what simulation codes to be used in the analyses, events to be analyzed, and the parameters of interest to evaluate.

- **Finding 2b**: However, the Board finds that some of the DOE-sponsored evaluations of postclosure criticality may be based on assumptions that are not fully supportable, and some of the codes used in the criticality consequence analyses may not be appropriate. (See Section 4.2.1.1 of the Board's report)[6]

- ***Recommendation 2****: The Board recommends that DOE address the points noted in Finding 2b of this report regarding the ongoing consequence analysis of postclosure criticality.*

- **Finding 3**: The Board finds that a set of criteria needs to be developed for use in assessing the various options for modifying fuel assemblies and baskets for DPCs to be loaded in the future and in prioritizing R&D activities. The criteria could include (1) how rapidly each option could be implemented in practice, (2) how many DPCs to be loaded in the future potentially could benefit, (3) the associated cost of

[6] The Board provided specific comments and considerations on steady-state criticality events, transient criticality events, the initial isotopic inventory, and uncertainty quantification. For steady-state criticality events, the Board listed five items that DOE would need to consider. For transient criticality events, the Board listed eight items that DOE would need to consider (NWTRB 2024a).

implementation of each option per DPC, and (4) the criticality prevention effectiveness of each option.

- ***Recommendation 3****: The Board recommends that DOE establish a set of criteria to evaluate the various options for modifying fuel assemblies and baskets for DPCs to be loaded in the future. Using these criteria, DOE should assess the various options to determine R&D priorities. In developing the criteria and in evaluating the various options, the Board recommends DOE consultation with fuel owners and cask vendors to gain industry insights on and acceptance of potential DPC modifications.*

During the reporting period, members of the Board staff also attended five meetings related to DOE's DPC R&D activities:

- American Nuclear Society's International High-Level Radioactive Waste Management Conference in Phoenix, Arizona, November 2022, to present a summary paper on the Board's review of DOE's DPC efforts and obtain related DOE updates.

- Nuclear Energy Agency's Workshop on Extended Storage and Transportation of Spent Fuel and Radioactive Waste from Current and Future Reactor Technologies held in Camden, New Jersey, December 2023, to obtain updates on DOE's assessment of factors influencing repackaging and to tour the Holtec International manufacturing plant in which DPCs are produced.

- DOE's Spent Fuel and Waste Science and Technology Annual Program Review Meetings held in 2022, 2023, and 2024.

Board Review: Packaging, Storage, and Transportation of SNF and HLW

Packaging, storage, and transportation of SNF and HLW were among the topics the Board reviewed during the 2022 to 2024 period (Figure 1). After the 2010 suspension of the Yucca Mountain project, the nation's nuclear waste management priorities and strategies began to shift dramatically, and the Board began reviewing the scientific and technical information related to the extended storage and subsequent transportation of commercial SNF. Since 2010, the Board has conducted numerous review activities on DOE's packaging, storage, and transportation R&D efforts related to both commercial and DOE-managed SNF and HLW, e.g., (NWTRB 2010, 2017, 2019, 2021). In 2017, the Board released a report on the management and disposal of DOE SNF (NWTRB 2017). In 2019, the Board released a report on preparing for nuclear waste transportation (NWTRB 2019). In 2021, the Board published a report of the performance of high burnup[7] commercial SNF during extended dry storage and transportation (NWTRB 2021a). In this reporting period, the Board continued its

[7] Fuel burnup is a measure of the thermal energy generated in a nuclear reactor per unit mass of nuclear fuel and is typically expressed in units of gigawatt-days per metric ton of uranium (GWd/MTU). The yearly average burnup of SNF placed into storage increased from an average of about 35 GWd/MTU in the 1990s to over 45 GWd/MTU in 2018. Most SNF currently stored in the United States is low burnup fuel.

review of DOE activities on these three topics as DOE conducted work that addressed the Board's past recommendations (NWTRB 2017, 2019, 2021).

Two other topics that the Board reviewed during this reporting period were advanced reactor waste disposition and dry-storage canister corrosion. In the Consolidated Appropriations Act, 2022, Congress earmarked $5 million for DOE to conduct R&D that addresses SNF from TRISO-fueled and metal-fueled advanced reactors. DOE sought information from advanced reactor developers necessary to address regulatory and legal issues (such as with the Standard Contract[8]) and to identify storage, transportation and disposal R&D gaps related to SNF and HLW that could be generated by advanced reactors. Regarding canister corrosion, DOE has been conducting R&D to address issues related to the nature and risk of chloride-induced stress corrosion cracking (CISCC), an aging-related degradation mechanism that may occur in welded dry storage stainless steel canisters during extended dry storage of SNF.

For the 2022 to 2024 reporting period, the Board held four public meetings, participated in five fact-finding meetings, sent four letters to DOE, and received four responses from DOE (Figure 1). The public meetings addressed management of DOE SNF (August 2024), packaging and transportation of SNF and HLW (March 2023), advanced reactor waste disposition (August 2023), long-term dry storage and transportation of high burnup commercial SNF (March 2022 and August 2023), and dry-storage canister corrosion (March 2022). These activities are discussed in more detail below.

Management of DOE SNF

The DOE Office of Environmental Management (DOE-EM) manages a significant inventory of ASNF at three main sites: in wet storage at Savannah River Site (SRS) and in dry storage at Idaho National Laboratory (INL) and Hanford. The DOE-managed SNF (DOE SNF) inventory originates mostly from past weapons production and from foreign and domestic research reactor discharges. DOE SNF encompasses over 300 different SNF types from a wide range of reactor types, such as light water reactors (LWRs), heavy-water-moderated reactors, graphite-moderated reactors, and fast-breeder reactors. The DOE SNF has various cladding materials and enrichments varying from depleted uranium to over 93% enriched U-235. In 2017, the Board released a comprehensive report on DOE SNF, titled *Management and Disposal of U.S. Department of Energy Spent Nuclear Fuel* (NWTRB 2017). Three main issues addressed in the report were aging management, packaging, and disposal of DOE SNF. The 2017 Board report included characteristics of all types of DOE SNF and focused on the significant inventory of ASNF that will need to be adequately dried during packaging prior to transportation and disposal. Extended long-term dry storage of ASNF (over 50

[8] The Standard Contract for Disposal of SNF and/or HLW ("DOE Standard Contract") establishes the terms and conditions under which DOE will make available nuclear waste disposal services to the owners and generators of SNF and HLW. DOE will take title to, transport, and dispose of SNF and/or HLW delivered to DOE by those owners or generators who execute the contract. See Nuclear Waste Policy Act of 1982, sec. 302, Pub. L. 97–425, 96 Stat. 2257 (42 U.S.C. 10222).

years) produces some additional technical challenges related to corrosion of aluminum cladding and the potential for radiolytic gas generation.

Since 2017, DOE has been sponsoring Idaho National Laboratory (INL) to implement a technology development program focused on strengthening the technical basis for extended dry storage of ASNF. A technical basis would eventually enable licensing of a road-ready dry storage system for ASNF. The technology development program for ASNF conducts research related to corrosion of aluminum cladding, radiolysis processes, gas generation rates, and drying processes to remove bound water from the cladding corrosion layers. As DOE has removed SNF from the water-filled basins at INL, which was completed in 2023, it has moved ASNF into temporary unsealed dry storage containers. Since 2017, DOE has been planning to repackage the ASNF at INL and move it to long-term dry storage until a final disposition path is chosen. In 2022, DOE changed its SNF disposition plan for SRS SNF in wet storage.[9] At the Hanford site, the ASNF is in dry storage in multi-canister overpacks that are assumed to be "road-ready" but still need final NRC approval. For the 2022 to 2024 reporting period, the Board held one public meeting that focused on addressing the management of DOE SNF at SRS and INL, toured the INL SNF storage facilities in conjunction with hosting a workshop on siting of radioactive waste facilities, and held one fact-finding meeting with DOE-EM to gain updates on the research activities related to management and disposal of ASNF.

The Board held a fact-finding meeting in August 2022 to receive updates on the progress of ASNF research tasks and to follow up with DOE on a Board letter (Bahr 2021a) resulting from an August 2021 public meeting on ASNF. The Board heard how the overall program was focused on storage, not transportation. Also, INL staff noted that the NRC was not officially involved in the program activities at that time. INL staff provided updates on the technology development tasks and described which tasks were open, closed, or newly added. They provided updates on experimental work to generate quantitative data on radiolytic gas generation from corroded aluminum alloys and updates on the modeling efforts for predicting ASNF performance in sealed DOE Standard Canisters. INL staff described the mini-canister radiolysis testing for ASNF and progress on developing and testing drying recipes. INL staff are also performing preliminary bounding pressurization estimates and flammability evaluation (i.e., hydrogen generation) for potential configurations of dry storage of DOE-managed ASNF. There were also updates on the Instrumented Lid Project, which involves sensor development for in-situ remote monitoring of ASNF in vented (unsealed) dry storage canisters that are stored at the CPP-603 facility at INL. INL staff explained new evaluations to determine the bounding pressure and H_2 gas concentration in a sealed DOE Standard Canister, for at least two potential loading configurations of Advanced Test Reactor SNF elements in two types of canisters with different dimensions.

[9] DOE approved a new plan that will accelerate the disposition of SNF at SRS by more than 20 years and result in a savings of more than $4 billion. Under the newly approved approach, called Accelerated Basin De-inventory (ABD), SRS will dissolve SNF at the site's H Canyon chemical separations facility (without uranium recovery) and send it through the site's liquid waste system to be vitrified and safely stored onsite until a federal repository is identified. Not all the SNF will be able to be processed before a State of South Carolina deadline, and disposition of the remaining SNF in wet storage remains to be decided.

In August 2023, the Board held an international workshop on siting of radioactive waste facilities in Idaho Falls, Idaho. To help prepare for a planned 2024 public meeting on DOE SNF, the day prior to the workshop, the Board and staff toured the INL site, focusing on DOE SNF storage facilities and analytical laboratories that DOE uses to characterize SNF.

In August 2024, the Board toured SNF and HLW facilities at SRS and held a public meeting in North Augusta, South Carolina, to review information on management and plans for disposal of DOE SNF. At the meeting, DOE-EM presented updates on DOE SNF storage, transportation, and plans for disposal, including a discussion of program successes, such as DOE's Spent Nuclear Fuel Working Group (SNFWG), and challenges. The Board received an update on the technology development program activities related to management of ASNF. SRS personnel summarized SNF management at the SRS L-Basin facility, including the types and amounts of stored SNF, storage capacities of the different types of storage, preparations for processing SNF in H-Canyon, and a planned SNF dry storage demonstration. SRS personnel provided an update on aging management activities and how container corrosion and SNF degradation are being monitored in L-Basin. The Board received updates on the accelerated basin de-inventory project and on potential disposition options for SNF remaining after termination of the project. The Board questioned what groups of SNF were identified for processing through the H-Canyon processing facility, the challenges for processing each group through H-Canyon, and the challenges for managing the remaining SNF after the project is finished. DOE staff described SNF management at INL, including efforts to complete an Idaho SNF management plan document and its plans for a Road-Ready Demonstration that will develop and demonstrate the designs, technology, processes, and regulatory framework for packaging DOE SNF for "road-ready" (transportable) dry storage. The Board questioned the anticipated packaging process involving DOE Standard Canisters and whether DOE is addressing waste acceptance requirements for disposal prior to packaging to ensure that "road-ready" packages can be disposed of without reopening them.

At the August 2024 public meeting, DOE-NE addressed an integrated waste management system under development that includes commercial SNF and DOE-managed SNF and HLW. Based on the information presented by DOE-NE, the Board sent DOE a letter in June 2025 (Swift 2025b). The Board commended DOE for its commitment to developing an integrated waste management system program plan that could initiate a workable pathway to site, license, construct, and operate a geologic repository. The Board noted its continued interest in following DOE's progress in implementing its program plan.

Members of the Board and staff also attended meetings during the reporting period in which DOE gave updates or made presentations related to its management and disposal of DOE SNF:

- SNFWG annual meeting, held virtually in May 2022, to obtain updates on DOE SNF management activities at DOE sites and on DOE-wide DOE SNF initiatives.

- National Cleanup Workshop, September 2022, Arlington, Virginia, to gain updates on DOE-EM's programs, key issues, and challenges at DOE-EM sites.

- Institute of Nuclear Materials Management 36th Spent Fuel Management Seminar in Alexandria, Virginia, January 2023, to interact with representatives of government, commercial nuclear organizations, and international program leaders, and to present a paper on SNF management programs in other countries.

- SNFWG annual meeting, May 2023, virtually, to obtain updates on DOE SNF management activities at DOE sites and on DOE-wide DOE SNF initiatives.

- National Cleanup Workshop, September 2023, Arlington, Virginia, to gain updates on DOE-EM's programs, key issues, and challenges at DOE-EM sites.

- Institute of Nuclear Materials Management 37th Spent Fuel Management Seminar in Arlington, Virginia, January 2024, to interact with representatives of government, commercial nuclear organizations, and international program leaders, and to present a paper on SNF management programs in other countries.

- Staff and Board members attended the Waste Management Symposium 2024, Phoenix, Arizona, to hear updates on DOE's activities and to present a staff paper on evaluating DOE's progress on management and plans for disposal of its SNF.

- SNFWG annual meeting, April 2024, Aiken, South Carolina, in-person and virtually, to hear updates from DOE and SRS and to help prepare for the Board's August 2024 SRS tour and public meeting.

- National Cleanup Workshop, September 2024, Arlington, Virginia, to gain updates on DOE-EM's programs, key issues, and challenges at DOE-EM sites.

Packaging and transportation of SNF and HLW

For over a decade, DOE has been conducting RD&D activities and evaluations to prepare for a future nationwide transportation campaign for SNF and HLW. For example, DOE has made significant progress in developing and demonstrating the Atlas railcar (certified by the Association of American Railroads) and the Fortis railcar (under development), both of which can support a variety of SNF transportation cask designs for transporting commercial SNF. During this period, DOE began planning for a Package Performance Project to conduct physical demonstrations of an SNF transportation cask in hypothetical accident scenarios. DOE has been evaluating the future removal of commercial SNF from shutdown and operating commercial nuclear power plant sites, including planning and executing detailed site visits to perform transportation infrastructure evaluations (Figure 6), and preparation of initial site-specific de-inventory reports.

The site evaluations include detailed reviews of all steps necessary to remove commercial SNF from the site. The DOE contractors developing the initial site-specific de-inventory reports, which are built upon the information gathered by the PNNL-led team, use a multi-attribute utility analysis as the basis for evaluating transportation modes and routes for removal of SNF from each site. The site-specific de-inventory reports are a first look at how a contractor may remove SNF and Greater Than Class C waste from these sites. The reports

represent one contractor's perspective and do not represent DOE's plans. By 2024, DOE had completed site evaluations for 20 nuclear power plant sites. Also, by 2024, DOE had completed eight initial site-specific de-inventory reports for the Big Rock Point, Crystal River, Humboldt Bay, Kewaunee, La Crosse, Rancho Seco, Yankee Rowe, and Zion sites.

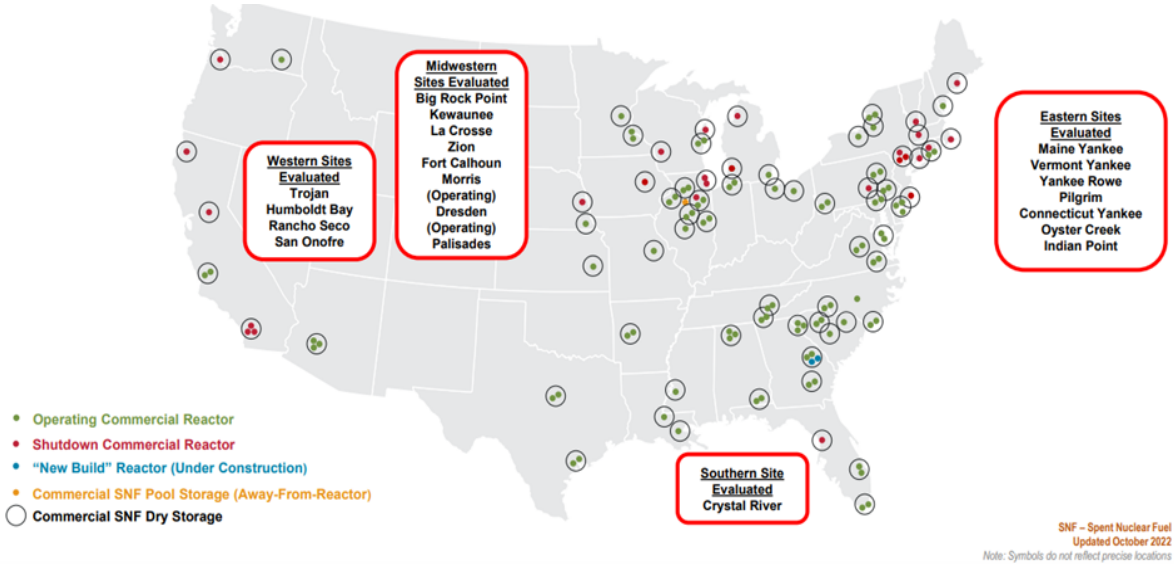


Figure 6. Locations of commercial SNF and list of sites that have been evaluated by DOE by region. Source: (Jackson 2023)

DOE activities related to supporting future transportation of SNF and HLW were the subject of the Board's ongoing review during the 2022 to 2024 period (Figure 1). During the reporting period, the Board held one fact-finding meeting, three public meetings, sent one letter to DOE, and received one letter from DOE.

In March 2022, the Board held a public meeting that reviewed several topics, including DOE's storage and transportation activities. DOE was considering the possibility of conducting a Package Performance Project which involves an SNF transportation cask in hypothetical accident scenarios and was in the early stages of developing a test plan for this project. The Board noted that DOE had reviewed earlier full-scale accident testing efforts including the 2001 package performance study initiated by the NRC, which included an opportunity for public comment on the draft protocols. The Board commended DOE for considering anew the need and scope of a package performance study that assesses the performance of both the cask and cask contents, particularly considering extended aging effects. The Board encouraged DOE to engage early with stakeholders to collect and incorporate broad public input in developing the plan.

In March 2023, the Board toured the Crystal River nuclear power plant site, heard details about DOE's site evaluation there, and held a public meeting the next day in Orlando, Florida, that focused on efforts related to removing SNF from commercial nuclear power plant sites and addressed DOE's proposed Package Performance Study (the name of the Package Performance Project at that time). The Board also invited representatives from three

Tribal nations to provide their perspectives on DOE's coordination of transportation and consent-based siting activities.

Figure 7. Atlas railcar loaded to a maximum 240-ton (480,000 pound) test load designed to simulate the heaviest transport container certified by the NRC. Modified from **(Bickford 2023)**

The Board noted that DOE has actively sponsored and engaged Tribes through various working groups such as the National Transportation Stakeholders' Forum, the Nuclear Energy Tribal Working Group, and the Tribal Radioactive Materials Transportation Committee. The Board heard an update on analyses of as-loaded commercial SNF canisters using the Used Nuclear Fuel-Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS) tool, including a comparison of the analysis results with NRC regulatory limits in the Certificate of Compliance (CoC) for transportation for different SNF canister systems. DOE is using these analyses to determine the number of SNF canisters at storage sites that cannot meet the transportation CoC requirements (the so-called "cannot ship list"), pursuant to Title 10, Code of Federal Regulations, Part 71, *Packaging and Transportation of Radioactive Materials* (10 CFR 71), without NRC-approved amendments or exemptions to the CoCs. The Board noted there may be some technical difficulties with meeting the 10 CFR Part 72, *Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste*, requirements for SNF storage following transportation of SNF, governed by 10 CFR Part 71.

DOE also provided updates on the development of the Atlas (Figure 7) and Fortis railcars for transporting SNF casks. Lastly, a representative from the NRC was invited to present key takeaways from the NRC's 2021 transportation readiness review (NRC 2021). Based on the information presented during the site tour, at the public and fact-finding meetings, and in related technical reports, the Board sent DOE a letter (Siu 2023) containing its findings and recommendations, as follows:

- **Finding 1a:** The Board finds that DOE is making progress in its IWM [integrated waste management] program, particularly in three major cross-cutting areas: (i) transportation preparations, (ii) storage design and regulatory considerations, and (iii) systems analysis tools and integration. The Board recognizes that DOE activities related to consent-based siting of a federal interim storage facility are in the early stages of a multiyear effort.

- **Finding 1b:** The Board finds that incorporating public feedback in the early development of a Package Performance Study is important; the Board previously encouraged DOE to engage early with stakeholders in developing a plan.[10] To date, DOE has obtained limited feedback from a few groups, but has not yet received broad public feedback on its proposal for a Package Performance Study.

- ***Recommendation 1:*** *If DOE pursues a Package Performance Study, the Board recommends that DOE first determine what the public's major safety concerns are, how public participants would like to be involved, and how meeting this goal can be integrated with regulatory testing goals. This will better enable DOE to identify the key issues to be addressed and to set clear outcomes for any demonstration. Further, planning for the demonstration should include a strategy for effective communication of test goals, expectations, and results to the public, and for a post-demonstration assessment of how well the test met its goals.*

- **Finding 2:** The Board finds that the DOE-sponsored site evaluations provide a good opportunity for DOE to meet with onsite staff and discuss technical details, including SNF condition, anomalies, and canister loading maps.

- **Recommendation 2:** During future site infrastructure evaluation visits, the Board recommends that DOE engage with site personnel and cask vendors regarding the NRC-approved transportation CoCs that apply to SNF in dry storage and assess whether the stored SNF will meet the requirements in the NRC-approved transportation CoCs. Site personnel and cask vendors who know the specific SNF contents for each storage canister and the approved contents for the transportation cask could potentially identify whether amendments or exemptions to the transportation CoCs will be needed prior to transportation.

- **Finding 3:** The Board finds that DOE can enhance its IWM system planning by engaging early with the NRC regarding the need for amendments or exemptions to the transportation CoCs for SNF canisters that do not currently meet the CoC requirements.

- ***Recommendation 3:*** *The Board recommends that DOE work with the NRC to identify the number and scope (including potential technical challenges) of amendments or exemptions to transportation CoCs that will be needed to allow the transportation of the affected SNF canisters.*

- **Finding 4:** The Board finds that there may be some technical difficulties with meeting the 10 CFR Part 72 requirements for SNF storage following the transportation of SNF, governed by 10 CFR Part 71. For example, 10 CFR Part 72 requires the licensee to demonstrate that the SNF cladding can meet its intended

[10] Bahr, J.M. 2022. Board letter to Dr. Kathryn Huff with comments from March 2022 Board meeting (June 7, 2022), available at: https://www.nwtrb.gov/docs/default-source/correspondence/jmb041.pdf?sfvrsn=4 (last accessed August 7, 2025).

confinement function before placing the SNF into dry storage; but it is unclear how the licensee will demonstrate adherence to this requirement for SNF inside a welded canister.

- ***Recommendation 4:*** *The Board recommends that DOE expand its engagement with the NRC to understand the technical difficulties with respect to meeting the 10 CFR Part 72 requirements for storage following the transport of commercial SNF, subject to 10 CFR Part 71 requirements. Recognizing that the issues could be different and unique for each specific SNF cask loading and for each cask or canister design, this action should commence well in advance of starting a large-scale transportation campaign, such as one that DOE may start in support of a new federal interim storage facility.*

DOE responded to the Board's letter in September 2024 (DOE 2024b) and reiterated that its primary motivation for pursuing a Package Performance Project was to build public trust and confidence in the safety of transporting SNF to federal storage and disposal facilities. However, the project was estimated to cost between $50 million and $100 million over up to five years. Until there was confidence that appropriations would be available to support the project, DOE was being careful to manage the current level of public outreach and engagement. DOE agreed with the Board that it would be beneficial to identify any need for transportation package CoC amendments or exemptions well in advance of transport of SNF from a site. DOE plans to coordinate with nuclear power plant sites and vendors to identify the status of CoCs, data needs, and a timeline for amending them.

In August 2024, the Board held a public meeting that included a DOE-NE program update that described the proposed Package Performance Demonstration. DOE stated that it was planning the project to build public trust and confidence in the safety of SNF transportation casks and SNF transportation by rail, to record high-resolution video to use in DOE communication products and public outreach, and to explore additional opportunities to strengthen relationships. DOE stated that it had just published a request for public comment on the project and had been hosting webinars explaining the project and the information that DOE was seeking. The Board commended DOE for addressing the Board's recommendation to engage the public early in developing the Package Performance Project, DOE's new name for the Package Performance Demonstration (Swift 2025b).

As part of its ongoing review of DOE's packaging and transportation RD&D activities, members of the Board and staff also participated in multi-organizational meetings that involved DOE representatives and addressed DOE RD&D or issues relevant to the Board's review of DOE activities. Those meetings relevant to DOE's packaging and transportation RD&D activities were the following:

- 2022 Nuclear Energy Institute Used Fuel Management Conference, May 3–5, Las Vegas, Nevada.

- 2022 National Transportation Stakeholders Forum, June 6–9, Philadelphia, Pennsylvania.

- 2023 Nuclear Energy Institute Used Fuel Management Conference, April 25–27, Las Vegas, Nevada.
- 2023 National Transportation Stakeholders Forum, May 22–25, St. Louis, Missouri.
- 2024 Nuclear Energy Institute Used Fuel Management Conference, May 7–9, Orlando, Florida.
- 2024 National Transportation Stakeholders Forum, June 3–6, Denver, Colorado.
- 2024 Naval Spent Fuel Transportation Accident Demonstration, September 18, Pocatello, Idaho.

Advanced reactor waste disposition

During the reporting period, the Board held two fact-finding meetings, one public meeting, sent one letter to DOE, and received one letter from DOE that addressed the disposition of waste resulting from advanced reactors. The Board also received a letter from DOE on advanced nuclear fuels including accident tolerant fuels for LWRs, which had been the subject of a public Board meeting in May 2021 (NWTRB 2022a). The Board's 2021 meeting focused on advanced nuclear fuels, including accident tolerant fuels for LWRs and the impact of these fuels on SNF management and disposal. The Board sent DOE a letter in August 2021 (Bahr 2021b) with its findings and recommendations, which were summarized in (NWTRB 2022a). The Board expects that many of its findings and recommendations are also applicable to the management and disposal of waste resulting from future advanced non-LWRs and Generation IV reactor designs.

DOE-NE responded to the Board's letter (Bahr 2021b) in April 2022 and DOE stated that its R&D work activities related to storage, transportation, and disposal of new SNF types were proceeding. DOE also stated that it would enhance public access to technical information on management of SNF from advanced nuclear fuel and accident tolerant fuels (DOE 2022b).

DOE conducted R&D that addresses waste from TRISO-fueled and metal-fueled advanced reactors. DOE documented its R&D efforts in a report titled *Advanced Reactors Spent Fuel and Waste Streams Disposition Strategies*, which surveyed SNF and potential HLW from TRISO, metallic, and molten-salt-fueled advanced reactors, accident tolerant fuels (ATFs), and advanced LWR fueled small modular and microreactors, and helped identify technical gaps related to storage, transportation, and disposal for advanced reactor fuels and waste streams (SNL 2023).

The NWPA, as amended, stipulates that an operating license for a reactor cannot be issued by the NRC unless the applicant has entered into a contract with the Secretary of Energy for the

disposal of SNF and HLW generated from the reactor's operation.[11] DOE will need enough data from the applicant, describing the characteristics of both the initial fuel and the discharged SNF and HLW, and operations (e.g., storage canister design and what constitutes "failed fuel") to allow DOE to determine whether to enter such a contract. During this reporting period, DOE sought such information from advanced reactor developers.

The Board held a public meeting in August 2023 that, in part, focused on getting updates on DOE's advanced reactor waste disposition activities. In 2023, DOE-NE produced internal technical reports for advanced reactor designs, with the goal of providing some of the reports to DOE Office of General Counsel to inform DOE's contractual negotiations with advanced reactor vendors or operators. At the public meeting, the Board learned that the internal reports included the expected amount of SNF and HLW; information about transportation, storage, and disposal; and a rough order of magnitude cost comparison with LWR activities. Overall, the Board commended DOE for making progress in addressing upcoming challenges with management and disposal of waste resulting from advanced reactors. Based on the information gathered at the fact-finding meetings, presented at the public meeting, and upon review of related technical reports, the Board sent a letter to DOE (Siu 2024a) with one finding on advanced reactor waste disposition, as follows:

- **Finding 6:** DOE has initiated an effort to assess the potential impacts of various advanced nuclear fuels on storing, transporting, and disposing of SNF and HLW by requesting data from advanced reactor vendors. DOE is also developing a strategy to identify knowledge gaps and outline areas where further research would contribute to a well-defined disposition pathway for SNF and HLW resulting from advanced reactor operations. This effort will inform DOE decisions concerning how to proceed and how to deal with the impacts. The Board commends DOE for initiating this assessment and strongly endorses the effort.

As part of the Board's review of DOE's management and disposition of waste resulting from advanced reactors, Board staff also attended multi-organizational meetings that involved DOE. Those activities in which the Board participated include the following:

- Waste Management Symposium 2023, Phoenix, Arizona, to hear updates on DOE activities and to present a staff paper on the preliminary considerations for SNF and HLW from advanced reactors.

- NRC, 2024 Workshop on Storage and Transportation of TRISO and Metal Spent Nuclear Fuels (virtual), at which staff provided an invited presentation on disposal aspects that will need to be considered during the packaging of this waste for storage and transportation.

[11] The Standard Contract for disposal of SNF and/or HLW ("DOE Standard Contract") establishes the terms and conditions under which DOE will make available nuclear waste disposal services to the owners and generators of SNF and HLW. DOE will take title to, transport, and dispose of SNF and/or HLW delivered to DOE by those owners or generators who execute the contract. See Nuclear Waste Policy Act of 1982, sec. 302, Pub. L. 97–425, 96 Stat. 2257 (42 U.S.C. 10222).

- Regular meetings of the Electric Power Research Institute (EPRI) Extended Storage Collaboration Program (ESCP) Advanced Fuels task group.

Long-term dry storage and transportation of high burnup commercial SNF

Historically, dry storage of commercial SNF began in the 1980s when utilities needed to remove SNF from on-site storage pools to allow space for additional SNF to be stored from reactor discharges. Ample prior research and studies have provided confidence that no change in the performance of low burnup fuel was expected during dry storage over a period of 20 years and during subsequent transportation (EPRI 2000, 2002). However, two notable circumstances have emerged since this earlier situation. The first is related to the long-term conditions of the SNF in dry storage systems, and of the dry storage systems themselves, during extended periods of dry storage. Second, there have been advances in reactor fuel technology along with changes in power plant operations, including the introduction of fuel assembly designs by fuel vendors that allow the fuel to achieve higher burnups. Since the 1990s, an increasing quantity of SNF loaded into dry storage casks has been high burnup SNF (HBF).

DOE has been conducting R&D with the aim of obtaining data that can enhance the understanding of the characteristics and performance of HBF during extended storage and transportation conditions, and during subsequent operations expected to occur at a geologic repository site, which could include repackaging of SNF. Due to the wide variety of SNF types subjected to a range of reactor operating conditions and storage conditions, sophisticated fuel performance models are needed to predict the characteristics, condition, and performance of SNF, including HBF, in a variety of storage and transportation conditions.

In 2021, the Board published a comprehensive evaluation of DOE's activities on HBF (NWTRB 2021a). During this reporting period, the Board continued its focused review of DOE's R&D related to long-term dry storage and transportation of commercial HBF. The Board held two public meetings, two fact-finding meetings, sent three letters to DOE, and received one letter from DOE.

The Board held a public meeting in March 2022 to hear updates from DOE and national laboratory researchers on several topics, including a summary presentation on DOE's storage and transportation activities and updates to DOE's R&D 5-Year Plan (Saltzstein 2020). The Board noted that obtaining and testing high burnup BWR SNF cladding is identified in DOE's storage and transportation R&D 5-Year Plan (Saltzstein 2020) and in DOE's gap analysis (Teague 2019) as an action that is needed to fully "close multiple gaps," including potential cladding degradation due to hydride reorientation. Previously, the Board recommended that DOE indicate how its testing with pressurized water reactor (PWR) fuel and models do or do not apply to the broad range of HBF types and storage and transportation system designs for which information is still needed and to take steps to meet those remaining technical information needs (NWTRB 2021a). DOE still believes that PWR data for high burnup fuels bound BWR behavior. The Board was encouraged by DOE continuing to seek opportunities to do the necessary BWR SNF cladding testing and noted that similar questions of test result applicability are pertinent to newer ATFs and fuel

assemblies containing integral fuel burnable absorbers (IFBA). After reviewing the information presented and discussed at the public meeting, the Board (Bahr 2022b) made the following finding and recommendation:

- *The Board finds that DOE has not yet provided evidence for making this conclusion* [that pressurized water reactor PWR data for high-burnup fuels bound BWR behavior].

- The Board recommends that DOE either demonstrate that existing data and modeling regarding the behavior of high burnup PWR SNF bound the behavior of BWR and ATF SNF and SNF containing IFBAs or complete the necessary testing and modeling for these fuel types.

DOE responded to the Board's letter in July 2023 (DOE 2023b) and stated that it was exploring options to obtain data to confirm that PWR HBF behavior bounds BWR HBF behavior, ATF SNF, and SNF containing IFBAs. DOE is participating in the international Studsvik Cladding Integrity Project IV program with a goal of obtaining BWR data, as well as IFBA data, and DOE is collaborating with national laboratories to plan future testing of ATF SNF.

In August 2023, DOE provided an update on its HBF activities in a Board public meeting. These activities include DOE's plans for examining the irradiated PWR HBF that is now in dry storage in a specially modified TN-32B cask (the high burnup research cask; Figure 8). Based on the information obtained, the Board decided to hold a fact-finding meeting in Arlington, Virginia, at the Board's offices in February 2024. Another purpose of the fact-finding meeting was to obtain status updates from DOE on addressing the Board recommendations that were a result of the Board's multi-year review of DOE HBF R&D activities (NWTRB 2021a). In April 2024, the Board provided its comments on DOE's presentations at the August 2023 public meeting (Siu 2024a). Based on information from the fact-finding meeting, the Board noted that DOE may soon make significant changes to its HBF storage and transportation R&D program. The Board stated that it would provide, in a separate letter, the Board's assessment of the status of DOE's current R&D efforts relative to the Board's 2021 recommendations on HBF.

Upon discussion and critical review of the information presented at the fact-finding meeting and found in related technical reports, the Board corresponded with DOE in a letter (Siu 2024b) in May 2024 about the 13 recommendations in the report (NWTRB 2021b) and whether the Board felt the recommendations were closed or currently open ("reaffirmed").

Figure 8. The high burnup research cask at North Anna, Virginia is an instrumented TN-32B model cask certified by the NRC for storage and transportation of SNF. Source: (Bickford 2025)

Regarding documentation that summarizes the results of DOE R&D referenced in *Recommendation 1.a.*, the Board noted that DOE continues to document the results of its HBF sibling pin research and is working to produce a single summary report. When the summary report is published, the Board will consider *Recommendation 1.a.* closed. Regarding the collaboration with research activities at EPRI and in other countries referenced in *Recommendation 1.b.*, the Board also acknowledged DOE's commitment to continue working with EPRI and other countries and commended DOE for establishing a Memorandum of Understanding with EPRI. The Board considered *Recommendation 1.b.* to be closed but encouraged DOE to expand its collaboration with researchers in other countries. The Board reaffirmed *Recommendation 1.c.* regarding DOE efforts to demonstrate that the work completed to date bounds all existing SNF types referenced in *Recommendation 1.c.* The Board noted that it was not clear that the results of the HBF testing for irradiated PWR assemblies will bound all existing or new types of SNF, such as BWR HBF, SNF assemblies that include burnable absorbers, or ATF, which will soon join the inventory of SNF.

The Board also reaffirmed *Recommendation 2.a.*, on evaluating the amount of chemisorbed water remaining after drying commercial SNF canisters and the effect of water on SNF and canister internal components. During the fact-finding meeting, DOE representatives noted, and the Board acknowledged, that all commercial SNF canisters are dried using an NRC-accepted drying process (e.g., vacuum drying or forced helium dehydration). The NRC-accepted processes are based on one set of parametric study results and an assumption that drying will eliminate water to a quantity that will generate no more than one (1) mole of oxidizing gases via radiolysis—this equates to 0.1 vol% (0.43 moles) water (Knoll 1987). The Board noted several cases where commercial SNF canisters subjected to the NRC-accepted drying process were found to contain more than 0.1 vol% of water after drying, and that there were technical difficulties in quantifying water vapor content in one of those cases. There continues to be uncertainties regarding the amount of water remaining in an SNF

canister after drying and the effect on storage and transportation. The Board also reaffirmed *Recommendation 2.b.*, regarding measuring water content in a commercial SNF canister, on similar grounds.

The Board re-examined the recommendations pertaining to hydrogen effects in HBF cladding and considered *Recommendation 3.a.*, *3.b.*, and *3.c.* to be closed. Regarding the use of irradiated SNF cladding in testing, referenced in *Recommendation 3.a.*, the Board acknowledged that there was ongoing and proposed DOE-sponsored research on HBF focused on using only irradiated cladding. Regarding *Recommendation 3.b.*, on the development of standard test procedures, the Board acknowledged that DOE has worked to provide consistency in the testing program across the national laboratories. In addition, for *Recommendation 3.c.*, regarding the development of a database for test results related to hydride reorientation in zirconium-based alloy cladding, the Board noted that the national laboratories have routinely made their testing results publicly available through annual reports posted on the OSTI.gov website. If additional funding becomes available, the Board encouraged DOE to consider creating a unified database of testing results related to hydride reorientation in zirconium-based alloy cladding.

The Board re-examined the recommendations pertaining to HBF performance under normal conditions of dry storage and considered *Recommendation 4.a.*, *4.b.*, and *4.c.* to be closed. Regarding *Recommendation 4.a.*, on HBF testing results needed to close HBF technical information needs (gaps), the Board noted that DOE's most recent gap analysis report (Teague 2019) and 5-year storage and transportation R&D test plan (Saltzstein 2020) lay out the information to be collected during testing and identify what is needed to close each gap. Regarding *Recommendation 4.b.*, on preserving HBF sister rods or rod segments, the Board learned at the fact-finding meeting that DOE plans to preserve all unused HBF sister rods or rod segments for future examinations. Then, regarding *Recommendation 4.c.*, on thermal modeling development, the Board acknowledged that DOE, in cooperation with EPRI, continues to refine thermal models (COBRA-SFS and STAR-CCM+) that can predict temperature profiles in SNF canisters. These efforts are mature and include collaboration with research groups in other countries.

The Board re-examined and considered *Recommendation 5*, regarding SNF performance under normal conditions of transport, to be closed. The Board observed that the DOE-sponsored research and analysis of SNF under normal conditions of transport included extensive field testing with instrumented equipment as well as detailed modeling of the mechanical behavior of SNF assemblies. Finally, the Board reaffirmed *Recommendation 6*, regarding fuel performance modeling, in the case that DOE cannot obtain the needed data from SNF post-irradiation examinations to support amendments to NRC CoCs for transportation. The Board noted that the DOE HBF research efforts have obtained testing results that provide confidence that certain types of HBF can meet the requirements for extended storage and transportation. However, this testing has been limited to an incomplete range of fuel and cladding types, fuel operating histories, temperatures, and storage canister designs. The Board noted that to understand the characteristics and behavior of other types of HBF, such as PWR HBF with more extreme operating histories, DOE will need to obtain post-irradiation examination data relevant to these other HBF types. Finally, the Board noted that, based on the "roadmap" published in DOE's consent-based siting process document

(DOE 2023c), a federal consolidated interim storage facility may not begin operations until 2035 to 2040, at the earliest. DOE may use the intervening time to determine which approach to obtaining the necessary HBF data will be the most effective and efficient.

As part of the Board's review of DOE's HBF efforts, the Board and staff also attended multi-organizational meetings that involved DOE. Those activities in which the Board participated include the following:

- Nuclear Energy Institute (NEI) Used Fuel Management Conference, May 2022, Las Vegas, Nevada, to gain updates from DOE, industry, NRC, and others on spent fuel topics.
- EPRI ESCP Winter Meeting, November 2022, Charlotte, North Carolina.
- NEI Used Fuel Management Conference, April 2023, Las Vegas, Nevada, to gain updates from DOE, industry, NRC, and others on spent fuel topics.
- EPRI ESCP Winter Meeting, October 2023, Charlotte, North Carolina.
- NEI Used Fuel Management Conference, May 2024, Orlando, Florida, to gain updates from DOE, industry, NRC, and others on spent fuel topics.
- EPRI ESCP Winter Meeting, October 2024, Charlotte, North Carolina.

Dry-storage canister corrosion

Chloride-induced stress corrosion cracking (CISCC) is a type of degradation that leads to cracks in certain stainless-steel materials. Because many of the stainless-steel canisters holding commercial SNF are stored in outdoor environments that may be conducive to CISCC, these canisters may be susceptible to degradation from CISCC. For several years, EPRI, NRC, and DOE have been undertaking research to increase understanding of the CISCC mechanism and to develop techniques for detecting CISCC in spent fuel canisters and for mitigation and repair. During this reporting period, the Board held one public meeting, sent one letter to DOE, and received one letter from DOE on its dry storage canister corrosion R&D.

In March 2022, the Board held a virtual public meeting that reviewed several topics, including a presentation from national laboratory researchers on canister surface environment investigations and the potential for corrosion of commercial SNF storage canisters and aerosol transmission through stress-corrosion crack-like geometries. Based on the information presented at the public meeting and information in relevant DOE reports, the Board sent DOE a letter (Bahr 2022b) containing its findings, conclusions, and recommendations. The Board commended DOE for the R&D work it is conducting on CISCC. The Board commended DOE-NE for collaborating with DOE-EM and with industry on the Hanford Lead Canister project, which focuses on vertically stored canisters and shares some common objectives with DOE R&D activities on CISCC of commercial SNF dry-storage canisters. The Board encouraged DOE to continue its efforts but found that DOE had

not fully considered one area of focus regarding localized corrosion mechanisms. The Board's findings and recommendations pertaining to canister corrosion are as follows:

- *The Board finds that DOE has not fully considered whether a different localized corrosion mechanism such as crevice corrosion could be a precursor process for initiation of CISCC in addition to pitting corrosion.*

- *As DOE continues to develop the two full-scale canister demonstrations, the Board recommends that DOE consider whether localized corrosion such as crevice corrosion could be a precursor to CISCC and determine how that precursor mechanism could be assessed in the field demonstrations.*

Laboratory researchers explained their R&D on aerosol transmission through machined microchannels that are early surrogates for stress-corrosion cracks. In related work, DOE planned to obtain particle size distributions of fuel and aerosols released in different scenarios in the high burnup SNF sibling pin testing program and to measure aerosol release and depletion in an environment characteristic of dry storage. Eventually, the experimental data and modeling outputs on aerosol transmission will be used as inputs to consequence (dose) calculations for a postulated SNF canister breach. The Board noted that the overall risk of SNF canister degradation is best informed by combining the results of a realistic assessment of the consequences of canister penetration from degradation with the results of a more thorough assessment of the probability of breaching an SNF dry cask storage system. The Board's recommendation is as follows:

- *As DOE conducts R&D to support its consequence assessment of canister failure, the Board recommends that DOE complete refinements that it has described for its aerosol transmission experiments, including conducting some experiments using a single effect approach to facilitate easier model development, validation, and interpretation of results. In the near-term, DOE should clearly define the events and processes that affect aerosol generation within a sealed cask that can lead to potential aerosol transmission when a crack forms to subsequently guide the R&D needed to realistically assess the consequence of a canister failure.*

DOE responded to the Board's letter in July 2023 (DOE 2023b) and stated that the main goal of the full-scale canister demonstration is to gain realistic data on deposition of dust on canister surfaces. However, DOE plans to evaluate canisters for corrosion after full-scale canister demonstrations are completed, and the DOE lab-scale testing to evaluate localized corrosion mechanisms will continue. DOE agreed with the Board that continuing refinements of aerosol transmission experiments is important. DOE planned to conduct work to better define events and processes that affect aerosol generation within a sealed cask, such as gathering spent fuel rod aerosol release data from the sibling pins project, and refining estimates of internal canister conditions, such as the amount of water remaining after drying and the subsequent effects on cladding degradation. Additional R&D was pursued by DOE to better define fuel-to-canister release fractions from fuel cladding failure. Complementary modeling of aerosol deposition inside dry storage systems was underway to be used to delineate internal aerosol sources and to evaluate potential aerosol release mechanisms.

As part of the Board's review of DOE's efforts, Board staff also attended multi-organizational meetings that involved DOE, including the ASTM [American Society for Testing and Materials] International meetings that discuss spent fuel topics.

Board Review: Integrated Waste Management and Disposal System

During the reporting period, the Board followed up with DOE on the Board's *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward* report (NWTRB 2021b), focused on DOE's consent-based siting efforts for one or more federal consolidated interim storage facilities for commercial SNF, and evaluated DOE's system tools for an integrated waste management system. For these topics, the Board held a total of five public meetings, including a workshop, three fact-finding meetings, sent six letters to DOE, and received three letters from DOE.

In 2021, the Board released a report titled *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward* (NWTRB 2021b). The report contains Board findings and recommendations reflecting a decade's worth of Board experience reviewing the DOE's activities related to management and disposal of SNF and

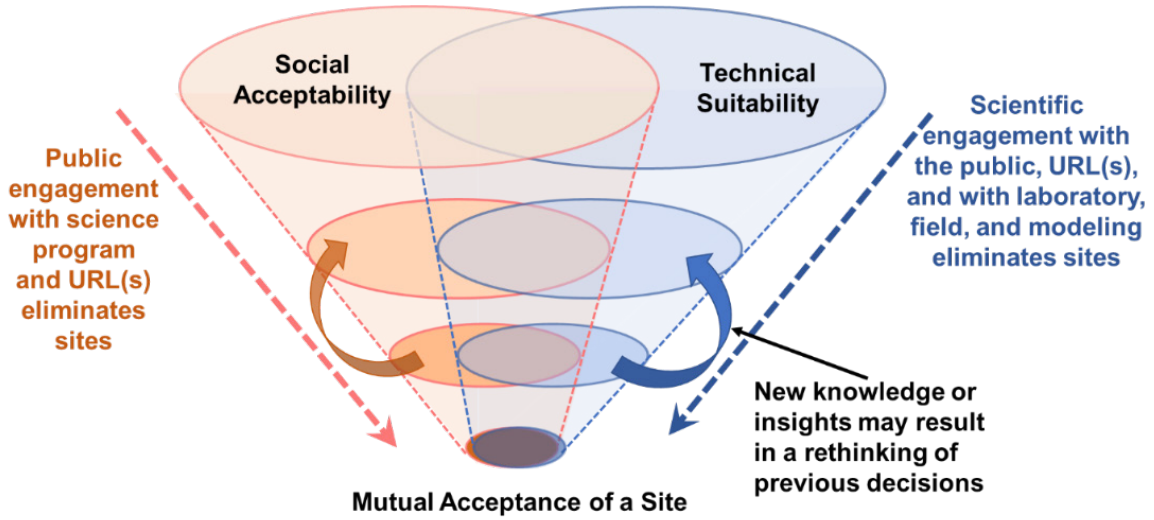


Figure 9. Development of a convergent pathway for siting a geologic repository. (NWTRB 2021b)

HLW. The report stresses the need for an integrated waste management approach and highlights that experience domestically and internationally demonstrates that geologic disposal of waste is as much a social challenge as a technical challenge (Figure 9).

DOE replied to the report in June 2022 (DOE 2022c), detailing a list of activities DOE was conducting and how those activities align with specific recommendations in the report. The Board sent a letter thanking DOE in July 2022 and requested a one-on-one meeting to further discuss the Board's recommendations and DOE's response (Bahr 2022c).

Consent-based siting

Through the Consolidated Appropriations Acts of 2021, 2022, and 2023, DOE was congressionally directed to move forward under existing authority to identify a site for a federal CISF for commercial SNF using a consent-based siting process. In 2021, DOE renewed an effort to site federal facilities for the temporary, consolidated storage of commercial SNF using a consent-based siting approach as part of an overall strategy for an integrated waste management system. In 2022, DOE announced a $26 million funding opportunity, and subsequently, 12 awardees[12] were announced in 2023—the awardees were collectively called the consent-based siting consortia. The consortia would serve as information, engagement, and resource hubs to relay feedback to and from the public and to DOE about consent-based siting.

The Board's activities on DOE's consent-based siting efforts during the review period included three fact-finding meetings, three public meetings, and one international workshop, a workshop proceedings report (Figure 1), and four letters to DOE. The Board received two letters from DOE.

In November 2021, the Board held a public meeting to review DOE's R&D activities related to the GDSA framework but included with that public meeting was a presentation from DOE that described the new consent-based siting process. The Board made no findings or recommendations on DOE's early activities but commended DOE for starting the new effort and for recognizing the crucial importance of effective risk communication, full public engagement, and inclusiveness in the siting process (Bahr 2022d).

At the Board's March 2022 virtual public meeting, DOE described its current efforts on consent-based siting and also summarized the work DOE-NE had been conducting to prepare for an integrated waste management system. The Board appreciated DOE's stated commitment to transparency, openness, and effectively engaging stakeholders, including historically underrepresented communities, in any consent-based siting process (Bahr 2022b). However, the Board noted that DOE was already facing some significant challenges early in the process, and DOE did not appear to have met its stated aim of tapping perspectives from diverse populations and underserved populations. The Board noted that development of DOE's consent-based siting process could be informed by the details and distinctions of the consent-based siting programs in Sweden, Finland, France, and Switzerland. After examining the materials presented at the March meeting, the Board (Bahr 2022b) made the following finding and recommendation:

- *The Board finds that there are additional actions that DOE could take to meet its stated commitments, learn from domestic siting experiences and from siting processes in other nations, and strengthen its overall consent-based siting effort.*

- *Although the Board applauds DOE for undertaking significant consent-based siting activities, the Board recommends that DOE significantly strengthen and improve its*

[12] In 2024, DOE funded an additional Tribal consortium and released a revised draft of the consent-based siting process document.

efforts. A larger and broader range of participants should be engaged, and expanded efforts to include historically underrepresented communities should be undertaken. DOE should also make systematic use of the large body of scientific and technical literature in such fields as the social/behavioral sciences and the public health sciences. By informing all consent-based siting efforts with relevant outside scientific/technical knowledge and expertise on risk communication, risk perception, effective outreach, inclusiveness, and public engagement, DOE can identify ways to engage a broader range of participants, better understand public views and concerns, and improve the overall effectiveness and face validity of its consent-based siting work. The Board also recommends that DOE produce a candid "lessons learned" document on its deep borehole demonstration siting effort and review key lessons that have been learned from siting processes in other nations.

DOE responded to the Board's letter in July 2023 (DOE 2023b) and stated that it will continue to examine how domestic and international siting experiences and collaborations can be used to support successful advancement of consent-based siting in the U.S., including lessons learned from DOE's siting efforts for the Deep Borehole Field Test from 2015 to 2017. DOE reiterated how the consent-based siting consortia would help reduce barriers for participation by providing grants to community organizations and partners. DOE stated that it had hired social scientists with subject matter expertise, and work was underway to fund partnerships with Tribal-Serving Institutions, Historically Black Colleges and Universities, and Hispanic-Serving Institutions.

In March 2023, the Board held a public meeting in Orlando, Florida. Although the meeting focused on SNF transportation topics, DOE provided an update on consent-based siting activities. Part of DOE's effort includes providing funding to states, Tribes, and local communities to facilitate information exchange and mutual learning between DOE and interested parties. The Board commended DOE for continuing to work closely with Tribes and noted that DOE's emphasis on making Tribal government engagement a priority is a positive step for consent-based siting efforts (Siu 2023).

On August 30, 2023, the Board held a public meeting in Idaho Falls, Idaho, preceded by a full day for the Board's International Siting Workshop the previous day, both of which focused on DOE's consent-based siting activities. Prior to the public meeting and workshop, the Board held a fact-finding meeting on DOE's consent-based siting activities that helped the Board prepare for its review.

Figure 10. DOE staff and experts on siting of radioactive waste facilities from Sweden, Switzerland, and the U.S. participated in a facilitated panel discussion that allowed participants to candidly share their viewpoints, insights, lessons learned, and allowed Board members to question the panelists.

For the workshop, the Board invited four experts from Switzerland, Sweden, Canada (virtual participant), and the U.S. to discuss their experiences with siting in their respective countries. Three of these experts participated in a panel discussion to elucidate their experiences and to allow additional Board member questioning. DOE described its consent-based siting process and provided updates on its consent-based siting activities. DOE described activities that help it leverage domestic and international best practices and lessons learned in siting as well as environmental justice principles in its siting process. The workshop concluded with a final panel discussion (Figure 10).

In September 2024, the Board released a proceedings report, titled *Proceedings of the Board's 2023 International Workshop on Siting of Radioactive Waste Facilities* (NWTRB 2024b), that summarized the presentations and panel discussions held at the Board's workshop in August 2023. In the proceedings, it is noted that despite important differences between countries and organizations, there are many points of commonality and lessons learned (including failures and success factors) that may be transferable from countries that have well-developed programs for SNF and HLW disposal to those that are not as far along. Public trust in the key actor(s) or implementer, public trust in the safety of the technology, and social acceptability of a siting process were some of the most important success factors and lessons learned from the experiences of other countries' siting programs. For example, Sweden's program hired experts to train their scientists to be excellent communicators, to become more credible to a community, and be known by that community as trustworthy representatives of the organization In Switzerland, scientists went door-to-door in potentially affected communities during seismic surveys. The Swiss representative noted that public tours were provided at various laboratories and central interim storage facilities in Switzerland, and courses were offered to the public. The Canadian program focused on mutual learning and listening experiences, and the Canadian nuclear waste management implementer spent three years working with the public to define what an open, fair, and transparent process looks like. In all three countries represented, siting was a process that took decades to complete, and a well-defined process that is both technically and socially acceptable was a key success factor. Based on a synthesis of presentation information and

panel discussions at the workshop, four main takeaways were presented as general success factors for siting:

- gaining public trust through public engagement and communication,
- mutual learning and listening,
- being prepared for a long process, and
- having a well-defined process that is both technically and socially acceptable.

The Board's August 30, 2023, public meeting in Idaho Falls, Idaho, focused on DOE's efforts on consent-based siting. The Board heard about key activities in DOE's consent-based siting process, including DOE's plan to integrate the input from consortia members as a part of the mutual learning process. DOE staff were incorporating environmental justice and social science in consent-based siting and were developing digital tools for engagement. Overall, the Board commended DOE for its important and continued efforts to assemble the necessary staff and technical expertise, but noted several areas that DOE could strengthen moving forward: access to scientific and technical information, communication of complex scientific and technical information, building capacity and incorporating scientific and technical information from the disciplines of public health, medicine, emergency management, and health physics, measuring and evaluating progress toward achieving goals, and addressing intergenerational issues.

The Board observed that timely progress on a geologic disposal program for SNF and HLW is needed now to provide confidence that storage of SNF at a federal consolidated storage facility will be interim and not permanent. In addition, the Board observed that a consultation and concurrence approach with States and Tribes, rather than the consultation and cooperation approach currently embodied in the NWPA, as amended, will likely need to be explored. Based on the information presented and discussed at the fact-finding meeting, workshop, public meeting, and related technical reports, the Board corresponded with DOE (Siu 2024a) and made the following findings and recommendations:

- **Finding 1:** The Board finds that effectively meeting public information needs is an important component of consent-based siting. For interested parties to be informed about and empowered in the siting process,[13] they need consistent and timely access to scientific and technical information. Providing such information will support effective engagement, help inform understanding of the many complex consent-based siting issues, and foster trust between the public and DOE.

[13] NWTRB. 2015. Designing A Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: An Overview and Summary. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. November.

- ***Recommendation 1:*** *The Board recommends that consent-based siting-related information that will be produced by DOE and the consent-based siting consortia be made available to the public in as timely a manner as practicable.*

- **Finding 2:** The Board finds that the communication of complex scientific and technical information is a crucial part of consent-based siting efforts, and notes that DOE is contemplating various efforts to disseminate such information. In successful siting cases for radioactive waste facilities in Sweden and Switzerland, members of the public often preferred communication and information to come directly from scientists and engineers involved in the program rather than from public affairs or public relations staff. To meet this need, some program scientists and engineers engaged directly with the public, and worked to become more adept at explaining complex scientific and technical information about radioactive waste management facilities in clear, jargon-free language. The vital communication role played by scientists and engineers in successful siting efforts is consistent with what is also known from research and experience. The International Radiation Protection Association considers this a best practice.[14]

- ***Recommendation 2:*** *The Board recommends that DOE use successful siting cases for radioactive waste facilities in other countries, results from research, and best practices to explore what training or other efforts would be most helpful in preparing various scientists and engineers associated with the U.S. consolidated interim storage program to be able to engage in sustained and effective dialog with members of the public.*

- **Finding 3a:** The Board commends DOE for incorporating a wide range of social and behavioral science disciplines into its consent-based siting efforts. At the same time, the Board finds that additional cutting-edge work in radiation risk communication and related topics has taken place in such fields as public health, medicine, emergency management, and health physics. These fields need to regularly interact and communicate with members of the public about radiation, uses of radioactive and nuclear materials and technologies, and radiation safety and health. The Board finds that DOE has not yet fully incorporated this important, additional cutting-edge work in radiation risk communication and related topics into its consent-based siting efforts.

- **Finding 3b:** The Board finds that although DOE has been able to successfully increase consent-based siting capacity and staffing, additional sustained resources and personnel (including full-time staff with expertise in such areas as risk communication) would further strengthen the consent-based siting process as it

[14] International Radiation Protection Association, *Practical Guidance for Engagement with the Public on Radiation and Risk* (2020), accessed August 7, 2025, https://www.irpa.net/members/IRPA%20Guidance%20Public%20Engagement.pdf.

proceeds. By not having such expertise, important and directly relevant work could be missed or repeated unnecessarily by DOE.

- ***Recommendation 3:*** *As DOE continues to assemble needed expertise and information related to consent based siting, the Board recommends that DOE take steps to broaden its approach, such as: a) ensuring a high level of expertise and experience in such areas as risk communication, and b) systematically including technical literature and research from the disciplines of public health, medicine, emergency management, and health physics. Likewise, the Board recommends that when DOE gives public presentations on its consent-based siting activities, insights from these fields and publications describing key sources of information informing project efforts be included in slides.*

- **Finding 4:** The Board finds that as part of successful siting programs in Sweden and other countries, different evaluation approaches, methodologies, and metrics have been employed by each country to help assess the effectiveness of consent-based siting efforts. For example, in Sweden, the implementer collected, analyzed, and reviewed data over an extended time on the percent of the population willing to engage as part of the overall evaluation strategy. DOE described that in fiscal year 2024 it will be looking at potential metrics that could be applied to its communications and to its consent-based siting program. Likewise, the Board finds that such methods and metrics could be used by DOE, for example, to analyze which program-related activities are working well and which ones need to be strengthened, to measure whether consent-based siting program communications are effective, and to assess the extent to which different interested groups are being reached and engaged.

- **Recommendation 4:** As DOE's consent-based siting effort continues to develop, the *Board recommends that DOE identify state-of-the-art evaluation approaches, methods, indicators, and metrics that can be utilized to gauge the extent to which key goals are being achieved.*

- **Finding 5:** Consent-based siting issues have important implications not only for the present but also for the future (siting could take a decade or more and the transportation of SNF and storage at a sited facility could last decades). Thus, it will be important to understand key intergenerational issues and include the perspectives of younger people in the process. The Board finds that as DOE develops its own consent-based siting process, it would be valuable to identify and implement effective mechanisms to directly engage young people and gain a better understanding of intergenerational aspects of siting decisions.

DOE responded to the Board's letter in September 2024 (DOE 2024a) and stated that it would continue to ensure that fact sheets and document summaries would be made available to the public. In addition, DOE planned to issue a public document that captures the consent-based siting consortia lessons learned in 2025. DOE provided specific communication skills training to both technical staff and social scientists to prepare the DOE staff working on the U.S. consolidated interim storage program to better engage in sustained and effective

dialogue with members of the public. DOE also added three social scientists and an engineer to help cover the area of risk communications to broaden DOE's approach and ensure a high level of expertise and experience in areas such as risk communication. Additionally, the consent-based siting consortia developed initiatives that address intergenerational justice in different ways, including future-focused engagements, engagements with Tribal entities, future-focused non-governmental organizations, and youth-focused engagements.

In August 2024, the Board held a public meeting in North Augusta, South Carolina, that mostly focused on reviewing information related to management and disposal of DOE SNF. DOE-NE provided an update on the path forward for development of a federal interim storage facility for storing commercial SNF, including draft site screening criteria for the facility. DOE stated that a detailed plan for a path forward will be developed within approximately a year. In December 2024, the Board held a fact-finding meeting with DOE to gain more information on the next steps in the consent-based siting process and planned activities, how the consent-based siting team at DOE was integrating with other teams at DOE on public trust and communication (e.g., Package Performance Study or Package Performance Demonstration, now called the Package Performance Project) and to discuss DOE's draft siting criteria document. The Board (Swift 2025b) noted that the draft site screening criteria were logical, clear, simple, and defendable but that improvements to terminology describing the criteria (e.g., initial criteria) and re-organizing portions of the report could make the information clearer and more accessible to the intended audience.

As a part of the Board's review of DOE's consent-based siting efforts, Board staff also attended multi-organizational meetings that involved DOE. Those activities in which the Board participated include the following:

- Staff and Board members attended the Waste Management Symposium 2023, Phoenix, Arizona, to hear updates on DOE's activities and to present a staff paper on perspectives on consent-based siting from the Board's international siting workshop.

- Staff and a Board member attended the Waste Management Symposium 2024, Phoenix, Arizona, to hear updates on DOE's activities and other national repository siting efforts, such as Canada's, and for a staff member to receive the American Nuclear Society's Best Paper and Best Presentation awards for his 2023 paper.

- A staff member observed all the quarterly consent-based siting consortia meetings and made a presentation to the consortia on the Board's mission and its survey of national programs.

System tools for an integrated waste management system

In May 2024, as a part of its effort to develop one or more federal consolidated interim storage facilities, DOE approved Critical Decision-0 (Approve Mission Need)[15] for the

[15] Critical Decision-0 is the first step of a formal process that DOE uses to manage capital asset projects and determines a mission need for the Department. See DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets* (DOE 2023d).

Federal Consolidated Interim Storage Facility project. The project includes the removal of commercial SNF from nuclear power plant sites where it is currently stored and transportation of the SNF to one or more temporary storage facilities. In July 2024, DOE issued a request for information to industry for the design and construction of a CISF for storing commercial SNF. Also, during the reporting period, DOE made progress on continuing to maintain, upgrade, and perform analyses on systems engineering and analysis tools, such as the Stakeholder Tool for Assessing Radioactive Transportation (START), PASO, UNF-ST&DARDS, and NGSAM, in support of the CISF project and overall integrated waste management program needs.

NGSAM is an agent-based discrete event simulation tool designed for modeling the evolution and fate of SNF from its site of origin at a nuclear power plant site to a disposal site. START is a web-based application that utilizes geographic information systems technology to represent transportation network operations as well as proximate features, such as Tribal lands, emergency response capability, schools, and environmentally sensitive areas. For example, START can provide the SNF transportation routing information for use in NGSAM, and system analysts use the NGSAM tool to generate information about schedule, costs, infrastructure, etc. In addition, DOE used outputs from NGSAM in multi-objective evaluation framework (MOEF) analyses. MOEF is a set of capabilities, methods, processes, and tools that provide a means to evaluate alternative scenarios and system architectures for an integrated waste management system where there are multiple conflicting objectives and differing stakeholder perspectives on a proposed waste management system.

During the reporting period, the Board held two public meetings and one fact-finding meeting, wrote two letters to DOE, and received three letters from DOE, which addressed DOE's progress in developing decision-support tools, START and NGSAM. In March 2022, the Board held a virtual public meeting on DOE's integrated waste management system R&D activities, which included updates on NGSAM and START development. The Board commended DOE for advancing the development of NGSAM and expanding its capabilities to model individual elements of DOE SNF (Bahr 2022b). The Board noted that NGSAM capabilities did not address various packaging/repackaging options, such as direct disposal of DPCs. In addition, the Board observed that other federal agencies use different transportation planning tools and have information that DOE should leverage to gain insights for additional START development. After reviewing the information at the fact-finding and public meetings and examining information in related technical reports, the Board sent a letter to DOE (Bahr 2022b) with its findings and recommendations, as follows:

- *The Board finds that there is value in expanding NGSAM capabilities and analyses to more completely address possible integrated waste management systems options and in renewing the development of MOEF as a part of understanding and addressing stakeholder objectives in support of consent-based-siting activities.*

- *The Board recommends that DOE expand NGSAM capabilities and analyses to better address disposal of DPCs, including waste packaging operations and cost requirements, and that it include stakeholders involved in the consent-based siting process to inform NGSAM development and use.*

- *The Board finds that there are additional opportunities for developing and using START as a training tool and to improve outreach using the knowledge bases of other agencies.*

- *The Board recommends that DOE consider how START might be utilized as a resource to familiarize and train emergency response personnel for nuclear waste transport and as a component in tabletop exercises aimed at exploring emergency scenarios. Likewise, the Board recommends that DOE engage with other agencies involved in similar transportation efforts to leverage their experiences and approaches to stakeholder interactions and addressing hazards.*

DOE responded to the Board's letter in July 2023 (DOE 2023b) and stated that the fiscal year 2023 plans included applying the NGSAM capabilities toward analyzing scenarios involving direct disposal of DPCs, including analysis of cost and waste packaging considerations. DOE also planned to incorporate stakeholder input received throughout the consent-based siting process to inform development and use of its systems analysis tools, and in turn, apply systems analysis results to inform consent-based siting.

In March 2023, the Board held a public meeting on DOE's efforts related to removing SNF from commercial nuclear power plant sites. The Board received a presentation on an UNF-ST&DARDS analysis of the cooling time requirements and criticality safety requirements prior to transporting commercial SNF canisters. In August 2023, based on the information presented at the public and fact-finding meetings and in related technical reports, the Board sent DOE a letter (Siu 2023) containing the following finding:

- **Finding 1a:** The Board finds that DOE is making progress in its IWM [integrated waste management] program, particularly in three major cross-cutting areas: (i) transportation preparations, (ii) storage design and regulatory considerations, and (iii) systems analysis tools and integration. The Board recognizes that DOE activities related to consent-based siting of a federal interim storage facility are in the early stages of a multiyear effort.

DOE responded to the Board's letter in September 2024 (DOE 2024b) and thanked the Board for its input and noted that DOE looks forward to the Board's future insights on DOE's activities related to the management and disposal of SNF and HLW.

Board Interactions with Congress

The Board provided no testimony to Congress during the 2022 to 2024 period. The Board distributed its reports to members of Congress and congressional staff when it generated new material and provided briefings to congressional staff on those reports when requested. Board staff also continued the long-standing practice of briefing the relevant staff of the Congressional Research Service on new official correspondence and reports issued by the Board.

International Activities

Between 2022 and 2024, the Board continued to monitor and be informed by activities in other countries related to programs for the management and disposal of radioactive waste. Members of the Board and staff visited nuclear waste-related facilities in Switzerland and Canada, where sites for deep geologic repositories for SNF or HLW are being selected. One goal of these trips was to identify recent siting lessons learned that could be applicable to DOE's efforts to site a CISF. As part of its efforts to inform Congress and other stakeholders, the Board published informational resources on nuclear waste programs in other countries. The Board and staff interacted with foreign nuclear waste experts by inviting them to participate in Board public meetings and by meeting with them when they visited the United States. A member of the Board's staff participated in the Organisation for Economic Co-operation and Development's Nuclear Energy Agency IGSC activities.

Board trip to Switzerland

The Board conducted a detailed technical information exchange with Swiss nuclear waste officials in October 2022, one month after the Swiss nuclear waste disposal implementer, the Swiss National Cooperative for the Disposal of Radioactive Waste (Nagra), announced the proposed site for the Swiss geologic repository (Figure 11).

Figure 11. The site (Nördlich Lägern) of the proposed Swiss geologic repository for high-level and intermediate-level radioactive waste.

A member of the Board and two staff members met virtually with the Swiss Federal Nuclear Safety Inspectorate, which is the national regulatory body with responsibility for the nuclear safety and security of Swiss nuclear facilities. During a visit to Switzerland the following week, members of the Board and staff met with representatives of Nagra and the Swiss Federal Office of Energy, which is responsible at the government level for implementation of the Swiss policy for the backend of the nuclear fuel cycle and the storage and disposition of HLW and SNF. The Board delegation toured the SNF interim storage facility at Zwilag and the Swiss underground research laboratory at Mont Terri.

Members of the Board and staff also visited the site of the proposed Swiss deep geologic repository for high-level and intermediate-level waste, located north of Lägern near Stadel (canton of Zurich) (Figure 11) and Nagra's nearby information pavilion (Figure 12).

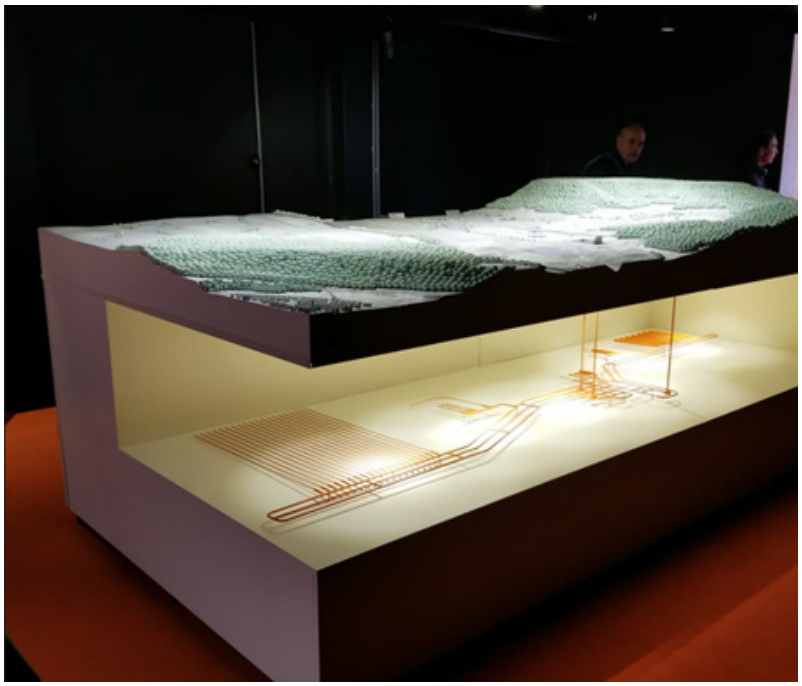


Figure 12. Three-dimensional model depicting surface features and separate areas underground for disposal of spent nuclear fuel and high-level radioactive waste (left) and intermediate-level waste (right). The model depicts an area that is 2 by 3 kilometers and at a depth of 1.5 kilometers.

Board trip to Canada

In October 2023, members of the Board and staff traveled to Ontario, Canada, at the invitation of the Nuclear Waste Management Organization of Canada (NWMO), the sole organization designated by the Canadian government to develop and implement long-term plans for managing used nuclear fuel from Canadian nuclear power plants, including the development of deep geological repositories. The Board delegation toured the Darlington Nuclear Generating Station to learn about SNF management and storage prior to its transport to a repository (Figure 13). The Board delegation also visited the potential host site community of South Bruce, meeting with local officials involved in the siting process and touring NWMO's borehole core storage facility and information center. The delegation's tour of NWMO's technology demonstration center in Oakville reinforced the Board's view that demonstrating waste emplacement and disposal technology is an invaluable part of any advanced waste management program and helps facilitate siting of a repository.

Other Board activities

The Board continued to provide updated information on national programs for waste disposal as a resource for Congress and the public. In July 2022, the Board issued its *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: 2022 Update* (NWTRB 2022b), a report that offered an updated edition of the survey first issued by the Board in 2009 and updated previously in 2016.

Figure 13. The Board learned about packaging and dry storage of spent nuclear fuel discharged from the CANDU [Canada deuterium uranium] reactors at the Darlington Nuclear Generating Station in Bowmanville in Ontario, Canada.

The new version described 30 technical and institutional attributes of nuclear waste programs in 13 countries, including the United States. Then, in September 2024, the Board also created and published an online, interactive Table of Repository Programs on the Board's website[16] that summarizes the progress in developing repository programs around the world for the disposal of spent nuclear fuel and high-level radioactive waste. For 13 selected countries, the table shows the major milestones reached in developing a repository and estimated dates for future milestones. Comparative information on national disposal programs provides useful technical and scientific information for decision-makers in

Congress and the Administration on different approaches for managing and disposing of SNF and HLW. Updated information will continue to be made available on the Board's website as a resource for Congress and the public.

During the 2022 to 2024 period, the Board also hosted representatives of Australian, Canadian, Finnish, and French nuclear waste disposal programs when they visited the United States and included them in Board meetings when appropriate. During its Summer 2023 public meeting and international workshop in Idaho, the Board received presentations from representatives of the nuclear waste management programs of Sweden, Switzerland, and Canada regarding the comparative experiences gained in those countries through their processes for siting radioactive waste facilities. In its virtual meetings, the Board invited speakers from multiple countries that represented government, industry, and national laboratories. For example, speakers from Spain and Finland

[16] The Interactive Table of Repository Programs summarizes the progress of 13 developing repository programs around the world. Please visit: https://www.nwtrb.gov/scope/nuclear-repositories (last accessed August 7, 2025).

contributed to the Board's public meetings on disposal of SNF and HLW in clay and crystalline host rocks.

As a US delegate to IGSC, an international organization, a member of the Board's staff participated in several IGSC activities, both virtually and in person. Those activities in which the Board participated include the following:

- Virtual attendance at a joint IGSC/Forum on Stakeholder Confidence meeting on uncertainty management in May 2022 and at an IGSC meeting on radiation protection in underground repositories in July 2024.

- Virtual attendance at the IGSC's annual meeting in 2023 that addressed when reasonable confidence is achieved and delivered an invited presentation on pre-licensing dialogue between the regulator (NRC) and implementer (DOE) in the Yucca Mountain program.

- Attended the IGSC Safety Case Symposium, Budapest, Hungary, in October 2024 that focused on progress toward construction of repositories and presented a paper on the challenges to developing safety cases for disposal of US SNF and HLW.

- Attended the Nuclear Energy Agency's Workshop on Extended Storage and Transportation of Spent Fuel and Radioactive Waste from Current and Future Reactor Technologies held in Camden, New Jersey, December 2023.

These activities broadened the Board's basis for reviewing DOE's R&D activities and highlighted issues that affect the success of national programs for the management and disposal of SNF and HLW.

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ACRONYMS

ADVANCE Act	Accelerating Deployment of Versatile, Advanced Nuclear for Clean Energy Act
ASNF	aluminum-clad spent nuclear fuel
ASTM	American Society for Testing and Materials
ATF	accident tolerant fuel
Board	U.S. Nuclear Waste Technical Review Board
BRC	Blue Ribbon Commission on America's Nuclear Future
BWR	boiling water reactor
CFR	Code of Federal Regulations
CISCC	chloride-induced stress corrosion cracking
CISF	consolidated interim storage facility
CoC	Certificate of Compliance
DOE	U.S. Department of Energy
DOE-EM	U.S. Department of Energy, Office of Environmental Management
DOE-NE	U.S. Department of Energy, Office of Nuclear Energy
DPC	dual-purpose canisters
EPRI	Electric Power Research Institute
ESCP	Extended Storage Collaboration Program
GDSA	Geologic Disposal Safety Assessment
GWd/MTU	gigawatt-day per metric ton of uranium
HBF	high burnup fuel
HLW	high-level radioactive waste
IFBA	integral fuel burnable absorbers
IGSC	Integration Group for the Safety Case
INL	Idaho National Laboratory

IWM	Integrated Waste Management
ISFSI	independent spent fuel storage installation
LWR	light water reactor
MOEF	multi-objective evaluation framework
NGSAM	Next Generation System Analysis Model
NEI	Nuclear Energy Institute
NRC	U.S. Nuclear Regulatory Commission
NWMO	Nuclear Waste Management Organization (Canada)
NWPA	Nuclear Waste Policy Act
NWPAA	Nuclear Waste Policy Amendments Act
PASO	Performance Assessment of Strategy Options Model
PNNL	Pacific Northwest National Laboratory
PWR	pressurized water reactor
R&D	research and development
RD&D	research, development, and demonstration
SNF	spent nuclear fuel
SNFWG	Spent Nuclear Fuel Working Group
SNL	Sandia National Laboratories
SRS	Savannah River Site
START	Stakeholder Tool for Assessing Radioactive Transportation
TRISO	tri-structural isotropic
UNF-ST&DARDS	Used Nuclear Fuel-Storage, Transportation & Disposal Analysis Resource and Data System
URL	underground research laboratory
WCS	Waste Control Specialists

GLOSSARY

Aging management program A program that evaluates the changes in a component over its expected usage period to determine if these changes will affect the component's ability to perform its function.

Aluminum-based SNF The term "aluminum-based SNF" is used by the U.S. Department of Energy for aluminum-clad, uranium oxide spent nuclear fuel; aluminum-clad, uranium-aluminum alloy spent nuclear fuel; and spent nuclear fuel without cladding stored in aluminum cans. See also **fuel cladding**.

Backfill The material used to refill excavated parts of a repository during and after waste emplacement.

Bentonite A soft, light-colored clay formed by chemical alteration of volcanic ash. Bentonite has been proposed for backfill and buffer material in many repositories.

Burnup A measure of reactor fuel consumption expressed as the percentage of fuel atoms that have undergone fission or the amount of energy produced per unit weight of fuel, measured in gigawatt-days per metric ton of uranium in the fuel (GWd/MTU).

Canister (in a dry storage system for spent nuclear fuel) A metal cylinder that is sealed at both ends and may be used to perform the function of confinement in a dry cask storage system for spent nuclear fuel. Typically, a separate overpack or horizontal storage module performs the radiological shielding and physical protection function.

Cask A heavily shielded container used for the dry storage or shipment (or both) of radioactive materials such as spent nuclear fuel or other high-level radioactive waste. Casks are often made from lead, concrete, or steel.

Chemisorbed water Water that is bound to species by forces whose energy levels approximate those of a chemical bond.

Clays Minerals that are essentially hydrated aluminum silicates or occasionally hydrated magnesium silicates, with sodium, calcium, potassium, and magnesium cations. Also denotes a natural material with plastic properties, which is essentially a composition of fine to very fine clay particles. Clays differ greatly, mineralogically, and chemically and consequently in their physical properties. Because of their large specific surface areas, most of them have good sorption characteristics.

Clay/shale (host rock) Denotes a sedimentary deposit of clay that has not hardened into a sedimentary rock or shale deposit. Both clay and shale have relatively low permeability and relatively high capacity for sorption of positively charged chemical species.

Consent-based siting An approach to siting facilities that focuses on the needs and concerns of people and communities.

Containment Methods or physical structures designed to prevent the dispersion of radioactive substances. Although approximately synonymous with confinement, containment is normally used to refer to methods or structures that prevent radioactive substances from being dispersed in the environment if confinement fails.

Crystalline (host rock) A generic term for igneous rocks and metamorphic rocks (e.g., granite, gneiss, and basalt).

Deep borehole disposal Waste disposal in a cylindrical excavation drilled into deep rock.

Deep-mined, geologic disposal A facility for disposal of radioactive waste located underground (usually several hundred meters or more below the surface) in a geological formation intended to provide long-term isolation of radionuclides for the biosphere.

Direct disposal A phrase to denote disposal of a dual-purpose (storage and transportation) canister containing SNF without repackaging of the SNF and with a disposal overpack placed around the dual-purpose canister prior to disposal in a repository.

Engineered barrier The designed or engineered components of a repository, including waste packages and other features.

Fission gas Gaseous fission products that are produced from the splitting of fissile radionuclides.

Fuel assembly A structured group of fuel rods (long, slender, metal tubes containing pellets of fissionable material, which provide fuel for nuclear reactors). Depending on the design, each reactor vessel may have dozens of fuel assemblies (also known as fuel bundles), each of which may contain 200 or more fuel rods.

Fuel cladding Also referred to as "cladding" generally. Cladding is the thin-walled metal tube that forms the outer jacket of a nuclear fuel rod. It prevents corrosion of the fuel by the coolant and provides containment against the release of fission products into the coolant. Aluminum, stainless steel, and zirconium alloys are common cladding materials.

Fuel rod A long, slender, metal tube containing pellets of fissionable material, which provide fuel for nuclear reactors. Fuel rods are assembled into bundles that are called fuel assemblies, which are loaded individually into the reactor core.

Fuel pellet A thimble-sized ceramic cylinder (approximately 3/8-inch in diameter and 5/8-inch in length), consisting of uranium (typically uranium oxide, UO_2), which has been enriched to increase the concentration of uranium-235 (U-235) to fuel a nuclear reactor. Modern reactor cores in pressurized-water reactors and boiling-water reactors may contain up to 10 million pellets, stacked in the fuel rods that form fuel assemblies. See also **fuel rod** and **fuel assembly**.

High burnup spent nuclear fuel Reactor fuel with burnups exceeding 45 gigawatt-days per metric ton. Burnup is a measure of reactor fuel consumption expressed as the percentage of

fuel atoms that have undergone fission, or the amount of energy produced per unit weight of fuel, measured in gigawatt-days per metric ton of uranium in the fuel (GWd/MTU).

Independent spent fuel storage installation A complex designed and constructed for the interim storage of spent nuclear fuel; solid, reactor-related, greater than Class C waste; and other associated radioactive materials. A spent fuel storage facility may be considered independent, even if it is located on the site of another NRC-licensed facility.

Multi-canister overpack A stainless steel container for interim storage of spent nuclear fuel. The multi-canister overpack is a cylindrical tube with a plate welded at the bottom and a shield plug at the top; five or six baskets loaded with intact fuel rods or fuel pieces are stacked inside the multi-canister overpack.

Shale A fine-grained sedimentary rock that forms from the compaction of silt and clay-size mineral particles that we commonly call "mud."

Vitrification Mixing processed radioactive waste with glass fragments in a furnace to stabilize the waste into a form that will neither react nor degrade for extended periods of time.

Volcanic tuff A general term for volcanic rocks that formed from fragmented magma and fragments of other rocks, and that erupted from a volcanic vent, flowed away from the vent as a suspension of solids and hot gases, or fell from the eruption cloud, and consolidated at the location of deposition. Tuff is the most abundant type of rock at the proposed Yucca Mountain repository site.

Waste package The waste form and any containers, shielding, packing and other absorbent materials immediately surrounding an individual waste container.

APPENDICES

A. Board Members During the Reporting Period

B. Board Strategic Plan 2022–2026

C. Board Publications

D. Board Meetings: January 1, 2022–December 31, 2024

E. Correspondence with the U.S. Department of Energy: January 1, 2022–December 31, 2024

Appendix A. Board Members During the Reporting Period

PETER SWIFT, PH.D., CHAIR

Dr. Peter Swift was appointed to the U.S. Nuclear Waste Technical Review Board and designated as Chair by President Joseph Biden on September 16, 2024.

Dr. Swift is a consulting geoscientist with over 30 years of experience in high-level radioactive waste management and disposal. He was formerly a Senior Scientist at Sandia National Laboratories in Albuquerque, New Mexico, where he served from 2011 to 2020 as the National Technical Director of the U.S. Department of Energy's Office of Nuclear Energy, Spent Fuel and Waste Technology Research and Development Campaign. Prior experience includes key roles in the certification and licensing processes for both the Waste Isolation Pilot Plant and the formerly proposed Yucca Mountain repository for spent nuclear fuel and high-level radioactive waste in Nevada. Specific to the Yucca Mountain project, he led the total system performance assessment effort that developed estimates of the long-term safety of the site and then served as the Chief Scientist for the program's Lead Laboratory during DOE's 2008 submittal of the license application to the U.S. Nuclear Regulatory Commission.

Dr. Swift is a Fellow of the Geological Society of America, and a member or past member of the American Nuclear Society, the American Geophysical Union, the American Association of Petroleum Geologists, and the Geochemical Society.

Dr. Swift received a Ph.D. in Geosciences from the University of Arizona in 1987, master's and bachelor's degrees in geology from the University of Wyoming in 1982 and 1980, and a B.A. in English from Yale University in 1974.

JEAN M. BAHR, PH.D., CHAIR[a]

Dr. Jean M. Bahr was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012, and was designated by the President to serve as Chair of the Board on January 5, 2017.

Dr. Bahr is an Emeritus Professor at the University of Wisconsin-Madison. Prior to retirement, she was on the faculty of the Department of Geoscience, and a member of the UW-Madison Institute for Environmental Studies. She served as chair of Geoscience (formerly Geology and Geophysics) from 2005 to 2008 and of the Nelson Institute's Water Resources Management Graduate Program from 1995 to 1999. Dr. Bahr's research explores physical, geochemical, and biogeochemical controls on the movement of water and associated solutes in subsurface geologic systems.

Dr. Bahr has served on many advisory committees through the National Research Council of the National Academies and was a member of the Board on Radioactive Waste Management from 1992 to 1997. She chaired the Committee on Restoration of the Greater Everglades Priorities in Earth Science and Public Health. In addition to her service for the National Academies, Dr. Bahr has been a member of proposal review panels for the National Science Foundation, the U.S. Environmental Protection Agency, the U.S. Department of Energy, and the international Ocean Drilling Program. She served terms on the editorial boards of the journals *Water Resources Research*, *Ground Water*, and *Hydrogeology*.

Dr. Bahr was elected to Sigma Xi in 1984, named a Fellow of the Geological Society of America (GSA) in 1996, and received the GSA Hydrogeology Division's Distinguished Service Award in 2006. She was the 2003 GSA Birdsall-Dreiss Distinguished Lecturer and was elected President of GSA for 2009–2010. She was named a lifetime National Associate of the National Academies in 2002 and was the 2012 recipient of the Association for Women Geoscientists Outstanding Educator Award. She received the American Geophysical Union's Ambassador Award in 2017. She is the 2022 recipient of the American Geosciences Institute's Ian Campbell Medal for Superlative Service to the Geosciences.

Dr. Bahr received a B.A. in geology and geophysics from Yale University in 1976, and an M.S. and a Ph.D. in 1985 and 1987, respectively, in applied earth sciences (hydrogeology) from Stanford University.

Dr. Bahr resides in Millbrae, California, and Madison, Wisconsin.

[a] Dr. Jean M. Bahr served on the Board until she was replaced on December 12, 2022.

NATHAN SIU, PH.D., CHAIR[b]

Dr. Nathan Siu was appointed to the U.S. Nuclear Waste Technical Review Board and designated as Chair by President Joseph Biden on October 25, 2022. He served as Chair of the Board from December 12, 2022, through September 16, 2024, and was reappointed as a member the same day.

Nathan Siu is an independent risk assessment consultant. He retired from the U.S. Nuclear Regulatory Commission (NRC) in 2021, where he was a Senior Technical Adviser for Probabilistic Risk Assessment (PRA) in NRC's Office of Nuclear Regulatory Research. His responsibilities included advising management on PRA issues; developing PRA research programs to address key issues; providing PRA-related advice and support to technical staff; supporting PRA-related cooperative research activities with U.S. and international organizations; and supporting technology transfer to other technical communities. Prior to joining NRC in 1997, he was an Engineering Fellow at the Idaho National Engineering Laboratory, an Associate Professor of Nuclear Engineering at the Massachusetts Institute of Technology, and an Associate Consultant at Picard, Lowe, and Garrick, Inc.

Dr. Siu is internationally recognized for his expertise in risk assessment for nuclear facilities. He is a past Chair of the Working Group on Risk Assessment for the Organisation for Economic Co-operation and Development's Nuclear Energy Agency and served as a consultant on an International Atomic Energy Agency project on advanced PRA methods. He has chaired the NRC's Technical Advisory Group on NRC Level 3 PRA and served as a Chair of the NRC's Risk Management Team. He is a past member of the Editorial Board of *Reliability Engineering and System Safety* and the Board of Directors for the International Association for Probabilistic Safety Assessment and Management and has served in technical leadership positions in numerous technical meetings and conferences. Dr. Siu is a Fellow of the American Nuclear Society and has authored or co-authored over 180 technical papers and reports focusing on risk assessment methods and applications, but also addressing such topics as risk metrics, risk communication, enterprise risk management, and risk-related knowledge engineering.

[b] Dr. Nathan Siu served on the Board until July 2025.

RICHELLE ALLEN-KING, PH.D.[c]

Dr. Richelle M. Allen-King was appointed to the U.S. Nuclear Waste Technical Review Board by President Joseph Biden on September 16, 2024.

Dr. Allen-King is a Professor of Geological Sciences at the University at Buffalo, State University of New York. She is a hydrogeochemist with more than 35 years of experience studying the fate and transport of contaminants in groundwater with particular focus on the importance of geologic context. She is also interested in groundwater impacts on lake geochemistry in a changing climate. Dr. Allen-King has served as a member of the National Research Council's Water Science and Technology Board and on several National Research Council technical committees on groundwater use, contamination, and remediation. Particularly relevant were the National Research Council's Committee on Development and Implementation of a Cleanup Technology Roadmap, Committee on the Bioavailability of Contaminants in Soils and Sediments, and Committee on Innovations in Ground Water and Soil Cleanup. Dr. Allen-King has also served on committees and advisory panels for the U.S. Environmental Protection Agency, such as the Ecological Processes and Effects Committee. She has also contributed to multiple other science review committees and boards.

She was selected as a Henry Darcy Distinguished Lecturer, sponsored by the National Ground Water Association, and is a Fellow of the Geological Society of America.

Dr. Allen-King earned a B.A. in chemistry with specialization in earth sciences from the University of California, San Diego, and a Ph.D. in earth sciences from the University of Waterloo. She resides in Buffalo, New York.

[c] Dr. Richelle Allen-King served on the Board until July 16, 2025.

RONALD G. BALLINGER, SC.D.[d]

Dr. Ronald G. Ballinger was appointed to the U.S. Nuclear Waste Technical Review Board by President Joseph Biden on October 25, 2022.

Ronald G. Ballinger is a Professor Emeritus of Nuclear Science and Engineering and Materials Science and Engineering at Massachusetts Institute of Technology (MIT). Professor Ballinger was also Head of the H.H. Uhlig Corrosion Laboratory in the Department of Materials Science and Engineering at MIT. Professor Ballinger was active in the teaching of graduate and undergraduate subjects in reactor design, fuel performance, radiation effects, corrosion engineering, chemistry, mechanical behavior, and physical metallurgy.

Professor Ballinger served for eight years in the nuclear navy before attending college. He received his B.S. in mechanical engineering from Worcester Polytechnic Institute in 1975. He received his S.M. in nuclear engineering in 1977 and in materials science and engineering in 1978. He received his Sc.D. in nuclear materials engineering in 1982. After receiving his Sc.D., he joined the faculty at MIT.

Professor Ballinger's areas of specialization are materials selection and engineering of nuclear engineering systems with an emphasis on environmental degradation and life assessment of these systems. Specific areas of research were: (1) environmental effects on material behavior, (2) physical metallurgical and electrochemical aspects of environmentally assisted cracking in aqueous systems, (3) stress corrosion cracking and hydrogen embrittlement in light water reactor (LWR) systems, (4) failure analysis of engineering structures, (5) the effect of radiation on aqueous chemistry, (6) experimental fatigue and fracture mechanics, (7) degradation of materials properties and their effects on component life, (8) nuclear fuel performance, including gas reactor coated particle fuel and environmental degradation, processing, and storage of metallic uranium fuel, and (9) materials development for advanced reactor and fusion systems, including supercritical water, supercritical carbon dioxide, liquid metal, high-temperature gas reactor, and cryogenic structural applications.

Professor Ballinger was a founding member and still is a member of the International Cooperative Group on Environmentally Assisted Cracking of Light Water Reactor Materials (ICG-EAC). The ICG-EAC is charged with the development of methodology for understanding of LWR materials.

Professor Ballinger has served on several U.S. Department of Energy (DOE) committees dealing with the stabilization, processing, and disposition of metallic uranium fuel from the production reactors as well as from research reactors including teams to evaluate options for the Hanford, Savannah River, and Idaho National Engineering Laboratory sites. He has been a member of several DOE committees to evaluate advanced reactor options and materials for these options. These committees include: (1) Independent Technical Review Group: Design Features and Technology Uncertainties for the Next Generation Nuclear Plant, (2) Power

[d] Dr. Ronald G. Ballinger resigned from the Board in April 2025.

Conversion Unit Study Committee, and (3) the Idaho National Laboratory Materials Review Board. Professor Ballinger was a member of the Independent Performance Assessment Review Panel that evaluated the total system performance assessment for the license application for the Yucca Mountain waste repository.

Professor Ballinger was appointed to the NRC Advisory Committee on Reactor Safeguards in 2013. He was reappointed to a third four-year term in 2021.

LAKE BARRETT[e]

Mr. Lake Barrett was appointed to the U.S. Nuclear Waste Technical Review Board by President Joseph Biden on September 16, 2024.

Mr. Barrett is a part-time independent consultant in the energy field. He has worked in the nuclear energy and nuclear materials management areas for more than five decades. He served as special advisor to Japan for the recovery of the Fukushima Daiichi nuclear accident. Before that, he served as the head of the U.S. Department of Energy's Office of Civilian Nuclear Waste Management, which was responsible for implementing the United States' programs for spent nuclear fuel and high-level radioactive waste management, as mandated by the Nuclear Waste Policy Act. In that capacity, he led the complex scientific Yucca Mountain Geologic Repository program through the statutory site selection process culminating with the Presidential site designation and following successful House and Senate votes before he retired from federal service.

Mr. Barrett also served at the U.S. Nuclear Regulatory Commission in various senior capacities, including as the site director during the stabilization, recovery, and cleanup of the Three Mile Island reactor accident. He has testified in congressional hearings concerning U.S. spent nuclear fuel policies and the Fukushima reactor accident. He also has extensive managerial and engineering experience in DOE's Defense Programs and in private industry at both Bechtel Power Corporation, with commercial nuclear power plants, and Electric Boat Division of General Dynamics, with nuclear reactor and submarine systems design, operation, and decommissioning. He has degrees in mechanical and nuclear engineering and has been the recipient of various executive branch and congressional honors.

[e] Mr. Lake Barrett resigned from the Board in May 2025.

STEVEN M. BECKER, PH.D.[f]

Dr. Steven M. Becker was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012.

Dr. Becker is a Professor of Community and Environmental Health at Old Dominion University in Norfolk, Virginia. He is a leading international expert on emergency planning, disaster preparedness and response, public health preparedness, and risk communication for radiological, chemical, and nuclear incidents as well as other new and emerging health challenges. Dr. Becker has served as principal investigator for several major research studies aimed at improving emergency messages for the general public, first responders, and hospital and healthcare professionals. In addition, he has extensive on-the-ground experience at the sites of accidents, emergencies, and disasters around the world. In 2011, he was a member of a three-person assistance team invited to Japan in response to the earthquake-tsunami disaster and the emergency at the Fukushima Daiichi nuclear plant. While on scene, the team carried out a rapid site assessment, interfaced with Japanese disaster professionals, and provided training to more than 1,100 Japanese hospital and healthcare personnel and emergency responders.

Dr. Becker's research on emergency preparedness, public health, and risk communication has been recognized with awards from such scientific organizations as the Health Physics Society and Oak Ridge Associated Universities. For the last 19 years, he also has been an invited faculty member in the Harvard School of Public Health training course on radiological emergency planning.

Dr. Becker holds a B.A. from George Washington University, an M.A. from Columbia University, and a Ph.D. from Bryn Mawr College. He also was a Dozor Visiting Scholar at Ben-Gurion University of the Negev in Israel and a Visiting Fellow at the Japan Emergency Medicine Foundation and National Hospital Tokyo Disaster Medical Center. In 2017, Dr. Becker was named a member of the Nuclear and Radiation Studies Board of the National Academies of Sciences, Engineering, and Medicine.

[f] Dr. Steven M. Becker served on the Board from 2012 until September 16, 2024.

ALLEN G. CROFF, M.B.A.[g]

Allen G. Croff was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on February 23, 2015.

Mr. Croff is an adjunct professor in the Civil and Environmental Department at Vanderbilt University in Nashville, Tennessee. His areas of expertise include radioactive waste generation, classification, processing, storage, transportation, and disposal; nuclear fuel cycle systems and economic analysis and regulation; modeling radionuclide production and depletion; radionuclide separation and transmutation; waste repository site identification, regulation, and assessment; and cleanup of U.S. Department of Energy (DOE) legacy sites.

Mr. Croff worked at Oak Ridge National Laboratory for almost 30 years. He is a member of the National Council on Radiation Protection and Measurements (NCRP) and has served on ten committees of the National Academy of Sciences and on its Nuclear and Radiation Studies Board. He was also a member of DOE's Nuclear Energy Research Advisory Committee and served on the staff of the Blue Ribbon Commission on America's Nuclear Future. He was Chairman of the Nuclear Development Committee of the Nuclear Energy Agency for ten years and Vice-Chairman of the U.S. Nuclear Regulatory Commission's Advisory Committee on Radioactive Waste Management for four years.

Mr. Croff's writings and publications include contributions to five books, ten National Academy of Sciences reports, an NCRP report, and numerous national laboratory reports and peer-reviewed conference papers.

Mr. Croff received a B.S. (1971) in chemical engineering from Michigan State University, a Nuclear Engineer degree (1974) from the Massachusetts Institute of Technology, and an M.B.A. (1981) from the University of Tennessee.

Mr. Croff resides in Saint Augustine, Florida.

[g] Mr. Allen G. Croff served on the Board from 2015 until September 16, 2024.

TERESA FRYBERGER, PH.D.[h]

Dr. Teresa Fryberger was appointed to the U.S. Nuclear Waste Technical Review Board by President Joseph Biden on October 25, 2022.

Teresa Fryberger has worked as a consultant for the American Chemical Society (ACS) since her retirement in 2019. At ACS, she played a key role in developing the strategy and plans for the newly launched ACS Campaign for a Sustainable Future.

Dr. Fryberger's areas of expertise include a wide range of topics in chemical and environmental sciences and policy. Most relevant to the work of this board is her experience in nuclear waste management research, the use of research results data for decision-making, and federal research management policy and operations.

Before her retirement, Dr. Fryberger served as a Senior Board Director at the National Academies of Sciences, Engineering, and Medicine, where she led two boards—the Board on Chemical Sciences and Technology and the Board on Environmental Studies and Toxicology. Prior to the Academies, she held executive positions at the National Aeronautics and Space Administration and the Department of Energy. While at the Department of Energy, she was detailed to the White House from 2004 to 2006, where she gained policy experience at the Office of Science and Technology Policy and held the position of Assistant Director for Environment. Dr. Fryberger has also worked in leadership positions at two national laboratories—Pacific Northwest National Laboratory and Brookhaven National Laboratory. During her eight years at the U.S. Department of Energy, she managed the Efficient Separations Research Program for the treatment of high-level nuclear waste and led the Environmental Management Science Program, which sponsored foundational research for the defense waste cleanup effort.

Dr. Fryberger was named a Fellow of the American Association for the Advancement of Science in 2018. Prior to joining the National Academies as a Board Director in 2013, she was a member of the Chemical Science Roundtable and served on two National Research Council study committees that focused on nuclear defense waste research and management.

Dr. Fryberger earned her Ph.D. in physical chemistry from Northwestern University (1986) and her B.S. in chemistry from the University of Oklahoma (1979). After receiving her Ph.D., she was a National Research Council Postdoctoral Fellow at the National Institute of Standards and Technology.

Dr. Fryberger resides in Arlington, Virginia.

[h] Dr. Teresa Fryberger served on the Board from 2022 until July 2023.

MILES GREINER, PH.D.[i]

Dr. Miles Greiner was appointed to the U.S. Nuclear Waste Technical Review Board by President Joseph Biden on September 16, 2024.

Dr. Greiner is a Foundation Professor of Mechanical Engineering at the University of Nevada, Reno (UNR), a Fellow of the American Society of Mechanical Engineers (ASME), and past chair of the UNR Mechanical Engineering Department. Since 1993, he has directed the UNR Nuclear Packaging Program, which conducts externally funded research to develop and experimentally validate computational methods to predict the thermal performance of nuclear packaging under normal and severe fire accident conditions. This includes performing large-scale experiments and computational studies of heat transfer to massive objects engulfed in pool fires, developing methods to predict transport during used nuclear fuel package vacuum drying, and developing wireless methods to monitor nuclear packaging internal conditions. Since 2016, Dr. Greiner has directed a UNR educational program, which awards graduate certificates in Nuclear Packaging and in Transportation Security and Safeguards. He has published over 100 journal articles and conference papers on nuclear packaging topics. Dr. Greiner earned his Ph.D. in mechanical engineering from the Massachusetts Institute of Technology.

[i] Dr. Miles Greiner served on the Board until July 16, 2025.

TISSA H. ILLANGASEKARE, PH.D., P.E.[j]

Dr. Tissa H. Illangasekare was appointed to the U.S. Nuclear Waste Technical Review Board on January 18, 2017, by President Barack Obama.

Dr. Illangasekare presently holds the AMAX Endowed Distinguished Chair of Civil and Environmental Engineering position at the Colorado School of Mines. He is also the founding director of the Center for Experimental Study of Subsurface Environmental Processes, a university/industry/national laboratory collaborative center. His research experience and expertise are in mathematical and numerical modeling of flow and transport in porous and fractured media, management of hydrocarbon, organic, and nuclear wastes, saturated and unsaturated zone processes, multiphase flow, carbon storage, modeling of land-atmospheric interaction, remediation of contaminated sites, and application of sensor technologies for environmental, soil, and hazard monitoring.

Dr. Illangasekare has served on many national and international advisory boards, including the National Academy of Science's Nuclear and Radiation Studies Board. He has also been a member of several National Research Council committees that include "Subsurface Contamination at DOE Complexes" and "Management of Certain Radioactive Waste Streams Stored in Tanks at Three Department of Energy Sites." He has served as a member of the Board of Directors of the Consortium of Universities for the Advancement of Hydrologic Sciences. He served as President of the International Porous Media Society (InterPore). Dr. Illangasekare served as editor of *Water Resources Research* and *Earth-Science Reviews* and co-editor of *Vadose Zone Journal*. He is currently an editor of American Geophysical Union's (AGU) *Advances* and *Perspectives in Earth and Planetary Systems* and the Section Chief Editor of *Frontiers in Water and Human Health*. He is a Fellow of the AGU, the American Association for the Advancement of Science, the American Society of Civil Engineers, the Soil Science Society of America, and the National Academy of Sciences of Sri Lanka. He is a registered Professional Engineer and a Professional Hydrologist, Board Certified Environmental Engineer by the American Academy of Environmental Engineers (by eminence), and Diplomate of American Academy of Water Resources Engineers. Dr. Illangasekare has published over 200 refereed journal papers and contributed to 15 book chapters. He is the recipient of the 2012 Darcy Medal from the European Geosciences Union for outstanding scientific contributions in water resources research and engineering. He was the 2015 recipient of the AGU's Langbein Lecture Award (Bowie lecture), given in recognition of lifetime contributions to the science of hydrology, and he received the 7th Prince Sultan Abdulaziz International Prize for Groundwater at the United Nations from the Secretary General in 2016. He was a Shimizu Visiting Professor in the Department of Civil and Environmental Engineering and a Global Climate Energy Program Visiting Professor at the Department of Earth Resources Engineering at Stanford University. He was a Visiting Scholar in the Department of Civil and Environmental Engineering at University of California, Berkeley. He is currently a

[j] Dr. Tissa H. Illangasekare served on the Board from 2017 until September 16, 2024.

Visiting Professorial Fellow in the School of Civil & Environmental Engineering at the University of New South Wales, Sydney, Australia.

Dr. Illangasekare received a B.Sc. (Honors) degree in civil engineering (1971) from the University of Ceylon, an M.Eng. degree in hydrology and water resources development from the Asian Institute of Technology (1974), and a Ph.D. (1978) in civil engineering from Colorado State University. He also received an Honorary Doctorate in Science and Technology from Uppsala University, Sweden.

Dr. Illangasekare resides in Boulder, Colorado.

SILVIA JURISSON, PH.D.[k]

Dr. Silvia Jurisson was appointed to the U.S. Nuclear Waste Technical Review Board by President Joseph Biden on September 16, 2024.

Dr. Jurisson is Professor Emerita of Chemistry and Radiology at the University of Missouri. She has been involved in inorganic and radiochemistry research with applications to radioisotope production and separations, radiopharmaceutical chemistry, radio-environmental chemistry, and biological systems, and has trained many graduate, undergraduate, and postdoctoral students over the past 30 years. She has over 150 publications in peer-reviewed journals. She is an Associate Editor of Radiochimica Acta, and a Councilor for the Nuclear Division of the American Chemical Society (ACS). She received the John H. Hubbell Award from Elsevier in 2018, the TERACHEM Award in 2018, and the Glenn T. Seaborg Award for Nuclear Chemistry from the ACS in 2012. She was elected as a Fellow of the American Association for the Advancement of Science in 2014, a Fellow of the ACS in 2016, and a Fellow of the Society of Radiopharmaceutical Sciences in 2022.

Early in her career, she had postdoctoral training at the University of New South Wales (1983–1984) with Professor W. Greg Jackson, the Australian National University (1984) with Professor Alan M. Sargeson, and the University of Missouri (1984–1986) with Professor David E. Troutner. She spent five years in the pharmaceutical industry at Bristol Myers Squibb before beginning her academic career at the University of Missouri in 1991. She earned her B.S. in chemistry from the University of Delaware, and her Ph.D. in inorganic and radiopharmaceutical chemistry at the University of Cincinnati.

[k] Dr. Silvia Jurisson served on the Board until July 16, 2025.

KENNETH LEE PEDDICORD, PH.D., P.E.[1]

Dr. Kenneth L. Peddicord was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012. Dr. Peddicord was reappointed to the Board by the President on July 1, 2014.

Dr. Peddicord is a professor of nuclear engineering at Texas A&M University, where he has been a member of the faculty since 1983. From 1972 to 1975, he was employed as a research nuclear engineer at the Eidgenössisches Institut für Reaktorforschung (the Swiss Federal Institute for Reactor Research), now the Paul Scherrer Institut, in Würenlingen, Switzerland. From 1975 to 1981, he was an assistant professor and an associate professor of nuclear engineering at Oregon State University. From 1981 to 1982, he was a Visiting Scientist at the EURATOM Joint Research Centre in Ispra, Italy.

At Texas A&M University, Dr. Peddicord has served as Head of the Department of Nuclear Engineering, Associate Dean and Interim Dean of the College of Engineering, Associate Vice Chancellor and Vice Chancellor of The Texas A&M University System for Research and Federal Relations. From 2007 to 2019, he was director of the Nuclear Power Institute (NPI), a joint institute of the Texas Engineering Experiment Station and Texas A&M University. NPI was a partnership involving universities, community colleges, industry, high schools and junior highs, teachers, students, elected and civic leaders, and government agencies. The focus was to inform, attract, and prepare students for the nuclear industry and to support the development of the peaceful uses of nuclear energy worldwide.

Dr. Peddicord has published more than 200 articles, papers, and reports. His technical interests include nuclear engineering education, human resources and nuclear workforce development, advanced nuclear fuels, and small modular reactors and microreactors. He is a licensed Professional Engineer in the State of Texas.

Dr. Peddicord received a B.S. degree in mechanical engineering from the University of Notre Dame in 1965, and an M.S. in 1967 and a Ph.D. in 1972 in nuclear engineering from the University of Illinois at Urbana-Champaign.

Dr. Peddicord resides in College Station, Texas.

[1] Dr. Kenneth Lee Peddicord served on the Board from 2015 until September 16, 2024.

SETH TULER, PH.D.[m]

Dr. Seth Tuler was appointed to the U.S. Nuclear Waste Technical Review Board by President Joseph Biden on September 16, 2024.

Dr. Tuler is an Associate Professor in the Department of Integrative and Global Studies Division, Worcester Polytechnic Institute, and Senior Research Fellow at the Social and Environmental Research Institute, Shelburne, Massachusetts. His research interests focus on risk governance, public participation in risk assessment and decision making, and developing tools to characterize human impacts and vulnerabilities to risk events. He has extensive experience with interdisciplinary research in multiple policy arenas, including climate adaptation planning, oil spill response planning, nuclear waste management, and regional land-use planning.

Dr. Tuler was a member of the Federal Advisory Committee on Energy-Related Epidemiologic Research and chaired its Subcommittee for Community Affairs for two years. He served on the National Academy of Sciences' Committee on Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste and was asked to co-author two technical reports for the Blue Ribbon Commission on America's Nuclear Future on social distrust and public engagement. More recently he served on the National Academies of Sciences, Engineering, and Medicine's Committee on Alternatives for the Demilitarization of Conventional Munitions; National Academies of Sciences, Engineering, and Medicine's Standing Committee on Chemical Demilitarization; and National Research Council Committee on Review of Criteria for Successful Treatment of Hydrolysate, a hazardous byproduct of chemical weapons demilitarization, at two facilities in Pueblo, Colorado, and Blue Grass, Kentucky.

[m] Dr. Seth Tuler served on the Board until July 16, 2025.

PAUL J. TURINSKY, PH.D.[n]

Dr. Paul J. Turinsky was appointed to the U.S. Nuclear Waste Technical Review Board by President Barack Obama on September 25, 2012. Dr. Turinsky was reappointed to the Board by the President on July 1, 2014, and served as deputy chair from 2021 to 2022.

Dr. Turinsky is Professor Emeritus of Nuclear Engineering at North Carolina State University in Raleigh, North Carolina. He previously was the Chief Scientist for the Department of Energy's (DOE) Innovation Hub for Modeling and Simulation of Nuclear Reactors.

Dr. Turinsky's areas of expertise are computational reactor physics in support of mathematical optimization of fuel management and nuclear fuel-cycle multiobjective decisions; uncertainty quantification and data assimilation in support of optimum experimental design applied to nuclear power plant safety and fuel-cycle assessments; and adaptive model refinement applied to nuclear power plant transient simulation.

Dr. Turinsky's writings and publications include contributions to three books and numerous peer-reviewed technical publications. He is the recipient of the American Society for Engineering Education Glenn Murphy Award, the Edison Electric Institute Power Engineering Educator Award, the U.S. Department of Energy E.O. Lawrence Award in Atomic Energy, and the American Nuclear Society (ANS) Eugene P. Wigner Reactor Physics Award and Arthur Holly Compton Award.

Dr. Turinsky was on the faculty of Rensselaer Polytechnic Institute and has held engineering and management positions at Westinghouse Electric Corporation. He also served on the Commissariat à l'Énergie Atomique Scientific Committee of the Nuclear Energy Division, the Duke Power Company Nuclear Safety Review Board, the DOE Fuel Cycle R&D External Review Committee, and the Board of Managers of Battelle Energy Alliance.

Dr. Turinsky is a Fellow of the ANS and the American Association for the Advancement of Science, and a member of the Society for Industrial and Applied Mathematics and the American Society for Engineering Education, and was elected a member of the National Academy of Engineering.

Dr. Turinsky received a B.S. (1966) in chemical engineering from the University of Rhode Island, an M.S.E. (1967) and a Ph.D. (1970) in nuclear engineering from the University of Michigan, and an M.B.A. (1979) from the University of Pittsburgh.

Dr. Turinsky resides in Raleigh, North Carolina.

[n] Dr. Paul J. Turinsky resigned from the Board in May 2024.

SCOTT W. TYLER, PH.D.[o]

Dr. Scott W. Tyler was appointed to the U.S. Nuclear Waste Technical Review Board by President Joseph Biden on October 25, 2022, and served as deputy chair until 2024.

Dr. Tyler is Professor Emeritus in the Department of Geological Sciences and Engineering at the University of Nevada, Reno. He is also co-director of the National Science Foundation (NSF)-supported Center for Transformative Environmental Monitoring Programs Community User Facility focusing on the development and application of fiber-optic-based sensing of environmental temperature and strain. His research spans the atmospheric boundary layer, through the vadose zone and into the deep groundwater.

With training in mechanical engineering and hydrogeology, he has extensive experience in the fate and transport of high- and low-level commercial and defense-related radioactive waste in the subsurface, in both fractured rock and soils. His early work in radionuclide transport ranged from pore-scale analysis of water and solute transport in soils to reconstruction of modern and paleo-groundwater recharge through the thick unsaturated zones at the Nevada Test Site, related to radionuclide migration from nuclear weapons testing and from low-level waste disposal. He has also studied deep groundwater circulation beneath saline lakes, pore scale modeling of root/soil interactions, evaporation, and transpiration in hyper-arid regions of the world, and processes of convection in groundwater systems. His recent work focuses on the measurement of the dynamics and thermal evolution of Antarctic ice shelves and the ocean waters below. As part of the NSF-supported International Thwaites Glacier Collaboration project, he has designed and developed fiber-optic moorings on the Thwaites Glacier to monitor temperature in both the floating ice shelf and the underlying ocean that has been operating at Thwaites since 2020.

Tyler has published approximately 130 peer-reviewed journal articles and book chapters in the fields of hydrology and hydrogeology. He is a Fellow of the American Geophysical Union, the Geological Society of America, and the Soil Science Society of America. He holds degrees in mechanical engineering from the University of Connecticut and hydrogeology from the New Mexico Institute of Mining and Technology and the University of Nevada, Reno. He is a member of the University of Connecticut's Academy of Distinguished Engineers and has served as chair of the Hydrogeology Division of the Geological Society of America and president of the Hydrology Section of the American Geophysical Union.

[o] Dr. Scott W. Tyler served on the Board until July 2025.

BRIAN WOODS, PH.D.[p]

Dr. Brian Woods was appointed to the U.S. Nuclear Waste Technical Review Board by President Joseph Biden on October 25, 2022.

Dr. Brian Woods is the school head of and professor in the School of Nuclear Science and Engineering at Oregon State University. He holds the Henry W. and Janice J. Schuette Chair in Nuclear Engineering and Radiation Health Physics at Oregon State.

Dr. Woods has worked at the U.S. Department of Energy as an engineer within the Office of Environmental Restoration and Waste Management as well as serving for four years in the U.S. Navy as a diver. Prior to coming to Oregon State, he worked as a Nuclear Safety Analyst at Dominion Energy's Innsbrook Technical Center outside of Richmond, Virginia. Dr. Woods has been at Oregon State University since 2003 teaching undergraduate and graduate courses on applied thermal hydraulics, nuclear reactor safety, fluid dynamics, nuclear rules and regulations, and the societal aspects of nuclear technology.

His areas of research interest include experimental and computational fluid dynamics and heat transfer, advanced reactor design, and nuclear reactor and fuel safety. Dr. Woods is the founder of the Advanced Nuclear Systems Engineering Laboratory at Oregon State and has been actively involved in thermal hydraulic and reactor safety research projects sponsored by the U.S. Nuclear Regulatory Commission, the U.S. Department of Energy, the Idaho National Laboratory, the International Atomic Energy Agency, Westinghouse, NuScale, Kairos Power, TerraPower, and General Atomics. He has authored over 140 technical publications. He is a past chair of the American Nuclear Society's Thermal Hydraulics Division, past president of the Alpha Nu Sigma nuclear engineering honor society, and a founding member of the American Society of Mechanical Engineers' VVUQ 30 Subcommittee on Verification, Validation, and Uncertainty Quantification in Computational Nuclear System Thermal Fluids Behavior.

Dr. Woods received a B.S. in mechanical engineering from the University of Virginia in 1988, and an M.S. and a Ph.D. in 1999 and 2001, respectively, in nuclear engineering from the University of Maryland.

Dr. Woods resides in Salem, Oregon.

[p] Dr. Brian Woods served on the Board until July 2025.

Appendix B. Board Strategic Plan 2022–2026

U.S. Nuclear Waste Technical Review Board

Strategic Plan
Fiscal Years 2022 to 2026

March 2022

U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD

MESSAGE FROM THE CHAIR

March 2022

It is my pleasure to present the U.S. Nuclear Waste Technical Review Board's *Strategic Plan for Fiscal Years 2022-2026*. This plan supersedes the Board's *Strategic Plan for Fiscal Years 2018-2022*, which was published in 2018. This updated plan describes the Board's mission and the vision and values that guide the Board's work and the development of the Board's Strategic Objectives.

As an independent Federal agency in the Executive Branch, the Board is committed to effectively carrying out its statutory mandate to evaluate the technical and scientific validity of the Department of Energy's activities related to managing and disposing of spent nuclear fuel and high-level radioactive waste. The Board's *Strategic Plan for Fiscal Years 2022-2026* provides a roadmap to guide us in achieving our Strategic Objectives and a benchmark against which to evaluate the Board's performance in meeting those objectives in the years ahead.

Jean M. Bahr
Chair

U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD
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OVERVIEW

The U.S. Nuclear Waste Technical Review Board was established as an independent federal agency in the 1987 amendments to the Nuclear Waste Policy Act (NWPA) to "...evaluate the technical and scientific validity of activities [related to managing and disposing of spent nuclear fuel and high-level radioactive waste] undertaken by the Secretary [of Energy], including:

1) site characterization activities; and

2) activities relating to the packaging or transportation of high-level radioactive waste or spent nuclear fuel."

As recorded in the legislative history of the Nuclear Waste Policy Amendments Act (NWPAA), the purpose of the Board is to provide independent expert advice to the Department of Energy (DOE) and Congress on technical issues and to review the technical and scientific validity of activities undertaken by the DOE to implement the NWPA. In accordance with this mandate, the Board conducts objective, ongoing, and integrated technical and scientific peer review of DOE activities related to the disposition of commercial and DOE-managed spent nuclear fuel (SNF) and high-level radioactive waste (HLW). According to the legislative history, the Board is expected to "review the activities [of the Secretary] as they are occurring, not after the fact." The Board reports its findings and recommendations to Congress and the Secretary of Energy.

MISSION STATEMENT

By performing ongoing and independent peer review of the highest quality, the Board will make a unique and essential contribution to increasing confidence in the technical and scientific validity of DOE activities related to managing and disposing of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) and to informing, from a technical and scientific perspective, policy discussions undertaken by decision-makers on managing and disposing of SNF and HLW. The Board will provide objective and relevant technical and scientific information to Congress, the Administration, DOE, and the public on a wide range of technical and scientific issues related to the management and disposition of such waste.

VALUES

The Board's technical and scientific peer review reflects its commitment to the following values:

- **Objectivity**. Board members have no real or perceived conflicts of interest related to the Board's mission. Board findings and recommendations are based on impartial evaluations of the technical and scientific validity of the Secretary's activities.

- **Openness**. Board deliberations are transparent and are conducted in such a way that the Board's integrity and objectivity are above reproach.

- **Technical and Scientific Competence.** Board findings, conclusions, and recommendations are technically and scientifically sound and are based on expert judgment and the best available technical and scientific information and analyses.

- **Timeliness**. Board findings, conclusions, and recommendations are communicated clearly and in time for them to be useful to Congress, the Secretary, and the public.

MEMBERS

The Board is composed of eleven members who are appointed by the President from a list of nominees submitted by the National Academy of Sciences (NAS). Nominees to the Board must be eminent in a field of science or engineering and are selected solely on the basis of established records of distinguished service. The Board is nonpartisan and apolitical.

POWERS

The NWPAA grants significant investigatory powers to the Board: "The Board may hold such hearings, sit and act at such times and places, take such testimony, and receive such evidence as it considers appropriate." At the request of the Board, and subject to existing law, DOE is required to provide all records, files, papers, data, and information necessary for the Board to conduct its technical and scientific review, including drafts of work products and documentation of work-in-progress. According to the legislative history of the NWPAA, Congress indicated this was necessary because the Board's "…effectiveness is dependent upon its ability to affect actions of the Secretary while they are happening, and not just after the fact."

HISTORY AND CONTINUING ROLE

For more than 20 years, DOE focused on developing a permanent geologic repository for disposal of SNF and HLW at Yucca Mountain in Nevada. During that time, the Board performed continuous peer review of DOE's activities and conveyed its findings and recommendations to Congress and the Secretary of Energy in reports, testimony, and activities and correspondence. As the Administration and Congress decide on a path forward for the disposition of nuclear waste, DOE continues to have responsibility under the NWPA for managing and disposing of SNF and HLW, and the Board's statutory responsibility for evaluating DOE's implementation of those activities remains unchanged.

By performing unbiased and ongoing technical and scientific peer review of DOE's nuclear waste management activities, the Board makes an essential contribution to increasing confidence in the scientific process and to informing, from a technical and scientific perspective, decisions on nuclear waste management. The Board provides objective information to Congress, the Administration, DOE, government and non-government organizations, and the public on a wide-range of issues related to SNF and HLW management and disposition.

All Board reports, factsheets, correspondence, testimony, and meeting materials are available on the Board's website at www.nwtrb.gov.

STRATEGIC OBJECTIVES

The Board has established three Strategic Objectives for fiscal years (FY) 2022-2026. The Strategic Objectives reflect the Board's continuing commitment to its mission established in the NWPAA, which includes (1) conducting an ongoing, independent technical and scientific evaluation of DOE activities related to the NWPA and (2) advising Congress and the Secretary. During FYs 2022-2026:

- The Board will continue its evaluation of DOE activities related to implementation of the NWPA and relevant amendments to that Act. Based on its evaluation, the Board will report its findings, conclusions, and recommendations to Congress and the Secretary.

- The Board will develop objective technical and scientific information that will be useful to policy makers in Congress and the Administration on issues related to SNF and HLW management and disposal. The Board will communicate such information to Congress and the Secretary in letters, reports, and testimony.

- The Board will compile information and report to Congress and the Secretary on its findings, conclusions, and recommendations from experience gained during thirty-five years of reviewing the U.S. nuclear waste management and disposal program and from observing waste management efforts in other countries.

ACHIEVING THE STRATEGIC OBJECTIVES

LEADERSHIP ENGAGEMENT – On an annual basis, in accordance with the Government Performance and Results Act, as amended, the Board's leadership identifies Performance Goals that will lead to the accomplishment of the Strategic Objectives. The Performance Goals are included in the Board's Performance Plan.

ONGOING EVALUATION OF PERFORMANCE – The Board includes in its annual Congressional Budget Justification an evaluation of the Board's performance in achieving its Performance Goals for the preceding fiscal year.

EVIDENCE BASED EVALUATION OF BOARD PERFORMANCE – The Board's Performance Plan for a given year includes its *Strategic Objectives*, its *Performance Goals*, its *Management Goals*, and a description of Board activities and practices supporting the achievement of the Goals. The Board's Performance Plan is updated annually. In updating and implementing the plan, the Board's leadership is committed to using a learning agenda approach by consistently building and using evidence to:

1) proactively evaluate the agency's performance to determine what works well and where performance can be improved;

2) focus on where the needs are greatest to effectively, efficiently, and accountably fulfill the agency's mission; and

3) ascertain how the agency can achieve better results.

Adopting a learning agenda approach ensures that the Board's Performance Goals and Strategic Objectives are prioritized to meet the agency's mission.

The Board uses annual evaluations of its performance as input in developing its Performance Goals for the following fiscal year. The Performance Goals reflect the objectives of the agency leadership and are outcome-oriented. The annual evaluations of the Board's performance are also used as input in developing the Board's budget allocations for the subsequent year. The evaluation of the Board's performance in achieving its Performance Goals is evidence-based, and the referenced documents and meeting records may be accessed on the Board's website at www.nwtrb.gov.

STAKEHOLDER AND PUBLIC ENGAGEMENT

As part of its peer review and information gathering activities, the Board organizes public meetings at which technical information is presented by representatives of DOE, its contractors, and other organizations involved in nuclear waste management and disposal. At these meetings, Board members and Board staff question the presenters, and time is provided for input and comments from interested members of the public. The Board usually holds two or three public meetings per year, either "in-person" or virtually. Meetings are announced in the *Federal Register,* typically four to six weeks before being held, and details of how to access the webcast of an in-person meeting or attend a public meeting are posted to the Board's website in advance of the meeting. Recordings of Board meetings are archived and are available on the Board's website.

TRANSPARENCY, PARTICIPATION, AND COLLABORATION

The Board is committed to the principles of open government, specifically the principles of transparency, participation, and collaboration.

TRANSPARENCY – As discussed in the previous section, the Board holds public meetings, at which it discusses DOE's activities with DOE staff and staff from the National Laboratories, DOE contractors, and other experts. In addition, the Board reports the results of its review of DOE activities to Congress and the Secretary of Energy on an ongoing basis. All Board reports, correspondence, fact sheets, written meeting materials, and meeting webcast videos are posted on the Board's website. When developing or updating its Strategic Plan, the Board seeks comments from the Office of Management and Budget and Congress and posts a copy of the plan on the Board's website.

PARTICIPATION – Opportunities for public comment are provided at all Board public meetings. In addition to public meetings held by the full Board, Board panels or other small groups of Board members and staff may hold other meetings, as needed, to investigate specific technical and scientific topics.

COLLABORATION – The Board members and senior professional staff enhance their scientific and technical expertise through knowledge-sharing and peer engagement. Board members and staff participate in technical symposia and conferences related to SNF and HLW management and disposal. On occasion, Board members and/or staff travel to other countries to meet with organizations involved in the management and disposal of SNF and HLW, to observe their technical programs and best practices, perform benchmarking, assess potential analogs, and for other purposes. The information gathered from these visits is used to enhance the Board's evaluation of DOE activities and to advise Congress and the Secretary of Energy.

CROSSCUTTING FUNCTIONS

Many organizations and entities are involved in some aspect of managing and disposing of SNF and HLW. Within the Federal government, these include Congress, the Government Accountability Office, DOE, the Nuclear Regulatory Commission, the Environmental Protection Agency, the Department of Transportation, and the NAS. Outside of the Federal government, interested organizations include the State of Nevada and other state governments, Tribal Nations, affected local governments, the National Association of Regulatory Utility Commissioners, the National Governors Association and regional groups, the National Conference of State Legislatures, the Nuclear Energy Institute, the Electric Power Research Institute, environmental justice organizations, and other environmental organizations, such as the Natural Resources Defense Council.

The Board's technical and scientific evaluation is at once different from and complementary to the activities of most of these entities. The Board is (1) unconstrained by any stake in the outcome of the activities it reviews, beyond technical and scientific validity; (2) charged with advising both Congress and the Secretary of Energy on technical issues related to nuclear waste management and disposal; (3) limited to reviewing the technical and scientific validity of DOE activities (not the policy implications or regulatory compliance); and (4) a permanent independent federal agency whose members are appointed by the President.

MANAGEMENT CHALLENGES

Factors that are outside the Board's control could affect the Board's ability to achieve its Strategic Objectives or Performance Goals. The Board will continue to evaluate the status of the challenges discussed below, identify any new factors, and, if necessary, update its Strategic Objectives and Performance Goals, as appropriate.

- *The Board has no statutory authority to implement, or to require DOE to implement, its recommendations.* The Board is a technical and scientific peer-review body that makes findings, conclusions, and recommendations. The Board's enabling statute does not obligate DOE to comply with Board recommendations. However, according to the legislative history of the NWPAA, in creating the Board, Congress expected that DOE would accept Board recommendations or "…clearly state its reasons for disagreeing". If DOE does not accept a Board recommendation, the Board can reiterate its recommendation, advise Congress, or both.

- *Operational constraints may impede the Board's ability to fully meet its performance goals on the timetable planned*. Operational constraints can affect the Board's ability to complete its review of DOE activities and to provide its technical and scientific findings, conclusions, and recommendations to Congress and the Secretary of Energy in accordance with its annual Performance Goals. Funding levels and allocation decisions may affect the nature and extent of DOE activities that are subject to the Board's review.

- *Administrative, judicial, or legislative actions may alter nuclear waste policy.* Changes to the program or the law made by any of the external entities may also affect the nature or extent of the Board's technical and scientific review. Since passage of the NWPAA in 1987, several administrative or judicial actions have affected the direction of DOE's nuclear waste management program, and these actions have on occasion affected the Board's work.

Effective Use of Resources

Technical and scientific analyses of DOE waste management and disposal activities are performed by Board members, all of whom are eminent scientists and experts in their fields. The Board members serve part-time and are supported by a small, full-time professional staff whose members are highly credentialed in relevant scientific and technical disciplines. When necessary, the Board is authorized to hire expert consultants to support its in-depth reviews of specific technical topics. Board members and members of the Board's senior professional staff are assigned by the Chair to lead or support Board activities, as appropriate. The Board maintains the option of organizing panels or working groups to help facilitate, integrate, and focus its technical and scientific review, and for other purposes.

Culture of Accountability

The Board considers its independence and objectivity to be among its most important assets. To avoid any real or perceived conflict, the NWPAA stipulates that individuals nominated to serve on the Board may not be an employee of DOE, a laboratory under contract with the DOE, or an entity performing HLW or SNF activities under contract with DOE.

The Board reports its findings, conclusions, and recommendations to Congress and the Secretary of Energy, and the Chair and other members of the Board and Board staff testify before Congress, as requested. Board reports, testimony, correspondence, and other documents related to its activities, along with meeting agendas, transcripts, presentations, webcasts, and public comments, are posted on the Board's website at www.nwtrb.gov.

Appendix C. Board Publications

Board Publications

Proceedings of the Board's 2023 International Workshop on Siting of Radioactive Waste Facilities
September 2024.

> The Board conducted an international workshop that focused on the processes for developing consent during the siting of radioactive waste facilities (consent-based siting). The workshop was held on August 29, 2023, in Idaho Falls, Idaho and virtually. The workshop consisted of a panel of Board members, internationally recognized experts, three of whom were from outside of the United States, and the U.S. Department of Energy. These proceedings summarize the workshop presentations, discussion, key themes, and takeaways.

Evaluation of the U.S. Department of Energy Research and Development Activities on the Disposition of Commercial Spent Nuclear Fuel in Dual-Purpose Canisters
February 2024.

> The report is a product of the Board's multi-year review of the U.S. Department of Energy's research and development activities related to the disposition of commercial spent nuclear fuel stored inside U.S. Nuclear Regulatory Commission approved dry-storage casks at independent spent fuel storage installations. The Board's observations, findings, and recommendations are presented in the report to Congress and the Secretary of Energy.

Report to the U.S. Congress and Secretary of Energy—Board Activities for the Period January 1, 2019–December 31, 2021
November 2022.

> The report summarizes Board activities, findings, conclusions, and recommendations from January 1, 2019, through December 31, 2021. During the period, the Board focused on research and development activities undertaken by the U.S. Department of Energy related to the packaging, storage, transportation, and disposal of spent nuclear fuel and high-level radioactive waste and integrated waste management system activities for those wastes.

Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: 2022 Update
July 2022.

> The report is an update of a survey report first issued by the Board in 2009 that was updated in 2016. The report describes 30 technical and institutional attributes of nuclear waste programs in 13 countries.

Report to the U.S. Congress and the Secretary of Energy—Board Activities for the Period January 1, 2016–December 31, 2018
August 2021.

The report summarizes Board activities, conclusions, and recommendations from January 1, 2016, through December 31, 2018. During the period, the Board focused on activities undertaken by the U.S. Department of Energy related to the packaging, storage, transportation, and disposal of spent nuclear fuel and high-level radioactive waste.

Evaluation of the Department of Energy's Research Program to Examine the Performance of Commercial High Burnup Spent Nuclear Fuel During Extended Storage and Transportation
July 2021.

The report is a product of a multi-year effort, during which the Board reviewed the U.S. Department of Energy's research activities, which have the aim of obtaining data that can enhance the understanding of the performance of high burnup spent nuclear fuel in extended storage and transportation conditions.

Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward
April 2021.

The report is the current Board members' synthesis of their nearly decade-long experience reviewing the U.S. Department of Energy's activities related to the management and disposal of spent nuclear fuel and high-level radioactive waste. The report provides the Board members' six overarching recommendations and associated action items in areas related to (i) ensuring an integrated organizational approach, (ii) anticipating required infrastructure and personnel needs, (iii) expanding the research paradigm to embrace hypothesis testing, (iv) applying an interactive, adaptive waste management program approach, (v) expanding engagement with the international community, and (vi) embracing openness, transparency, and engagement to build public trust.

Filling the Gaps: The Critical Role of Underground Research Laboratories in the U.S. Department of Energy Geological Disposal Research and Development Program
January 2020.

The report is a product of the Board's review of the U.S. Department of Energy's (DOE) underground research laboratory (URL)-related research and development activities and their relationship to the spent nuclear fuel and high-level radioactive waste disposal program. The Board's report presents and evaluates the DOE's research on complex coupled processes and addresses the use of URL R&D results for developing safety cases and knowledge gap analyses. The report describes the critical role of URLs in technology development and demonstration, training, and public confidence building.

Preparing for Nuclear Waste Transportation
September 2019.

The report is based on the Board's review of the U.S. Department of Energy's (DOE) research and analysis to support transporting spent nuclear fuel (SNF) and high-level

radioactive waste (HLW). The report compiles and discusses the technical and integration issues that DOE will need to address to ensure that SNF and HLW are ready for a nationwide transportation effort to a nuclear waste repository or an interim storage site.

Geologic Repositories: Performance Monitoring and Retrievability of Emplaced High-Level Radioactive Waste and Spent Nuclear Fuel
May 2018.

In this letter report, the Board presents its observations from a meeting on March 27, 2018. At the meeting, the Board heard from experts from several international repository programs on (i) operational and performance confirmation monitoring of a geologic repository for high-level radioactive waste (HLW) and spent nuclear fuel (SNF) and (ii) retrievability of emplaced HLW and SNF.

Management and Disposal of U.S. Department of Energy Spent Nuclear Fuel
December 2017.

The report is based on the Board's review of the U.S. Department of Energy's (DOE) efforts to manage the spent nuclear fuel (SNF) under its control at four federal facilities. The report records the quantities and characteristics of DOE SNF at each of the four storage sites and examines the technical issues related to DOE SNF packaging and storage that might affect continued storage, transport, and final disposal of SNF.

Report to the U.S. Congress and the Secretary of Energy—Board Activities, January 1, 2013–December 31, 2015
October 2016.

The report is one in a series of "summary" reports issued periodically since the beginning of Board operations in 1989 that chronicle Board activities over a defined period. The report is archival in nature and does not break new ground. Rather, it documents Board activities, findings, and recommendations for the reporting period. During the period, the Board focused on activities undertaken by the U.S. Department of Energy (DOE) related to the packaging, transportation, and disposal of spent nuclear fuel and high-level radioactive waste.

Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: An Update
February 2016.

This revision of a 2009 report describes 30 technical and institutional attributes of nuclear waste programs in 13 countries. It does not make judgments; rather, the report provides factual information for Congress and the Secretary of Energy that can be used for evaluating waste management options.

Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program
January 2016.

The report is based on the Board's evaluation of information presented by the U.S. Department of Energy (DOE) and subject-matter experts from the United States and other countries at a Board workshop on deep borehole disposal held in Washington, D.C., on October 20–21, 2015. In the report, the Board makes technical and scientific findings, conclusions, and recommendations on two topics: (1) technical and scientific issues that may affect the feasibility of the deep borehole disposal option for select radioactive waste forms, and (2) whether results that will be obtained from the DOE Deep Borehole Field Test will provide the necessary technical data and scientific understanding for determining the feasibility of disposing of some radioactive waste forms in deep boreholes.

Designing a Process for Selecting a Site for a Deep-Mined Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel—Overview and Summary
November 2015.

To provide information about efforts in the United States and other countries to site a deep-mined, geologic repository for high-level radioactive waste and spent nuclear fuel, the Board prepared two reports that rely on a comparative historical inquiry into two dozen siting efforts that have taken place over the past half century in ten different countries. The *Overview and Summary* provides a short synopsis of the major insights that derive from that study. The *Detailed Analysis*, referred to below, is an in-depth account that provides the empirical foundations for those insights. The reports contain four recommendations that policymakers might consider if they choose to begin a new siting effort for a first or second repository.

Designing a Process for Selecting a Site for a Deep-Mined Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel—Detailed Analysis
November 2015

To provide information about efforts in the United States and other countries to site a deep-mined, geologic repository for high-level radioactive waste and spent nuclear fuel, the Board prepared two reports that rely on a comparative historical inquiry into two dozen siting efforts that have taken place over the past half century in ten different countries. The *Overview and Summary*, referred to above, provides a short synopsis of the major insights that derive from that study. The *Detailed Analysis* is an in-depth account that provides the empirical foundations for those insights. The reports contain four recommendations that policymakers might consider if they choose to begin a new siting effort for a first or second repository.

Evaluation of Technical Issues Associated with the Development of a Separate Repository for U.S. Department of Energy-Managed High-Level Radioactive Waste and Spent Nuclear Fuel
June 2015.

The report is based on the Board's review of U.S. Department of Energy (DOE) reports and studies supporting a new DOE initiative involving the development of two mined geologic repositories: one to dispose of defense high-level radioactive waste (HLW) and possibly some DOE-managed spent nuclear fuel (SNF), and another to dispose of commercially generated HLW and SNF, together with other DOE-managed HLW and SNF. The new initiative also includes consideration of options for disposal of smaller DOE-managed waste forms in deep boreholes. In the report, the Board makes technical and scientific findings, conclusions, and recommendations related to the implementation of DOE's new initiative.

A Report to the U.S. Congress and the Secretary of Energy—Board Activities, January 1, 2008—December 31, 2012
December 2014.

The report is one in a series of "summary" reports issued periodically since the beginning of Board operations in 1989 that chronicle Board activities over a defined period. The report is archival in nature and does not break new ground. Rather, it documents Board activities, findings, and recommendations for the reporting period. The five years covered by the report were consequential for the Board and for the U.S. program to manage and dispose of spent nuclear fuel and high-level radioactive waste.

Review of U.S. Department of Energy Activities to Preserve Records Created by the Yucca Mountain Repository Project
August 2013.

The report chronicles the Board's review of U.S. Department of Energy (DOE) efforts to preserve records developed over almost 30 years by the Yucca Mountain Repository Project. In 2010, funding for the repository program was eliminated, and DOE notified the U.S. Nuclear Regulatory Commission of the Department's intention to withdraw the Yucca Mountain license application. At that point, responsibility for archiving and preserving Yucca Mountain scientific and engineering information was transferred to DOE's Office of Legacy Management. The Board began evaluating DOE activities related to archiving and preserving Yucca Mountain data and information in 2010 as part of its ongoing technical and scientific review and in response to direction from the House Committee on Appropriations.

Nuclear Waste Assessment System for Technical Evaluation (NUWASTE): Status and Initial Results
June 2011.

The report describes work performed by the Board to evaluate the effects of spent nuclear fuel and high-level radioactive waste management on various fuel-cycle

options being considered at that time by the U.S. Department of Energy (DOE). Of particular interest to the Board were the types and quantities of radioactive waste streams that would be generated. The Board developed a computer-based systems analysis tool, the Nuclear Waste Assessment System for Technical Evaluation, or NUWASTE, to support its technical evaluation of DOE activities in this area. Included in the report are initial findings from NUWASTE analyses.

Technical Advancements and Issues Associated with the Permanent Disposal of High-Activity Wastes: Lessons Learned from Yucca Mountain and Other Programs
June 2011.

The purpose of the report was to extract and record technical and scientific knowledge, while still available, from the Yucca Mountain deep geologic repository program and programs in other countries for managing spent nuclear fuel (SNF) and high-level radioactive waste (HLW). In the report, the Board examined the history of the Yucca Mountain program and several other nuclear waste programs from a technical perspective and discussed technical information and insights that may be useful for future U.S. efforts to manage and dispose of SNF and HLW.

Experience Gained from Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries
April 2011.

The report explores the efforts of 13 nations to find a permanent solution for isolating high-level radioactive waste and spent nuclear fuel generated within their borders. It builds on information in the Board's 2009 *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel*. Unlike the earlier document, however, the report describes the programs and their histories and discusses inferences that can be drawn from their experiences.

Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel—Executive Summary
December 2010.

The report was prepared to inform the U.S. Department of Energy and Congress about the current state of the technical basis for extended dry storage of spent nuclear fuel (SNF) and for subsequent SNF transportation.

Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel
December 2010.

The report presents an overview of available public literature on spent nuclear fuel (SNF) storage and handling, and the safety of extended SNF dry storage and subsequent transportation.

Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel
October 2009.

The report describes 30 technical and institutional attributes of nuclear waste programs in
13 countries. It does not make judgments; rather the report provides factual information for Congress and the Secretary of Energy that can be used for evaluating waste management options.

Letter Report to Congress and the Secretary of Energy
October 27, 2009.

The report in letter form updates Congress and the Secretary of Energy on the mission, continuing role, and refocused goals of the U.S. Nuclear Waste Technical Review Board as the U.S. approach to managing spent nuclear fuel and high-level radioactive waste undergoes an evolution.

Report to Congress and the Secretary of Energy
September 2008.

The report is one in a series of "summary" reports issued periodically since the beginning of Board operations in 1989 that chronicle the Board's activities over a defined period of time. The report focused on Board activities from March 1, 2006, to December 31, 2007. During that time, the Board evaluated critical technical issues dealing with the waste management system, including pre-closure operations and post-closure performance of the proposed Yucca Mountain repository, and the crosscutting issue of thermal management.

Technical Evaluation of U.S. Department of Energy Yucca Mountain Infiltration Estimates: A Report to Congress and the Secretary of Energy
December 2007.

In the report, the Board presents its evaluation of revised U.S. Department of Energy estimates of water infiltration at Yucca Mountain. The infiltration estimates were revised because violations of quality assurance procedures were alleged to have been committed by U.S. Geological Survey employees involved in gathering and analyzing infiltration data at Yucca Mountain in the 1990s.

Report to Congress and the Secretary of Energy
January 2007.

The report contains summaries of Board findings and recommendations contained in the following: letters to the Director of the Office of Civilian Radioactive Waste Management (OCRWM) following Board meetings held in February, May, and September 2006; a letter and enclosures sent to OCRWM following a Board workshop on deliquescence-induced localized corrosion in September 2006; and

testimony that the Board's Chairman presented in May 2006 before the Senate Energy and Natural Resources Committee.

Report to Congress and the Secretary of Energy
June 2006.

In the report, the Board summarizes its major activities from January 1, 2005, through February 28, 2006. During that period, the Board focused its attention on the U.S. Department of Energy's efforts to develop post-closure performance estimates for the proposed repository at Yucca Mountain in Nevada. Correspondence and related materials are included in the appendices to the report, along with the Board's strategic plan for fiscal years 2004–2009, its performance plans for fiscal years 2005–2006, and its performance evaluation for 2005.

Letter Report to Congress and the Secretary of Energy
December 2005.

In this letter report to Congress and the Secretary of Energy, the Board presents its views on the status of some important issues related to the technical basis for U.S. Department of Energy activities for designing the nuclear waste management system, including the engineered system, the natural system, the repository system, and the assessment of the performance of the systems. The Board also outlines issues that it expects may continue to be of interest in the future.

Report to Congress and the Secretary of Energy
May 2005.

In the report, the Board summarizes its major activities from January 1, 2004, through December 31, 2004. During that period, the Board focused on the Department of Energy's efforts to develop a system for accepting, transporting, and handling high-level radioactive waste and spent nuclear fuel before disposal in the repository proposed for Yucca Mountain. Correspondence and related materials are included in the appendices to the report, along with the Board's strategic plan for fiscal years 2004–2009, its performance plans for 2005, and its performance evaluation for 2004.

Letter Report to Congress and the Secretary of Energy
December 2004.

This letter and enclosure constitute the Board's second report to Congress and the Secretary of Energy for calendar year 2004. The letter briefly summarizes areas where the Board believes the U.S. Department of Energy made progress, areas requiring attention, and the Board's priorities for the coming year. The enclosure contains a more detailed discussion of those topics.

Report to Congress and the Secretary of Energy
May 2004.

In the report, the Board summarizes its major activities from January 1, 2003, through December 31, 2003. During that period, the Board continued its evaluation of U.S. Department of Energy (DOE) activities and held meetings on a range of technical and scientific issues, including seismicity, DOE plans for transporting spent nuclear fuel and high-level radioactive waste, the design and operation of facilities at the Yucca Mountain proposed repository site, performance confirmation activities, and the potential for localized corrosion. Correspondence and related materials are included in the appendices to the report, along with the Board's strategic plan for fiscal years 2004–2009, its performance plans for 2004 and 2005, and its performance evaluation for 2003.

Report to Congress and the Secretary of Energy
December 19, 2003.

The report and attachments constitute the Board's second report to Congress and the Secretary of Energy for calendar year 2003. It is composed of letters on localized corrosion sent to the Director of the Office of Civilian Radioactive Waste Management on October 21, 2003, and November 25, 2003.

Board Technical Report on Localized Corrosion
November 25, 2003.

This technical document supports the Board conclusions in its October 21, 2003, letter to the U.S. Department of Energy on the potential for localized waste package corrosion during the thermal pulse.

Report to the Secretary of Energy and the Congress
April 2003.

The report summarizes the Board's major activities between January 1, 2002, and December 31, 2002. During this period, the Board focused on evaluating the technical basis of the U.S. Department of Energy's (DOE) work on analyzing a planned repository site at Yucca Mountain in Nevada. Included in an appendix to the report are letters to DOE on technical issues the Board identified as part of its ongoing review in 2002. Also included in the appendices are the Board's strategic plan for fiscal years 2003–2008, its performance plans for 2003 and 2004, and its performance evaluation for 2002.

Report to the Secretary of Energy and the Congress
April 2002.

The report summarizes the Board's major activities between February 1, 2001, and January 31, 2002. During this period, the Board focused on evaluating the technical basis of the U.S. Department of Energy's (DOE) work on a Yucca Mountain site recommendation, including DOE's characterization of the Yucca Mountain site,

DOE's design of the repository and waste packages, and the estimates of how a repository system developed at the site might perform. The report includes a description of activities the Board undertook to develop its assessment of the technical basis for the DOE's repository performance estimates.

Letter Report to Congress and the Secretary of Energy
January 24, 2002.

This letter report summarizes the Board's technical and scientific evaluation of the U.S. Department of Energy's investigations and assessments supporting its recommendation of the Yucca Mountain site as a potential location for a deep geologic repository for spent nuclear fuel and high-level radioactive waste.

Proceedings from an International Workshop on Long-Term Extrapolation of Passive Behavior, Arlington, Virginia, July 19–20, 2001
December 2001.

This is a compilation of submissions to a Board workshop on issues predicting corrosion behavior for periods of unprecedented duration. The workshop was held on July 19–20, 2001, in Arlington, Virginia. A panel of three Board members and 14 internationally recognized corrosion scientists, eight of whom were from outside the United States, participated in the workshop. Following the workshop, most panelists submitted papers with their views on issues on predicting very long-term corrosion.

Report to the Secretary of Energy and the Congress
April 2001.

In the report, the Board summarizes its views on four priority areas for evaluating the potential repository at Yucca Mountain:

Meaningful quantification of conservatisms and uncertainties in the U.S. Department of Energy's performance assessments.

Progress in understanding the underlying fundamental processes involved in predicting the rate of waste-package corrosion.

An evaluation and a comparison of the base-case repository design with a low-temperature design.

Development of multiple lines of evidence to support the safety case of the proposed repository, the lines of evidence being derived independently of performance assessment and thus not being subject to the limitations of performance assessment.

Letter Report to the Secretary of Energy and the Congress
December 2000.

This letter report presents a brief update of the Board's views on the status of the U.S. Department of Energy's repository development program.

Report to the U.S. Congress and the Secretary of Energy
April 2000.

In the report, the Board summarizes its major activities in calendar year 1999. Among the activities discussed in the report is the Board's 1999 review of the U.S. Department of Energy's (DOE) viability assessment (VA) of the Yucca Mountain site. The Board's evaluation of the DOE-VA concludes that Yucca Mountain continues to warrant study as the candidate site for a permanent geologic repository and that work should proceed to support a decision on whether to recommend the site for repository development. The Board suggests that the 2001 date for a decision is very ambitious and that focused study should continue on natural and engineered barriers. The Board states that a credible technical basis does not currently exist for the above-boiling repository design included in the VA. The Board recommends evaluation of alternative repository designs, including lower-temperature designs, as a potential way to help reduce the significance of uncertainties related to predictions of repository performance.

Report to the U.S. Congress and the Secretary of Energy
April 1999.

In the report, the Board summarizes its major activities during calendar year 1998. The report discusses the research needs identified in the U.S. Department of Energy's (DOE) recently issued Viability Assessment of the Yucca Mountain site, including plans to gather information on the amount of water that will eventually seep into repository drifts, whether formations under the repository will retard radionuclide migration, the flow-and-transport properties of the groundwater that lies approximately 200 meters beneath the repository horizon, and long-term corrosion rates of materials that may be used for the waste packages. The report describes other activities the Board undertook in 1998, including a review of the hypothesis that there were hydrothermal upwellings at Yucca Mountain, a workshop held to increase understanding of the range of expert opinion on waste package materials, and a review of the DOE's draft environmental impact statement for the Yucca Mountain site.

Report to the U.S. Congress and the Secretary of Energy: Moving Beyond the Viability Assessment
April 1999.

In the report, the Board presents its views on the U.S. Department of Energy's (DOE) December 1998 Viability Assessment of the Yucca Mountain site in Nevada. The Yucca Mountain site is being characterized to determine its suitability as the location of a permanent repository for disposing of spent nuclear fuel and high-level radioactive waste. The Board discusses the need to address key uncertainties that remain about the site, including the performance of the engineered and natural

barriers. The Board addresses DOE's plans for reducing those uncertainties and suggests that consideration be given to alternative repository designs, including ventilated low-temperature designs that have the potential to reduce uncertainties and simplify the analytical bases for determining site suitability and for licensing. The Board also comments on DOE's total system performance assessment, the analytical tool that pulls together information on the performance of the repository system.

Report to the U.S. Congress and the Secretary of Energy
November 1998.

In the report, the Board presents its views on the direction of future scientific and technical research, underway and planned by the U.S. Department of Energy as part of its program for characterizing a site at Yucca Mountain in Nevada as a potential repository for spent nuclear fuel and high-level radioactive waste. The Board discusses some of the remaining key scientific and technical uncertainties related to performance of a potential repository. The report addresses some of these uncertainties by examining information about the proposed repository system presented at Board meetings and other technical exchanges. The Board comments on some of the important connections between the site's natural properties and the current designs for the waste package and other engineered features of the repository.

Letter Report: Board Completes Review of Material on Hydrothermal Activity
July 24, 1998.

This letter and attachments present the Board's review of material related to Mr. Jerry Szymanski's hypothesis of ongoing, intermittent hydrothermal activity at Yucca Mountain and large earthquake-induced changes in the water table there. The report includes a cover letter, the Board's review, and the reports of the four consultants the Board contracted with to assist in the review.

1997 Findings and Recommendations
April 1998.

The report details the Board's technical and scientific evaluation in 1997 of U.S. Department of Energy (DOE) activities, including the development of DOE's viability assessment, due later this year; underground exploration of the candidate repository site at Yucca Mountain in Nevada; thermal testing underway at the site; what happens when radioactive waste reaches the water table beneath Yucca Mountain; spent nuclear fuel transportation; and using expert judgment. The Board makes four recommendations in the report concerning (1) the need for DOE to begin now to develop alternative design concepts for a repository, (2) the need for DOE to include estimates of the likely variation in doses for alternative candidate critical groups in its interim performance measure for Yucca Mountain, (3) the need for DOE to evaluate whether site-specific biosphere data are needed for a license application, and (4) the need for DOE to make full and effective use of formally elicited expert judgment.

Letter Report to the Secretary of Energy and the Congress
December 23, 1997.

The letter report addresses several key issues, including the U.S. Department of Energy's viability assessment of the Yucca Mountain site, design of the potential repository and waste package, the total system performance assessment, and the enhanced characterization of the repository block.

Report to the U.S. Congress and the Secretary of Energy: 1996 Findings and Recommendations
March 1997.

The report summarizes Board activities during calendar year 1996. Chapter 1 provides an overview of the U.S. Department of Energy's high-level radioactive waste management program from the Board's perspective, including the viability assessment, program status, and progress in exploration and testing. Chapter 2 examines three technical issues—hydrology, radionuclide transport, and performance assessment—and provides conclusions and recommendations. Chapter 3 deals with the repository system, including underground operations, thermal loading, and engineered barriers. Also discussed are the repository layout, design alternatives, and construction planning. Chapter 4 provides an overview of recent Board activities, including an international exchange of information on repository programs, the Board's visit to the River Mountains Tunnel, and a presentation to the U.S. Nuclear Regulatory Commission.

Nuclear Waste Management in the United States—The Board's Perspective
June 1996.

The document contains a talk by Board Chairman John Cantlon delivered at Topseal '96, an international conference on nuclear waste management and disposal. The conference was sponsored by the Swedish Nuclear Fuel and Waste Management Company (SKB) and the European Nuclear Society. The publication highlights Dr. Cantlon's views on the status of the U.S. repository program, including U.S. Department of Energy efforts to characterize the Yucca Mountain site and to develop a waste isolation strategy. The publication also describes legislative and regulatory changes under consideration at that time and the technical implications of those potential changes.

Report to the U.S. Congress and the Secretary of Energy: 1995 Findings and Recommendations
April 1996.

The report summarizes Board activities during calendar year 1995. Chapter 1 provides an overview of the U.S. Department of Energy's high-level radioactive waste management program, including highlights, current status, legislative issues, milestones, and Board recommendations. Chapter 2 reports on Board panel activities, and Chapter 3 provides information on new Board members, meetings attended,

interactions with Congress and congressional staff, Board presentations to other organizations, interactions with foreign programs, and a review of the Board's report on spent nuclear fuel interim storage.

Disposal and Storage of Spent Nuclear Fuel—Finding the Right Balance
March 1996.

This special report caps more than two years of study and analysis by the Board into the issues surrounding interim storage of commercial spent nuclear fuel and the timing of developing a federal centralized storage facility. The Board suggests in the report that the U.S. Department of Energy should remain focused on permanent geologic disposal and the site investigations at Yucca Mountain in Nevada. Planning for a federal centralized spent nuclear fuel storage facility and the required transportation infrastructure should begin early, but actual construction of a facility should be delayed until after a site-suitability decision is made on the Yucca Mountain site.

Letter Report to the Secretary of Energy and the Congress
December 13, 1995.

The letter report discusses the U.S. Department of Energy's (DOE) progress in exploring the underground at Yucca Mountain with a tunnel-boring machine, advances in developing a waste isolation strategy for the proposed repository, recent DOE work on engineered barrier design, and DOE activities related to repository performance assessment.

Report to the U.S. Congress and the Secretary of Energy: 1994 Findings and Recommendations
March 1995.

The report summarizes Board activities during calendar year 1994. It covers aspects of the U.S. Department of Energy's (DOE) Program Approach, the DOE's emerging waste isolation strategy, and the DOE's transportation program. It explores the Board's views on minimum exploratory requirements and thermal-loading issues for the repository. A chapter of the report focuses on the lessons learned on site assessment from high-level radioactive waste disposal projects around the world. Another chapter deals with volcanism and problem resolution. The Board also presents observations from its visit to Japan and the Japanese nuclear waste disposal program. Board findings and recommendations in the report center on structural geology and geoengineering, hydrogeology and geochemistry, the engineered barrier system, and risk and performance analysis.

Report to the U.S. Congress and the Secretary of Energy: January to December 1993
May 1994.

The report summarizes Board activities, primarily during 1993. In it, the Board reports on nuclear waste disposal programs in Belgium, France, and the United Kingdom; elaborates on the Board's understanding of the radiation protection

standards being reviewed by the National Academy of Sciences; and, using "future climates" as an example, examines the U.S. Department of Energy's (DOE) approach to "resolving difficult issues." Recommendations center on the need for a systems approach in implementing DOE Office of Radioactive Waste Management programs, setting priorities among site-suitability activities, appropriate use of total system performance assessment and expert judgment, and the dynamics of the Yucca Mountain ecosystem.

Letter Report to Congress and the Secretary of Energy
February 1994.

The letter report restates a recommendation made in the Board's 1993 *Special Report* that an independent review of the Office of Civilian Radioactive Waste Management's management and organizational structure be initiated as soon as possible. The letter report adds two recommendations: sufficient and reliable funding should be assured for site characterization and performance assessment, whether the program budget remains level or is increased, and the U.S. Department of Energy's decision-making process on siting a Yucca Mountain repository should consider the views of various stakeholders.

Underground Exploration and Testing at Yucca Mountain: A Report to Congress and the Secretary of Energy
October 1993.

The report focuses on the exploratory studies facility at Yucca Mountain in Nevada, including the conceptual design, planned exploration and testing, and excavation plans and schedules. In addition to a number of detailed recommendations, the Board makes three general recommendations. First, the Department of Energy (DOE) should develop a comprehensive strategy that integrates exploration and testing priorities with the design and excavation approach for the exploratory facility. Second, underground thermal testing should be resumed as soon as possible. Third, DOE should establish a geoengineering board with expertise in engineering, constructing, and managing large underground projects.

Special Report to Congress and the Secretary of Energy
March 1993.

The report discusses institutional and policy issues that potentially affect the technical and scientific credibility of the U.S. Department of Energy's (DOE) repository program. Three important issues are presented: first, the repository program is driven by unrealistic deadlines; second, the repository program lacks an integrated waste management plan; and third, program management needs to be improved. To address these issues, the Board makes the following recommendations: amend the current schedule to include realistic intermediate milestones; develop a comprehensive, well-integrated plan for overall management of all spent nuclear fuel and high-level defense waste from generation to disposal; and implement an independent evaluation of the organization and management of DOE's Office of

Civilian Radioactive Waste Management. The Board notes that the recommendations should be implemented without slowing the progress of site-characterization activities at Yucca Mountain.

Sixth Report to the U.S. Congress and the U.S. Secretary of Energy
December 1992.

The report summarizes recent Board activities, congressional testimony, changes in Board makeup, and the effects of the Little Skull Mountain earthquake. Chapter 2 details panel activities and offers seven technical recommendations on the dangers of a schedule-driven program, including the need for top-level systems studies; consideration of the impact of defense high-level radioactive waste; the use of high-capacity, self-shielded waste package designs; and the need for setting priorities among the numerous studies in the site-characterization plans. In Chapter 3, the Board offers candid insights into the high-level waste management program in five countries, specifically those issues that might be applicable to the U.S. program, including program size and cost, utility responsibilities, repository construction schedules, and alternative approaches to licensing. Appendix F provides background on the Finnish and Swiss programs.

Fifth Report to the U.S. Congress and the U.S. Secretary of Energy
June 1992.

The Board's fifth report focuses on thermal loading strategies in the United States and the importance and uncertainties of this crosscutting issue. The report discusses the Board's position on the technical implications of thermal loading for the U.S. spent nuclear fuel (SNF) and high-level radioactive waste (HLW) management system. The report also includes updates on Board and panel activities during the reporting period. The Board makes recommendations in the report to the U.S. Department of Energy (DOE) on the following subjects: the exploratory studies facility, repository design enhancements, repository sealing, seismic vulnerabilities (vibratory ground motion and fault displacement), DOE's approach to the engineered barrier system, and SNF and HLW transportation.

Fourth Report to the U.S. Congress and the U.S. Secretary of Energy
December 1991.

The report explores in depth, and makes recommendations on, the following technical areas: exploratory studies facility construction; testing priorities; rock mechanics; tectonic features and processes; volcanism; hydrogeology and geochemistry in the unsaturated zone; the engineered barrier system; regulations promulgated by the U.S. Environmental Protection Agency, the U.S. Nuclear Regulatory Commission, and the U.S. Department of Energy (DOE); DOE performance assessment program; and the quality assurance program for the Yucca Mountain project.

Third Report to the U.S. Congress and the U.S. Secretary of Energy
May 1991.

The report describes Board activities and congressional testimony. Other topics include exploratory shaft facility design alternatives; repository design; risk-benefit analysis; waste package plans and funding; spent nuclear fuel corrosion; transportation and waste management systems; environmental program concerns; U.S. Department of Energy (DOE) task force studies on risk and performance assessment; federal quality assurance requirements for the repository program; and measuring, modeling, and applying radionuclide sorption data. The Board makes 15 recommendations to DOE on these issues. Background information on the German and Swedish nuclear waste disposal programs is included in Appendix D of the report.

Second Report to the U.S. Congress and the U.S. Secretary of Energy
November 1990.

The Board's second report establishes a framework for discussing repository development and makes specific technical and scientific recommendations concerning tectonic features and processes, geoengineering considerations, the engineered barrier system, transportation and systems, environmental and public health issues, and risk and performance analysis. The report also offers concluding perspectives on progress made by the U.S. Department of Energy, the state of Nevada's role, the project's regulatory framework, the nuclear waste negotiator, other oversight agencies, and the Board's future plans.

First Report to the U.S. Congress and the U.S. Secretary of Energy
March 1990.

The first Board report sets the stage for the Board's evaluation of the U.S. Department of Energy's program to manage disposal of the nation's spent nuclear fuel (SNF) and high-level radioactive waste (HLW). The report briefly outlines the legislative history of the SNF and HLW management program, including its legal and regulatory requirements. The Board's evolution is described, along with its protocol, panel structure, and reporting requirements. The report identifies major technical and scientific issues the Board identified for further evaluation and highlights five cross-cutting issues.

Appendix D. Board Meetings: January 1, 2022–December 31, 2024

Board Meetings: January 1, 2022–December 31, 2024

March 1–2, 2022	**Winter 2022 Board Virtual Meeting** DOE R&D Related to Non-site-specific Disposal, DOE's Integrated Waste Management System, and Consent-Based Siting Process to Identify Federal Interim Storage Facilities
September 13–14, 2022	**Summer 2022 Board Meeting** Arlington, Virginia DOE R&D Related to Geologic Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste in Clay-Bearing Host Rocks and R&D on Clay-Based Engineered Barriers
March 28, 2023	**Spring 2023 Board Meeting** Orlando, Florida DOE Efforts Related to Removing Spent Nuclear Fuel from Commercial Nuclear Power Plant Sites
August 29, 2023	**Summer 2023 Board Workshop** Idaho Falls, Idaho International Workshop on Siting of Radioactive Waste Facilities
August 30, 2023	**Summer 2023 Board Meeting** Idaho Falls, Idaho DOE Consent-Based Siting Process Activities and Research and Development Activities Related to High Burnup Spent Nuclear Fuel and Advanced Reactor Waste Disposition
May 21–22, 2024	**Spring 2024 Board Meeting** Knoxville, Tennessee DOE Research and Development Activities Related to Non-Site-Specific Disposal of Radioactive Waste in Crystalline Host Rocks and Corrosion of Commercial Spent Nuclear Fuel After Disposal
August 29, 2024	**Summer 2024 Board Meeting** North Augusta, South Carolina DOE Management and Plans for Disposal of DOE Spent Nuclear Fuel and Program Updates from DOE's Office of Spent Fuel and High-Level Waste Disposition

Appendix E. Correspondence with the U.S. Department of Energy: January 1, 2022–December 31, 2024

Correspondence with the U.S. Department of Energy January 1, 2022–December 31, 2024

Letter from Chair Jean M. Bahr to Dr. Kathryn Huff, Principal Deputy Assistant Secretary for Nuclear Energy; January 7, 2022
Subject: Board comments on information presented at the November 2021 Board meeting.

Letter from Mr. Andrew Griffith, Acting Assistant Secretary for Nuclear Energy, to Chair Jean M. Bahr; April 7, 2022
Subject: DOE response to August 12, 2021, Board letter on the Board's Spring 2021 Meeting.

Letter from Chair Jean M. Bahr to Dr. Kathryn Huff, Assistant Secretary for Nuclear Energy; June 7, 2022
Subject: Board comments on information presented at the March 2022 Board meeting.

Letter from Dr. Kathryn Huff, Assistant Secretary for Nuclear Energy, to Chair Jean M. Bahr; June 8, 2022
Subject: DOE response to April 2021 Board report on Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward.

Letter from Chair Jean M. Bahr to Dr. Kathryn Huff, Assistant Secretary for Nuclear Energy; July 6, 2022
Subject: Board requested a follow-up meeting with DOE regarding the April 2021 Board report on Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward and DOE's response to the report.

Letter from Dr. Kathryn Huff, Assistant Secretary for Nuclear Energy, to Chair Jean M. Bahr; September 28, 2022
Subject: DOE response to January 7, 2022, Board letter on the Board's November 2021 Meeting.

Letter from Chair Jean M. Bahr to Dr. Kathryn Huff, Assistant Secretary for Nuclear Energy; December 14, 2022
Subject: Board comments on information presented at the September 2022 Board meeting.

Letter from Dr. Kathryn Huff, Assistant Secretary for Nuclear Energy, to Chair Nathan Siu; July 5, 2023
Subject: DOE response to June 7, 2022, Board letter on the Board's March 2022 Meeting.

Letter from Dr. Kathryn Huff, Assistant Secretary for Nuclear Energy, to Chair Nathan Siu; August 21, 2023
Subject: DOE response to December 14, 2022, Board letter on the Board's September 2022 Meeting.

Letter from Chair Nathan Siu to Dr. Kathryn Huff, Assistant Secretary for Nuclear Energy; August 24, 2023
Subject: Board comments on information presented at the March 2023 Board meeting.

Letter from Chair Nathan Siu to Dr. Kathryn Huff, Assistant Secretary for Nuclear Energy, with Forwarding Letters to Congress; April 24, 2024
Subject: Board comments on information presented at the August 2023 Board meeting.
Note: The Board letter to DOE was forwarded to four separate committees or subcommittees in Congress.

Letter from Chair Nathan Siu to Dr. Michael Goff, Acting Assistant Secretary for Nuclear Energy; May 28, 2024
Subject: Board comments on DOE research on high burnup spent nuclear fuel (SNF), as a follow-up to the Board's report on high burnup SNF (July 2021) and a staff-to-staff fact-finding meeting with DOE-NE staff, February 28, 2024.

Letter from Dr. Michael Goff, Acting Assistant Secretary for Nuclear Energy, to Chair Nathan Siu; September 9, 2024
Subject: DOE response to August 24, 2023, Board letter on the Board's March 2023 Meeting.

Letter from Dr. Michael Goff, Acting Assistant Secretary for Nuclear Energy, to Chair Nathan Siu; September 18, 2024
Subject: DOE response to April 24, 2024, Board letter on the Board's August 2023 Meeting.

Letter from Chair Peter Swift to Dr. Michael Goff, Acting Assistant Secretary for Nuclear Energy; May 22, 2025
Subject: Board comments on information presented at May 2024 Board meeting.

Letter from Chair Peter Swift to Dr. Michael Goff, Principal Deputy Assistant Secretary for Nuclear Energy; June 9, 2025
Subject: Board comments on information presented at August 2024 Board meeting.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

January 7, 2022

Dr. Kathryn Huff
Principal Deputy Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Dr. Huff:

On behalf of the U.S. Nuclear Waste Technical Review Board (Board), I want to thank you and your staff, as well as the staff from the national laboratories, for supporting the Board's 2021 Fall Meeting, which was held virtually on November 3–4, 2021. The purpose of the meeting was to review information on the U.S. Department of Energy, Office of Nuclear Energy (DOE-NE) research and development (R&D) activities related to the Geologic Disposal Safety Assessment (GDSA) Framework. This letter presents the Board's observations, findings, and recommendations resulting from the meeting. The agenda, presentation materials, and an archived recording of the webcast for the meeting are posted on the Board's website at https://www.nwtrb.gov/meetings/past-meetings/fall-2021-virtual-board-meeting---november-3-4-2021. A meeting transcript is also available there.

The Board also thanks the staff from DOE and the national laboratories for supporting a technical fact-finding meeting, which was held virtually on October 13–14, 2021. This fact-finding meeting enabled the Board to prepare for the November 2021 public meeting.

Background

Over the past several years, DOE has been developing a modeling capability for evaluating the post-closure performance of potential repositories for spent nuclear fuel (SNF) and high-level radioactive waste (HLW). According to DOE, the suite of computational models and codes called the GDSA Framework is part of its efforts to develop a sound technical basis for evaluating geologic disposal in the United States in different host rocks and different disposal options.[1] The Board sees DOE's efforts as having the capability to address several recommendations the Board made in its Six Recommendations Report,[2] issued in April 2021,

[1] DOE uses the term "disposal option" to refer to the collection of specific repository features including engineered barriers, such as buffer or backfill, the type of disposal waste package, and the waste emplacement geometry (vertical or horizontal with respect to the orientation of emplacement tunnels).

[2] NWTRB. 2021. *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. April.

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namely, to anticipate the required high-performance computing and data management infrastructure required for a multi-decade waste management program and to facilitate application of iterative and adaptive approaches to development of a geologic repository. The Board's meeting examined DOE's R&D activities related to the GDSA Framework. Although DOE presentations in previous Board meetings have touched upon some aspects of the GDSA Framework and the Board has commented on those in Board reports or letters to DOE,[3,4] the November 2021 meeting was an opportunity for the Board to conduct a high-level review focused on DOE's GDSA efforts.

At the meeting, the Board received a brief update from William Boyle (DOE-NE) on DOE's Spent Fuel and Waste Disposition Program. Alisa Trunzo (DOE-NE) then described DOE's current efforts on a consent-based approach to siting a federal interim storage facility for SNF, and also summarized the work DOE-NE has been conducting to prepare for an integrated waste management system. Ms. Trunzo stated that DOE is committed to a consent-based approach to siting a federal interim storage facility that fully embraces principles of openness, transparency, public engagement, equity, environmental justice, and broad participation including that of historically underrepresented groups and communities. She noted also that DOE is incorporating expertise in the social sciences and resources from the national laboratory system to help move the program forward. She stated that DOE is funding an integrated research project for up to three years and $3 million for a university-led team to perform research that will inform how DOE implements a consent-based siting process. Further, she noted that DOE's approach is aligned with the recommendations in the Board's Six Recommendations Report for how to move the nation's nuclear waste management program forward.

The Board then heard several presentations from the national laboratory researchers who are conducting the work for DOE. These presentations included an overview of R&D activities related to developing the GDSA Framework and descriptions of several GDSA Framework components, including the multiphase flow and reactive transport code PFLOTRAN, the uncertainty quantification and sensitivity analysis code DAKOTA, the discrete fracture network model dfnWorks, the Fuel Matrix Degradation Model for commercial SNF, and a biosphere model. Other presentations by national laboratory researchers described the uncertainty and sensitivity analysis tools being applied in the GDSA Framework, the application of the GDSA Framework to generic repository reference cases in bedded salt, shale, and crystalline host rocks, and a case study in integrating insight and experience from the international community into geologic disposal safety assessments.

The Board also heard a presentation by two U.S. Nuclear Regulatory Commission (NRC) staff members and another by a representative from the Radioactive Waste Management organization in the United Kingdom (U.K.). The NRC staff members discussed their

[3] NWTRB. 2020. *Filling the Gaps: The Critical Role of Underground Research Laboratories in the U.S. Department of Energy Geologic Disposal Research and Development Program*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. January.

[4] Bahr, J.M. 2021. Board letter to Dr. Kathryn Huff with comments from December 2020 Board meeting (December 30, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb028.pdf?sfvrsn=4. (Accessed January 6, 2022)

perspectives on developing and applying performance assessment computer codes based on their collective experiences in these activities at the NRC and their participation in international programs. The U.K. representative described the development of environmental safety case models that will support geologic disposal of the U.K.'s radioactive waste.

Board Observations, Findings, and Recommendations

After discussing and examining the information presented at the fact-finding meeting and the public meeting, the Board has several observations, findings, and recommendations on DOE's program and GDSA R&D activities, which are provided below. The Board notes that all the meeting presentations were well done and addressed the questions the Board posed in the meeting agenda. A positive aspect of the meeting was hearing from a variety of staff and researchers, which the Board understands is important to DOE's efforts on knowledge management and human capacity building.

DOE's Consent-Based Process for an Interim Storage Facility

The Board commends DOE for starting a new effort on consent-based siting of an interim storage facility[5] and for recognizing the crucial importance of effective risk communication, full public engagement, and inclusiveness in the siting process. The Board supports DOE's commitment to transparency, openness, and effectively engaging stakeholders, including historically underrepresented communities, in any consent-based siting process. The Board is pleased DOE noted that its path forward for a consent-based siting process is well-aligned with the recommendations in the Board's Six Recommendations Report.

The Board also commends DOE for its plan to support its future risk communication efforts with social science expertise. At the same time, the Board observes that a great deal of relevant knowledge and expertise on risk communication, public engagement, and inclusiveness may be found in other fields, including behavioral science and the public health sciences. The Board notes that including these other fields would provide DOE a significantly broader and stronger knowledge base upon which to draw insights and expertise. Further, the Board supports DOE funding of a university-led team to conduct research on consent-based siting as the Board believes universities are well equipped to conduct multidisciplinary research that includes experts in the social and behavioral sciences, public health, and other relevant fields, and may enhance public confidence in DOE's efforts to improve risk communication.

At the meeting, in response to a Board member comment, the DOE representative stated that DOE is open to learning from experiences in other countries on the consent-based process for siting nuclear waste facilities. The Board notes that experiences in other countries, such as Sweden, Switzerland, and Canada, suggest that effective risk communication, public engagement, and inclusiveness in the siting process can be central to the success of any siting effort. The Board is encouraged by DOE's willingness to consider international experience. Although no two countries are identical, valuable insights can be gained by reviewing siting

[5] On December 1, 2021, DOE issued a Request for Information in the *Federal Register* (Vol. 86, No. 228) to collect comments and opinions about using a consent-based siting process to identify sites to consolidate and temporarily store the nation's SNF.

experiences elsewhere.[6] The Board notes that as DOE further develops its strategy for communication, engagement, and inclusiveness, it would be beneficial to systematically review key lessons that have been learned from siting processes in other nations. Ideally, this should include not only a review of literature on siting experiences in other countries, but direct interaction with government agencies, stakeholder organizations, and community groups that have been part of siting processes. The Board looks forward to hearing more in the future about DOE activities in this area.

Although DOE's current effort is focused on siting an interim storage facility, the Board notes that DOE previously worked on a consent-based process for both storage and disposal facilities for SNF and HLW.[7,8] The Board observes that strategies for effective communication, public engagement, and inclusiveness that DOE applies or develops in its current effort could be applicable to a future siting of a geologic repository for SNF and HLW.

The Board also observes that there may be lessons that could be learned from the challenges that arose with the proposal in 2016 to conduct a deep borehole experiment in Rugby, North Dakota. The Board noted in its Six Recommendations Report that this proposal encountered difficulties partly due to a lack of sufficient transparency and early engagement with the public. The Board suggests that as a follow-on to that project, DOE could do a detailed analysis of how the project was developed and the strategies for public engagement identified, and produce a candid "lessons learned" document that might be used for future consent-based siting and stakeholder engagement activities.

DOE's GDSA R&D Activities

The Board commends DOE for its R&D activities related to developing and enhancing its geologic disposal safety assessment capability. The Board notes that DOE is using state-of-the-art models, modeling approaches, and methods of analysis to develop and expand the GDSA Framework. There is a focused and excellent effort on uncertainty quantification and sensitivity analysis, which the Board believes can help increase the overall confidence in the results generated using the GDSA Framework. The Board also notes that DOE is actively applying lessons learned from the Waste Isolation Pilot Plant and Yucca Mountain projects, the international community, and publicly available sources.

- *The Board finds that DOE has a technically valid approach to developing its geologic disposal safety assessment capability that will enable it to evaluate the post-closure*

[6] NWTRB. 2015. *Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: A Detailed Analysis*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. January.

[7] DOE. 2016. *Designing a Consent-based Siting Process. Summary of Public Input Final Report*. December. https://www.energy.gov/sites/prod/files/2016/12/f34/Summary%20of%20Public%20Input%20Report%20FINAL.pdf. (Accessed January 6, 2022)

[8] DOE. 2017. *Draft Consent-Based Siting Process for Consolidated Storage and Disposal Facilities for Spent Nuclear Fuel and High-Level Radioactive Waste*. January. https://www.energy.gov/sites/prod/files/2017/01/f34/Draft%20Consent-Based%20Siting%20Process%20and%20Siting%20Considerations.pdf. (Accessed January 6, 2022)

performance of potential SNF and HLW repositories in different host rocks and with different disposal options. DOE is competently carrying out the development of the GDSA Framework and is making great progress in this effort while recognizing some of the challenges.

The Board encourages DOE to continue its GDSA Framework development efforts.

The Board notes that the GDSA Framework can be applied at various stages of the repository program, including site selection and evaluation, assessment of disposal options, and, eventually, to support a license application to construct a geologic repository. The repository performance modeling requirements will evolve as the repository program progresses through its various stages. The performance assessment models and codes should also evolve and improve as the repository program progresses — simpler during the early stages and later becoming more complex as more features, events, and processes are considered and advances in models and codes are made. Hence, the iterative nature of performance assessment code development. The Board believes that continued improvements in the GDSA Framework can be facilitated by applying it systematically to a broad suite of reference cases to begin exploration of the needed changes to the framework, to understand better the performance of the total system and that of the various engineered and natural barriers, and to assess the various disposal options. For example, a set of simulations for a crystalline host rock can evaluate what disposal options can lead to poor, mid-range, and good repository performance. The disposal options considered could explore various waste package designs, near-field configurations, far-field configurations, and biosphere assumptions. The Board acknowledges that DOE is currently using the GDSA Framework to simulate the performance of a small set of generic reference cases, but believes a strategy and intended outcome of the simulations need to be clearly defined and the GDSA Framework systematically applied.

- *The Board finds that DOE needs to more clearly define and articulate the near-term goals and applications of the GDSA Framework in order to better prioritize what needs to be incorporated into the software framework at different stages of the repository program.*

  The Board recommends that DOE define a clear strategy and intended outcome for the use of the GDSA Framework in the near term and systematically apply it to a broad suite of reference cases.

The Board notes that an important component of repository performance assessments, as well as evaluation of different disposal options, is the performance modeling and evaluation of engineered barriers, including waste forms, waste packages, and buffer materials. Performance assessment codes need to have a robust capability to assess the performance of engineered barriers, particularly for disposal options that are likely to rely heavily on those barriers. The GDSA Framework currently has limited capability to represent engineered barriers, such as fuel cladding and waste package materials, and to model their degradation. This limits DOE's ability to assess different disposal options, to determine engineered barrier importance, and to prioritize its R&D portfolio related to engineered barrier performance. The Board notes DOE indicated that it plans to improve the representation of the evolution of buffer and backfill behavior and waste package degradation in its numerical models.

- *The Board finds that the GDSA Framework currently does not have an adequate capability to assess the performance of engineered barriers, which may be necessary for evaluating engineered barrier capability and different disposal options.*

  The Board recommends that DOE expedite the development of the GDSA Framework such that it has sufficient capability to assess the performance of different engineered barriers. This capability is needed to assess different disposal options and to apply the GDSA Framework systematically to a broad suite of reference cases. The Board notes that in developing this capability, DOE also needs to take account of near-field processes that could affect the performance of engineered barriers.

The Board notes that there is great value in independent assessments, evaluations, and critiques of major code systems such as the GDSA Framework. The Board acknowledges that components of DOE R&D activities related to the GDSA Framework, such as modeling and laboratory work, are being peer-reviewed as part of journal and conference publication processes, as well as by technical experts in the national laboratories and entities such as the NWTRB. However, the Board believes that input from a broader set of stakeholders, including the public and regulators, on the development of the GDSA Framework can help improve the transparency of the processes being modeled (e.g., assumptions, conceptual models) and the modeling results. This improved transparency can be in the form of a clearer and simpler display of results and an ability to show how different components of a multibarrier system contribute to long-term safety. Transparency is important when interacting with stakeholders at all stages of the repository program, and is particularly important when interacting with regulators during the implementer's preparation of and the regulator's review of a license application to construct a repository. The NRC speakers at the meeting stated that stakeholder engagement was an important component of NRC's development of its performance assessment capability.

- *The Board finds that the development of the GDSA Framework can be improved by peer reviews by a broader spectrum of stakeholders.*

  The Board recommends that DOE solicit input on the development of the GDSA Framework from a broader spectrum of stakeholders, including the public and the regulator.

The Board observes that, although DOE has applied its own quality assurance (QA) program, the GDSA Framework, PFLOTRAN, and DAKOTA codes have not been developed under a Nuclear Quality Assurance (NQA-1)[9] or equivalent QA program. Yet this will be an important requirement for any future submission of a license to the NRC for repository construction. The Board believes that qualifying the computer codes using an acceptable QA program will be more costly, challenging, and time consuming the longer the implementation of the QA program is delayed. The Board notes that it would be appropriate for DOE to start an assessment of what needs to be done to have all the components of the GDSA Framework NQA-1 qualified (or equivalent). Moreover, it appears to the Board that the capabilities of the DAKOTA code are not being utilized in model calibration to determine the values and associated uncertainties of parameters that appear in various models. If that is the case, the Board notes it would be useful

[9] ASME NQA-1-2019, "Quality Assurance Requirements for Nuclear Facility Applications," American Society of Mechanical Engineers, New York, NY.

for the GDSA Framework team, including the process model developers, to work with the DAKOTA code team to identify how the DAKOTA capabilities can be used in model calibration.

Thank you again, on behalf of the Board, for the participation of DOE-NE staff and technical experts from the national laboratories at our November meeting. We look forward to continuing our ongoing review of DOE's technical activities related to managing and disposing of SNF and HLW.

Sincerely,

{Signed by}

Jean M. Bahr
Chair

cc: Dr. Kimberly Petry, DOE-NE
Dr. William Boyle, DOE-NE
Mr. Timothy Gunter, DOE-NE

Department of Energy
Washington, DC 20585

April 7, 2022

Dr. Jean M. Bahr
Chair
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Suite 1300
Arlington, Virginia 22201

Dear Dr. Bahr,

We appreciate your letter dated August 12, 2021, which presented observations, comments, and recommendations on the Board's Spring 2021 Meeting held on May 12-13, 2021. The Department of Energy (DOE) understands the Board's position in the letter where five recommendations were made. Enclosed is the Department's response to the five recommendations that were presented in the letter.

DOE appreciates the Board's input to our program and looks forward to continued input and insight from the Board on this topic as the testing progresses. If you have any questions, please feel free to contact Dr. Kimberly Petry, Acting Deputy Assistant Secretary for Spent Fuel and Waste Disposition, Office of Nuclear Energy at Kimberly.Petry@nuclear.energy.gov.

Sincerely,

Andrew Griffith
Acting Assistant Secretary
for Nuclear Energy

Enclosure

Department of Energy, Office of Nuclear Energy (DOE-NE) Response to Nuclear Waste Technical Review Board (NWTRB) Comments and Recommendations on Advanced Nuclear Fuels (ANF) and Accident Tolerant Fuels (ATF)
Spring 2021 NWTRB Meeting

Recommendation #1:
The Board recommends that the DOE Office of Spent Fuel and Waste Disposition coordinate and integrate in an ongoing fashion with the Office of Nuclear Fuel Cycle and Supply Chain on preparing for storage, transportation, and disposal of SNF resulting from deploying ANF/ATF in existing LWRs. Steps that can be taken include but are not limited to forming collaborative working groups, sharing laboratory facilities and equipment, and sharing irradiated fuel specimens and fuel characterization data.

DOE-NE Office of Nuclear Fuel Cycle and Supply Chain and DOE-NE Office of Spent Fuel and Waste Disposition will continue to cooperate and collaborate in sharing data, plans, laboratories, equipment, and ANF/ATF samples. In addition, DOE-NE has working relationships with the Electric Power Research Institute (EPRI), the Nuclear Regulatory Commission (NRC), the Extended Storage Collaboration Program (ESCP), international programs and industry. The relationships, sharing, integration and cooperation between all the groups and organizations are similar to those that were established for the High Burnup Demonstration and have proved to be very effective over the years. DOE-NE will continue to effectively use that model and processes for ANF/ATF issues now and in the future. In light of the Board's recommendation, however, DOE-NE will look for opportunities to further enhance coordination and integration between the Office of Nuclear Fuel Cycle and Supply Chain and the Office of Spent Fuel and Waste Disposition.

Recommendation #2:
The Board recommends that the next update to DOE's gap analysis report for SNF management be expanded in scope beyond storage and transportation to include disposal of SNF resulting from the use of ANF/ATF.

The national labs have begun work on a report that will continue the analysis of the evolving ANF/ATF technologies and potential waste streams from ANF/ATF reactor fuel cycles which includes disposal analyses. This report will pull from work on the disposal, storage, and transportation gap analyses and should address the substance of the Board's recommendation. R&D work on spent ANF/ATF is continuing for disposal, storage, and transportation, but because the test plans for these activities are changing and adapting at different schedules, the documents for disposal are better left separate from the documents for storage and transportation, for now. As more data and information become available in the future, DOE-NE may consider greater integration among those documents.

Recommendation #3:
The Board recommends that DOE-NE work to improve its access to fuel characterization data obtained during DOE-sponsored ANF/ATF development programs. Some of these data are important for assessing and closing the knowledge gaps related to ANF/ATF storage, transportation, and disposal.

The two DOE-NE offices are working closely on ANF/ATF issues, and they currently collaborate and share data that are available. The current non-disclosure agreements (NDAs) with private industry on proprietary data must be maintained. All data allowed by the NDAs that are currently available and needed for assessing and closing the knowledge gaps are shared. Once there is access to ANF/ATF at relevant burnups, DOE-NE will be able to test and model the behavior of the fuel in storage, transportation, and disposal conditions. This will allow DOE-NE to close any knowledge gaps that exist which should address the substance of the Board's recommendation.

Recommendation #4
The Board recommends that DOE evaluate the approaches used and experiences gained in other countries regarding early consideration of the potential impacts of new ANF/ATF designs on SNF storage, transportation, and disposal. Based on the lessons learned in other countries, DOE should implement mechanisms to provide feedback to ANF/ATF development work that accounts for the impact of these fuels on SNF management and disposal. The feedback process can also be used to prioritize SNF management research and development.

DOE-NE is involved in multiple international collaborations for storage, transportation, and disposal through the International Atomic Energy Agency, the Nuclear Energy Agency, the European Commission, EPRI's Extended Storage Collaboration Program (ESCP), the International Nuclear Energy Research Initiative (I-NERI), and other multi-national cooperation initiatives. Other countries also participate and share in these organizations. The purpose of each of these collaborations is to share data, information, and knowledge for the purpose of enabling more informed decisions. In line with the Board's recommendation, DOE-NE will continue to proactively and holistically evaluate modifications to the ANF/ATF with consideration given to international approaches and experiences.

Recommendation #5:
The Board recommends that DOE increase the accessibility of ATF information to the general public in the interest of clearly demonstrating openness, facilitating public engagement, factoring in public concerns in planned R&D, and avoiding the perception that there may be unexplored or unresolved issues (including issues affecting SNF management and disposal) related to the introduction of the new fuel designs.

DOE-NE Office of Spent Fuel and Waste Disposition plans, data, and reports are publicly available via the Office of Scientific and Technical Information (OSTI) and the DOE-NE website. Reports are sent to the NRC, EPRI, NWTRB, fuel vendors, utilities, and cask vendors prior to release so they can review them. The work is also presented in public conferences and papers published in peer-reviewed journals where anyone from the public can review and understand what has been and is being done. DOE-NE believes that segments of the public with interest in nuclear issues have full access to all relevant data. In light of the Board's recommendation, DOE-NE will look for opportunities to further enhance this access.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

June 7, 2022

Dr. Kathryn Huff
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Dr. Huff:

On behalf of the U.S. Nuclear Waste Technical Review Board (Board), I want to thank you and your staff, as well as the staff from the national laboratories, for supporting the Board's 2022 Winter Meeting, which was held virtually on March 1–2, 2022. The purpose of the meeting was to review information on the U.S. Department of Energy, Office of Nuclear Energy (DOE-NE) activities related to spent nuclear fuel (SNF) and high-level radioactive waste (HLW). DOE described research and development (R&D) on SNF and HLW in the areas of storage, transportation, non-site-specific disposal, and integrated waste management, and its consent-based siting process with regard to federal interim storage facilities. This letter presents the Board's observations, findings, and recommendations resulting from the meeting. The agenda, presentation materials, and an archived recording of the webcast for the meeting are posted on the Board's website at https://www.nwtrb.gov/meetings/past-meetings/winter-2022-board-virtual-meeting---march-1-2-2022. A meeting transcript is also available there.

Background

Over the past several years, DOE has been conducting R&D to enable storage, transportation, and disposal of SNF and HLW from existing and future nuclear fuel cycles and planning for an integrated waste management system to transport, store, and dispose of those wastes. In addition, DOE recently re-initiated an effort to use a consent-based siting process with regard to federal interim storage facilities for SNF. The Board recognizes these DOE efforts as positive steps towards having the capability to address several recommendations the Board made in its Six Recommendations Report,[1] issued in April 2021, namely, to:

- Ensure an integrated organizational approach.
- Anticipate the required high-performance computing and data management infrastructure required for a multi-decade waste management program.

[1] NWTRB. 2021. *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. April.

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- Facilitate application of iterative and adaptive approaches to development of a geologic repository.
- Embrace openness, transparency, and engagement.

The Board's meeting examined DOE's R&D activities related to storage, transportation, and disposal of dual-purpose (storage and transportation) canisters (DPCs). DOE presentations in previous Board meetings have touched upon some aspects of these efforts and the Board has commented on those in Board reports or letters to DOE.[2,3,4] At the meeting, DOE also updated the Board on some of its integrated waste management system R&D activities and its consent-based siting process. The Board has commented on some aspects of DOE's earlier efforts in these areas in Board reports or letters to DOE.[5,6,7]

At the meeting, the Board received an update from Timothy Gunter (DOE-NE) and from a national laboratory researcher on DOE's DPC direct disposal R&D activities. Then national laboratory researchers gave two presentations, one on a repository-scale performance assessment[8] that takes account of post-closure criticality and another on cladding degradation model development. Ned Larson (DOE-NE) provided a summary and status of storage and transportation R&D, including efforts related to DPCs. National laboratory researchers described canister surface environment investigations and the potential for corrosion of commercial SNF storage canisters and aerosol transmission through stress corrosion crack-like geometries.

The Board then heard several presentations on DOE's integrated waste management system R&D activities. A national laboratory staff member and a representative from a contractor at the Hanford, Washington, site described the Hanford Lead Canister (HLC) project, which is jointly supported by DOE-NE and the DOE Office of Environmental Management (DOE-EM). A national laboratory staff member brought the Board up to date on the Next Generation System Analysis Model (NGSAM) and described updated NGSAM requirements and

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[2] Bahr, J.M. 2021. Board letter to Dr. Rita Baranwal with comments from July 2020 Board meeting (January 11, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb026.pdf?sfvrsn=8. (Accessed June 2, 2022)

[3] NWTRB. 2019. *Preparing for Nuclear Waste Transportation–Technical Issues that Need to be Addressed in Preparing for a Nationwide Effort to Transport Spent Nuclear Fuel and High-Level Radioactive Waste*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. September.

[4] Ewing, R. 2015. Board letter to Mr. John Kotek with comments from June 2015 Board meeting (August 31, 2015). https://www.nwtrb.gov/docs/default-source/correspondence/rce083115.pdf?sfvrsn=12. (Accessed June 2, 2022)

[5] Ewing, R. 2015. Board letter to Mr. John Kotek with comments from June 2015 Board meeting (August 31, 2015). https://www.nwtrb.gov/docs/default-source/correspondence/rce083115.pdf?sfvrsn=12. (Accessed June 2, 2022)

[6] NWTRB. 2019. *Preparing for Nuclear Waste Transportation–Technical Issues that Need to be Addressed in Preparing for a Nationwide Effort to Transport Spent Nuclear Fuel and High-Level Radioactive Waste*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. September.

[7] Bahr, J.M. 2022. Board letter to Dr. Kathryn Huff with comments from November 2021 Board meeting (January 7, 2022). https://www.nwtrb.gov/docs/default-source/correspondence/jmb039.pdf?sfvrsn=4. (Accessed June 2, 2022)

[8] The Board notes that what was presented was not a formal performance assessment meant to address all the regulatory requirements described in the Code of Federal Regulations (CFR) at 10 CFR Part 63. As such the Board will refer to it as an assessment of post-closure criticality.

enhancements. Erica Bickford (DOE-NE) updated the Board on DOE's Stakeholder Tool for Assessing Radioactive Transportation (START) and described the current functions and capabilities of START. In the final meeting presentation, Alisa Trunzo (DOE-NE) updated the Board on DOE's current efforts on a consent-based approach to siting federal interim storage facilities. These efforts include a DOE request for information (RFI), for which DOE was still accepting comments, and plans for issuing a funding opportunity for interested groups and communities later this year.

Board Observations, Findings, and Recommendations

After discussing and examining the information presented at the public meeting along with related technical reports, the Board has several observations, findings, and recommendations on DOE's R&D activities and consent-based siting program, which are provided below. The Board notes that the meeting presentations were informative and addressed many of the questions the Board posed in the meeting agenda.

DOE's DPC Direct Disposal R&D Activities

Alternatives for disposal of commercial SNF

Since 2013, DOE has funded a DPC direct disposal R&D program that has focused on determining the technical feasibility of the safe, cost-effective, licensed, direct disposal (without removing and repackaging the SNF assemblies but including placing the DPC in a disposal overpack) of commercial SNF packages used by electric utilities operating nuclear power plants. A fundamental decision that will need to be made is whether to accept loaded DPCs into an integrated waste management system instead of accepting SNF assemblies.[9] The Board has noted that decisions in the near term on the disposability of SNF in DPCs and on the direction of the nation's geologic disposal program are needed because their interdependence will shape waste management and disposal activities over many years.[10]

The Board observes that a decision on disposability of SNF in DPCs would substantially impact how SNF is stored, transported, and disposed of, and may require interim storage of SNF for many decades to hundreds of years, depending on the availability of a repository that can accept DPCs. The Board has described how the complex structure of responsibilities and stakeholders presents challenges to DOE in executing a nuclear waste management program.[11] The Board notes that, as DOE pursues federal interim storage facilities using a consent-based approach, newly identified conditions of consent could make DOE's efforts to execute its program more complex. However, we believe a consent-based siting process that is well-conceived and well-executed has the potential to greatly increase public trust and confidence in siting efforts.

[9] " … For example, under the provisions of the Standard Contract, spent nuclear fuel in multi-assembly canisters is not an acceptable waste form, absent a mutually agreed to contract amendment. … ." (Gunter and Freeze, 2022). https://www.nwtrb.gov/docs/default-source/meetings/2022/march/gunter_freeze.pdf?sfvrsn=6. (Accessed June 2, 2022)

[10] Bahr, J.M. 2021. Board letter to Dr. Rita Baranwal with comments from July 2020 Board meeting (January 11, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb026.pdf?sfvrsn=8. (Accessed June 2, 2022)

[11] NWTRB. 2021. *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. April.

Following its July 2020 public meeting, the Board recommended that DOE provide information to decision-makers related to repository design concepts for various host rock types, the timing and rate of DPC disposal, and total system life cycle costs to inform their decisions on the use of DPCs.[12] DOE has completed a comparative cost analysis of SNF management alternatives[13] and has noted that a possible benefit of the direct disposal of DPC option is a lower cumulative worker dose.

- *The Board finds that additional analyses and quantitative information regarding the potential pros and cons of the DPC direct disposal option will be useful to decision-makers.*

  To provide decision-makers with information about the pros and cons of direct disposal of DPCs versus repackaging of SNF assemblies currently in DPCs, the Board recommends that DOE complete quantitative assessments for both concepts spanning the waste management lifecycle. These assessments should include estimates of costs and radiation doses related to packaging (or repackaging) of SNF, transportation, interim storage, and repository operations, including the ramifications of disposal in alternative geological media.

Independent technical review of the DOE DPC R&D program

As part of its R&D oversight, in 2021, DOE-NE funded an independent technical review (ITR) of its DPC direct disposal R&D program to help guide the future direction of the program. The Board commends DOE for sponsoring the ITR and soliciting feedback on its R&D program. The Board understands that the ITR was an internal (non-public) effort, and the Board appreciates being allowed access to the results of the ITR.[14] The ITR assessed some of the same R&D topics that were discussed in the Board's Winter Meeting, including cladding degradation modeling and post-closure criticality consequence assessments. The Board recognizes that the scope of these R&D efforts could change as DOE evaluates the results of the ITR and previous Board recommendations.[15]

In keeping with its mandate to conduct on an ongoing review before decisions are made, the Board held an initial fact-finding meeting with DOE on May 19, 2022 and is planning another fact-finding meeting with DOE to obtain more information on DOE's ITR. In the May 19, 2022, fact-finding meeting the discussion focused on neutronics calculations that affect the assessment of post-closure criticality. The Board plans to discuss further the scope of the ITR, including the criteria used to define "DPC disposability" and "feasibility of disposal." The Board would like to discuss the ITR results and how DOE will use the results to guide its DPC disposability

[12] Bahr, J.M. 2021. Board letter to Dr. Rita Baranwal with comments from July 2020 Board meeting (January 11, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb026.pdf?sfvrsn=8. (Accessed June 2, 2022)

[13] Freeze, G., E. Bonano, E. Kalinina, J. Meacham, L. Price, P. Swift, A. Alsaed, D. Beckman, and P. Meacham. 2019. *Comparative Cost Analysis of Spent Nuclear Fuel Cost Alternatives*. SAND2019-6999, Revision 1. Albuquerque, New Mexico: Sandia National Laboratories. June.

[14] Under the Nuclear Waste Policy Act, as amended, the NWTRB has the authority to request and review DOE draft reports.

[15] Bahr, J.M. 2021. Board letter to Dr. Rita Baranwal with comments from July 2020 Board meeting (January 11, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb026.pdf?sfvrsn=8. (Accessed June 2, 2022)

studies and its determination of whether direct disposal of DPCs is feasible (or not). The Board appreciates DOE's willingness to discuss these issues in the upcoming fact-finding meeting.

Assessment of post-closure criticality

DOE is conducting studies on post- closure criticality consequences to assist in assessing the technical feasibility of direct disposal of DPCs loaded with commercial SNF (both currently loaded DPCs and those still to be loaded). Other factors in DOE's assessment of the feasibility of direct disposal of DPCs include challenges associated with thermal management and engineering (weight and size) posed by large DPCs.

The criticality consequence studies involve post-closure repository calculations using the PFLOTRAN model-based Geologic Disposal Safety Assessment Framework coupled with neutronics calculations. Some of the recent criticality studies are still in draft form.[16] The studies do not yet consider the probability for criticality to occur which will be needed to assess risk. To date, all evaluations have been done for pressurized water reactor (PWR) SNF and have not evaluated boiling water reactor (BWR) SNF. DOE continues to make good progress in developing a capability to model the consequences of post-closure criticality. DOE has made improvements in PFLOTRAN, including capabilities to (i) change the radionuclide inventory and thermal output during the simulation, (ii) begin to take account of coupling between neutronics, in-canister thermohydraulic processes, and rates of heat transfer out of the canister, and (iii) take account of thermally induced mineralogic changes in permeability of the bentonite buffer. The Board observes that DOE appears to be building a case that radionuclide releases resulting from a postulated post-closure criticality event (consequences, not weighted by probability to yield risk) will not lead to significant changes in predicted doses (compared to cases with no criticality) for the unsaturated and shale scenarios that were simulated.

The Board notes that, in a comprehensive post-closure criticality assessment, several parameters will have a significant influence on the results. Among those parameters are the properties of the construction material of the outer layer of the waste package (i.e., the disposal overpack) and rate of degradation through the material. These factors will, in turn, determine when canister degradation could occur allowing water infiltration, and then, potentially, criticality. However, DOE has not yet included consideration of these parameters in its post-closure criticality assessments. The Board observes that other countries, such as Finland and Sweden, are employing waste packages that include a copper-based outer layer for waste disposal in crystalline rock repositories that are claimed to be long-lived. The Board notes that if DOE takes account of likely waste package materials and degradation rates for crystalline, argillite, and salt disposal concepts in its assessment of post-closure criticality, its assessment of the technical feasibility of the direct disposal of DPCs would be better informed and future R&D efforts better focused.

If DOE decides to continue criticality consequence studies without simultaneously considering the probability for criticality to occur, then the Board notes that DOE will need to consider the following questions and issues. First, how does criticality affect the performance of engineered

[16] The Board reviewed a draft report that formed the basis of the March meeting presentation on the repository-scale assessment incorporating post-closure criticality.

barriers and host rock, particularly in environments such as a crystalline repository under saturated conditions, which has yet to be evaluated? Second, does the range of infiltration rates DOE used for the unsaturated scenario, while reasonable for a site such as Yucca Mountain, capture the full range of plausible infiltration rates for other settings where there also could be a thick unsaturated zone? The Board encourages DOE to focus more on the effects of criticality events (transient and steady-state) on engineered material (e.g., waste package, bentonite buffer) properties, and on the processes that could lead to permanent termination of a criticality event, as well as the items the Board has previously identified.[17] As part of that effort, DOE will need to consider several neutronics-related issues including use of and validation of RAZERBACK and S3K, assessment of higher enrichments associated with HALEU,[18] and the impacts of BWR fuel on the potential consequences of criticality events. The planned evaluations for BWR SNF are important given the difference in water to uranium volume ratios and presence of water rods, water crosses, and part length fuel rods as compared to PWR SNF. Note that an alternative approach to assessing the risks from post-closure criticality may be to determine that the probability for criticality to occur is sufficiently small so that a detailed consequence assessment is not needed.[19]

SNF cladding degradation modeling

The Board appreciates the thorough presentation that summarized the consideration of SNF cladding in domestic and foreign repository programs. The Board commends DOE for completing the comprehensive, non-site-specific repository review and update of the features, events, and processes that could affect SNF cladding degradation. Degradation of cladding, SNF assembly hardware (e.g., grid spacers), and baskets within a DPC will affect the potential for criticality. Results from short-term testing[20] suggest that the grid spacers would degrade faster than cladding. DOE recognizes that partial grid collapse may occur for horizontally emplaced DPCs, which could permanently terminate criticality. The Board observes that this partial grid collapse scenario deserves attention because it could reduce the probability of criticality, but additional knowledge of grid material properties and stresses may be needed. To be noted is that BWR SNF is normally stored with the channel box in place, so the consequences of basket and grid spacer degradations may differ from that of PWR SNF. DOE is planning long-term cladding corrosion testing to validate extrapolations from short-term tests. The Board notes that efforts to refine cladding degradation modeling as part of the DPC direct disposal R&D effort will be influenced by DOE's decision on its overall approach for disposal criticality. These issues, as well as many of the topics mentioned above, will be influenced by DOE's

[17] Bahr, J.M. 2021. Board letter to Dr. Rita Baranwal with comments from July 2020 Board meeting (January 11, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb026.pdf?sfvrsn=8. (Accessed June 2, 2022)

[18] HALEU is high-assay, low-enriched uranium, which is uranium that has been enriched so that the concentration of the fissile isotope U-235 is between 5 and 20 percent of the mass of the fuel. This is higher than the 3 to 5 percent U-235 concentration, or "assay," of low-enriched uranium that fuels the existing fleet of light water reactors.

[19] Expected average doses for a scenario, such as post-closure criticality, in a probabilistic performance assessment are calculated by multiplying the conditional consequence by the probability (some value less than one) for the scenario to occur.

[20] Hillner, E., D. Franklin and J. Smee. 1998. *The Corrosion of Zircaloy-Clad Fuel Assemblies in a Geologic Repository Environment*. Bettis Atomic Power Laboratory Report WAPD-T-3173.

consideration and implementation of recommendations made by a DOE-sponsored ITR team that addressed a broad range of issues associated with the DPC direct disposal R&D program.

DOE's Storage and Transportation R&D Activities

DOE's summary presentation on its storage and transportation R&D activities covered the breadth of its R&D program. The Board commends DOE-NE for obtaining commercial DPCs for use in storage and disposal R&D efforts and for planning two full-scale field demonstration studies within its storage and transportation R&D program and its integrated waste management system R&D program.

The Board notes that obtaining and testing high burnup BWR SNF cladding is identified in DOE's storage and transportation R&D 5-year plan and in DOE's gap analysis as an action that is needed to fully "close multiple gaps," including potential cladding degradation due to hydride reorientation.[21,22] DOE still believes that pressurized water reactor PWR data for high-burnup fuels bound BWR behavior.

- *The Board finds that DOE has not yet provided evidence for making this conclusion.*

For example, the Board recommended "that DOE indicate how its tests [with PWR fuel] and models do or do not apply to the broad range of high burnup fuel types and storage and transportation system designs for which information is still needed and take steps to meet those remaining technical information needs."[23] The Board is encouraged that DOE is continuing to seek opportunities to do the necessary BWR SNF cladding testing. The Board notes that similar questions of test result applicability are pertinent to newer accident tolerant fuels (ATF) and fuel assemblies containing integral fuel burnable absorbers (IFBA).

- *The Board recommends that DOE either demonstrate that existing data and modeling regarding the behavior of high burnup PWR SNF bound the behavior of BWR and ATF SNF and SNF containing IFBAs or complete the necessary testing and modeling for these fuel types.*

DOE's focus in its transportation R&D activities is on normal conditions of transport. DOE is considering the possibility of conducting a package performance study of an SNF transportation cask to address non-normal conditions of transport (e.g., accidents) and is in the early stages of

[21] Saltzstein, S., B. Hanson, G. Freeze and K. Sorenson. 2020. *Spent Fuel and Waste Science and Technology Storage and Transportation 5-Year R&D Plan*. SAND2020-9310 R. Albuquerque: Sandia National Laboratories. August. This document describes activities whose completion is subject to future funding and DOE does not intend to update the plan.

[22] Teague, M., S. Saltzstein, B. Hanson, K. Sorenson, and G. Freeze. 2019. *Gap Analysis to Guide DOE R&D in Supporting Extended Storage and Transportation of Spent Nuclear Fuel: An FY2019 Assessment*. SAND2019-15479R. Albuquerque: Sandia National Laboratories. December. This document serves as the technical guidance for planned work and is updated.

[23] NWTRB. 2021. *Evaluation of the Department of Energy's Research Program to Examine the Performance of Commercial High Burnup Spent Nuclear Fuel During Extended Storage and Transportation*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. July.

developing a test plan. Like its successful multi-modal transportation test that addressed normal conditions of transport, DOE anticipates that surrogate fuel assemblies would be instrumented and placed inside a cask during testing. This would allow for the evaluation of both the cask and its internal contents under non-normal conditions of transport. The Board notes that DOE reviewed earlier full-scale accident testing efforts including the U.S. Nuclear Regulatory Commission (NRC)-sponsored package performance study. The NRC study included an opportunity for public comment on the draft protocols.[24] The Board commends DOE for considering anew the need and scope of a package performance study that assesses the performance of both the cask and cask contents, particularly considering extended aging affects, and encourages DOE to engage early with stakeholders in developing the plan.

DOE is conducting a comprehensive array of R&D activities that are addressing the technical issues related to the timing and conditions of occurrence of, and the risk of canister penetration from, chloride-induced stress corrosion cracking (CISCC) of welded stainless-steel dry-storage canisters during extended storage of SNF. The focused research on CISCC conducted under the storage and transportation R&D program includes:

- Defining the canister surface environment through thermodynamic modeling, independent spent fuel storage installation site sampling, a field demonstration study of horizontally stored canisters, and laboratory experiments.
- Determining canister degradation rates through corrosion experiments and modeling, pit-to-crack transition studies, and crack growth rate measurements.

These studies are complemented by development and evaluation of methods to mitigate and repair canister degradation. The Board commends DOE for the R&D work it is conducting on CISCC and encourages DOE to continue its R&D efforts on this technical issue. The Board notes one additional area that deserves focus.

- *The Board finds that DOE has not fully considered whether a different localized corrosion mechanism such as crevice corrosion could be a precursor process for initiation of CISCC in addition to pitting corrosion.*

  As DOE continues to develop the two full-scale canister demonstrations, the Board recommends that DOE consider whether localized corrosion such as crevice corrosion could be a precursor to CISCC and determine how that precursor mechanism could be assessed in the field demonstrations.

DOE-NE is also supporting, under its integrated waste management R&D program, the Hanford Lead Canister (HLC) project and is collaborating with DOE-EM and industry on that test. The Board commends DOE for supporting the HLC project. The project is a positive demonstration of the value of integration efforts across DOE programs, offices, and sites, which the Board previously has recommended to DOE.[25] The HLC project, which is focused on vertically stored

[24] Durbin, S., E. Lindgren, R. Rechard and K. Sorenson. 2014. *Full-Scale Accident Testing in Support of Used Nuclear Fuel Transportation*. SAND2014-17831 R. Albuquerque: Sandia National Laboratories. September.

[25] NWTRB. 2021. *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. April.

canisters, shares common objectives with DOE R&D activities on CISCC of commercial SNF dry-storage canisters. The speakers stated there is broad collaboration between DOE-NE, DOE-EM, and industry, and appear very open to input from researchers on how the HLC project can provide information that is useful to the dry-storage canister community. The Board encourages the HLC project investigators to further their collaboration with other researchers. The HLC project is still at an early stage, with ample opportunity to get input on how it can support research on corrosion mechanisms and sampling and characterizing atmospheric dusts that may deposit on canister surfaces.

The Board observes that there may be opportunities to incorporate monitoring and inspection results to inform HLC efforts. The Board encourages DOE to use monitoring and inspection results from other aging management efforts such as those at the Hanford 200 Area Interim Storage Area and at the Columbia Generating Station to inform development of the HLC test plan.

DOE is conducting R&D on aerosol transmission through machined microchannels that are early surrogates for stress corrosion cracks. The speaker indicated that in the next steps in the testing, they want to introduce more features that are prototypic of stress corrosion cracks. The Board agrees that refinements are needed. For example, if more prototypic stress corrosion crack geometries are used, the rates of depressurization and clogging (plugging) of a crack due to deposition of aerosol particles are likely to differ from what is now being measured. In particular, the crack geometry at the time of initial thru-wall crack penetration may lead to depressurization with effective filtering of aerosol size particles, thereby minimizing subsequent particle release due to prior depressurization as the crack enlarges. Also, the Board notes that, in the current experiments, multiple parameters that affect flow and transport are varied at the same time, which complicates modeling and interpretation. DOE recognizes these limitations and is preparing for testing of lab-grown corrosion cracks and clean (non-particulate) testing first for independent flow characterization before testing for particulate transmission. Eventually, the experimental data and modeling outputs on aerosol transmission will be used as input to consequence (dose) calculations for a postulated SNF canister breach.

The Board is encouraged by DOE's initial efforts and notes that DOE has described several potential refinements to the testing in its storage and transportation 5-year R&D plan.[26] In the storage and transportation 5-year R&D plan DOE listed the following improvements:

- "Via the sibling pin [high burnup PWR SNF] testing program, obtain the particle size distribution of fuel and aerosols released in different scenarios (e.g., burst vs. impact) and apply this distribution to the testing and modeling."
- "Measure aerosol release and depletion in environments characteristic of dry storage."

The Board agrees with these potential refinements. The Board notes that the overall risk of SNF canister degradation is best informed by combining the results of a realistic assessment of the

[26] Saltzstein, S., B. Hanson, G. Freeze and K. Sorenson. 2020. *Spent Fuel and Waste Science and Technology Storage and Transportation 5-Year R&D Plan*. SAND2020-9310 R. Albuquerque: Sandia National Laboratories. August.

consequences of canister penetration from degradation with the results of a more thorough assessment of the probability of breaching an SNF dry cask storage system. Prior scoping probabilistic risk assessments of dry casks[27,28] that describe the logic used and events that lead to radiologic release during storage can guide DOE to better define the processes and event sequences that are needed for a realistic assessment of the consequences of canister degradation.

- *As DOE conducts R&D to support its consequence assessment of canister failure, the Board recommends that DOE complete refinements that it has described for its aerosol transmission experiments, including conducting some experiments using a single effect approach to facilitate easier model development, validation, and interpretation of results. In the near-term, DOE should clearly define the events and processes that affect aerosol generation within a sealed cask that can lead to potential aerosol transmission when a crack forms to subsequently guide the R&D needed to realistically assess the consequence of a canister failure.*

DOE's Integrated Waste Management R&D Activities – System Tools

DOE-NE has developed several decision-support tools, including NGSAM and START, to assist in developing and managing an integrated waste management system. NGSAM is an agent-based discrete event simulation tool designed for modeling the evolution and fate of SNF from its site of origin at a nuclear power plant to a disposal site. START is a web-based application that utilizes geographic information systems technology to represent transportation network operations as well as proximate features, such as tribal lands, emergency response capability, schools and environmentally sensitive areas.

The NGSAM tool allows analysts to add, remove, and modify model logic and analyze a wide range of integrated waste management system configurations, approaches, and scenarios. NGSAM reference data are obtained from the Used Nuclear Fuel–Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS), another DOE-NE funded system tool, and the DOE Spent Fuel Database, which is funded by DOE-EM and is the definitive database for DOE SNF quantities and characteristics.

The Board commends DOE for advancing development of NGSAM and adding the capability to model DOE SNF at an individual fuel element level, and HLW. NGSAM analyses of packaging scenarios of the numerous types of DOE SNF at Idaho National Laboratory, which will require four different waste packages and eight internal basket configurations,[29] could provide additional insights about packaging DOE SNF in multi-purpose canisters to meet a 2035 deadline to remove SNF from Idaho. Expanded NGSAM capabilities for analyzing repository operations could provide insights to help DOE-NE better understand how repository operations, including

[27] U.S. Nuclear Regulatory Commission. 2007. *A Pilot Probabilistic Risk Assessment of a Dry Cask Storage System at a Nuclear Power Plant*. NUREG-1864. Washington D.C. March.

[28] EPRI. 2004. *Probabilistic Risk Assessment (PRA) of Bolted Storage Casks Updated Quantification and Analysis Report*. Technical Report 1009691. Palo Alto: Electric Power Research Institute. December.

[29] NWTRB. 2017. *Management and Disposal of US Department of Energy Spent Nuclear Fuel*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. December.

the rates of waste handling and emplacement, could impact overall waste management system operations and costs. DOE has focused on developing NGSAM capabilities, such as the capability to model individual elements of DOE SNF, but less so on NGSAM analyses and evaluations of various packaging/repackaging options, such as direct disposal of DPCs. While DOE has examined some cases which compared repackaging all DPCs to scenarios where standardized transportation, aging and disposal canisters are introduced in the future, DOE has not directly compared direct disposal of DPCs to repackaging options using NGSAM.

DOE has used outputs from NGSAM in multi-objective evaluation framework (MOEF) analyses. MOEF is a set of capabilities, methods, processes, and tools that provide a means to evaluate alternative scenarios and system architectures for an integrated waste management system where there are multiple conflicting objectives and differing stakeholder perspectives on a proposed waste management system.[30] DOE has supported MOEF analyses in the past and DOE may restart MOEF research depending on funding and program direction. The Board notes that by utilizing appropriate social science/behavioral science/public health expertise, DOE could develop a program that would include input from stakeholders on NGSAM capabilities and waste management scenarios to be analyzed that could inform their participation in a consent-based siting process.

- *The Board finds that there is value in expanding NGSAM capabilities and analyses to more completely address possible integrated waste management systems options and in renewing the development of MOEF as a part of understanding and addressing stakeholder objectives in support of consent-based-siting activities.*

  The Board recommends that DOE expand NGSAM capabilities and analyses to better address disposal of DPCs, including waste packaging operations and cost requirements, and that it include stakeholders involved in the consent-based siting process to inform NGSAM development and use.

DOE has made significant advances with the START tool, and DOE's continuous improvement and verification and validation efforts are positive. START includes a considerable amount of information that could be useful in familiarizing and training emergency response personnel for nuclear waste transport (e.g., where Transportation Emergency Preparedness Program trained personnel are located, where fire departments and healthcare facilities are based, sites of potential temporary evacuation or mass care, critical infrastructure locations, etc.). The Board commends DOE for beginning to communicate with and arrange training for local, state, and Tribal groups regarding START. The Board observes that other federal agencies use other transportation planning tools and have information that may allow DOE to gain insights for additional START development. DOE could learn how other agencies incorporate hazards, for example the effects of extreme/seasonal weather and climate change, and whether use of the other transportation tools with relevant stakeholders could inform DOE's outreach efforts with START.

[30] NWTRB. 2019. *Preparing for Nuclear Waste Transportation–Technical Issues that Need to be Addressed in Preparing for a Nationwide Effort to Transport Spent Nuclear Fuel and High-Level Radioactive Waste*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. September.

- *The Board finds that there are additional opportunities for developing and using START as a training tool and to improve outreach using the knowledge bases of other agencies.*

  The Board recommends that DOE consider how START might be utilized as a resource to familiarize and train emergency response personnel for nuclear waste transport and as a component in tabletop exercises aimed at exploring emergency scenarios. Likewise, the Board recommends that DOE engage with other agencies involved in similar transportation efforts to leverage their experiences and approaches to stakeholder interactions and addressing hazards.

DOE's Consent-Based Siting Process for Federal Interim Storage Facilities

The Board again commends DOE for starting a new effort on consent-based siting and for recognizing the crucial importance of effective risk communication, full public engagement, and inclusiveness in the siting process. The Board appreciates the stated commitment to transparency, openness, and effectively engaging stakeholders, including historically underrepresented communities, in any consent-based siting process. At the same time, based upon what the Board heard in the March meeting, the Board notes that DOE already appears to be facing some significant difficulties early in the process. DOE does not appear to have effectively broadened its outreach to engage a larger number and broader range of participants. Although several Tribal organizations are engaged, DOE does not appear to have met its stated aim of tapping perspectives from diverse populations, and from organizations representing minority communities and underserved populations. More efforts to understand past initiatives (e.g., DOE's deep borehole demonstration project that was terminated in 2017) and the details and distinctions of consent-based siting in the international programs, particularly the differences between what is happening on consent-based siting in Sweden and Finland vis-à-vis France and Switzerland[31] could inform DOE's development of its consent-based siting process.

- *The Board finds that there are additional actions that DOE could take to meet its stated commitments, learn from domestic siting experiences and from siting processes in other nations, and strengthen its overall consent-based siting effort.*

  Although the Board applauds DOE for undertaking significant consent-based siting activities, the Board recommends that DOE significantly strengthen and improve its efforts. A larger and broader range of participants should be engaged, and expanded efforts to include historically underrepresented communities should be undertaken. DOE should also make systematic use of the large body of scientific and technical literature in such fields as the social/behavioral sciences and the public health sciences. By informing all consent-based siting efforts with relevant outside scientific/technical knowledge and expertise on risk communication, risk perception, effective outreach, inclusiveness, and public engagement, DOE can identify ways to engage a broader range of participants, better understand public views and concerns, and improve the overall effectiveness and face validity of its consent-based siting work. The Board also recommends that DOE produce a candid "lessons

[31] In Finland and Sweden, interim storage and final repositories are in communities where they have nuclear power already. In France and Switzerland, potential repository sites are in locations where there is not anything nuclear in the community.

learned" document on its deep borehole demonstration siting effort and review key lessons that have been learned from siting processes in other nations.

The Board held a fact-finding meeting with DOE on April 22, 2022, to obtain more information on DOE's consent-based siting efforts. The Board and DOE discussed the results from the RFI and how DOE may apply the results to inform and shape its planned funding opportunity announcement. The discussion also included DOE's efforts to develop the necessary in-house expertise to support the consent-based siting effort and extend its outreach to a larger public audience. The Board appreciates DOE's flexibility and support for a fact-finding meeting so soon after the public meeting.

Thank you again, on behalf of the Board, for the participation of DOE-NE staff and technical experts from the national laboratories at our March meeting and in the subsequent fact-finding meetings. We look forward to continuing our ongoing review of DOE's technical activities related to managing and disposing of SNF and HLW.

Sincerely,

{Signed by}

Jean M. Bahr
Chair

cc: Mr. William (Ike) White, DOE-EM
Dr. Kimberly Petry, DOE-NE
Dr. William Boyle, DOE-NE
Dr. Erica Bickford, DOE-NE

Department of Energy
Washington, DC 20585

June 8, 2022

Dr. Jean M. Bahr
Chair
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard, Suite 1300
Arlington, Virginia 22201

Dear Dr. Bahr:

The U.S. Department of Energy (DOE) appreciates your April 2021 report to the Congress of the United States and the Secretary of Energy which provided the Board members' synthesis of their reviews of DOE's activities related to the management and disposal of spent nuclear fuel and high-level radioactive waste.

The report provides six overarching recommendations (and 27 associated action items) in several areas, including the design and effective operation of an integrated nuclear waste management program, guidance on creating a more effective and rigorous science and engineering program, and building public trust and international engagement to foster success. The Board stated that the "progress the nation is making in developing its waste management capability, as well as public and stakeholder acceptance, could be improved with regard to both timeliness and effectiveness by adopting these recommendations as core principles of the nuclear waste management program." DOE agrees with the Board that some of the action items identified require contributions from entities that are beyond DOE's control and require both authorization and appropriations by Congress.

Enclosed are DOE's responses to the six recommendations and associated action items. In general, there are existing activities in progress that address many of the Board's actions items. However, there are additional actions that could be taken and will be considered for future implementation. These are identified as "Relevant Existing Activities" and "Potential Future Actions" in the Enclosure.

DOE appreciates the Board's input to our program and looks forward to continued input and insight from the Board on DOE's activities related to the management and disposal of spent nuclear fuel and high-level radioactive waste. If you have any questions, please feel free to contact me or Kimberly Petry, Deputy Assistant Secretary for Spent Fuel and Waste Disposition, at (301) 903-5685.

Sincerely,

Kathryn Huff

Dr. Kathryn Huff
Assistant Secretary
for Nuclear Energy

Enclosure

Department of Energy (DOE) Response to the Nuclear Waste Technical Review Board (NWTRB) Report to the U.S. Congress and the Secretary of Energy

"Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward" (April 2021)

The DOE's responses to the six recommendations and associated action items are listed below. In general, there are many DOE activities that were already in progress that address the Board's action items. However, there are additional actions that will be considered for future implementation that may more fully address the action items. These are identified as "Relevant Existing Activities" and "Potential Future Actions" in the response below.

1) **NWTRB Recommendation #1: Ensure an Integrated Organizational Approach**
   a) ***NWTRB Recommended Action Item 1a****: Foster broader sharing of information among DOE offices, national laboratories, and contractors (e.g., university researchers supported by Nuclear Energy University Program grants).*
      i) Relevant Existing Activities:
         - Multiple laboratories work together to develop the Integrated Priorities List (IPL), as well as to coordinate program management and execution.
         - Work packages that involve contributions from multiple laboratories have monthly status meetings with contributing labs to enable effective integration of activities across the laboratories.
         - Technical Research & Development (R&D) projects are actively integrated across national laboratories and other DOE offices, with applicable developments and results presented at numerous domestic and international conferences each year.
         - Weekly meetings are held to discuss management integration.
         - Dozens of publicly available milestones/reports are published each year. Additionally, internal-use-only work is also shared as appropriate within controlled groups. Public reports are available from either the DOE website or the DOE Office of Scientific and Technical Information (OSTI) database. In addition, The DOE Office of Spent Fuel and Waste Disposition (SFWD) milestone reports are archived in Sharepoint databases (public and non-public reports) within the Sandia National Laboratories (SNL) External Collaboration Network (ECN) accessible to SFWD staff and external individuals with an account.
      ii) Potential Future Actions
         - Expand tools such as the Used Nuclear Fuel – Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS) [1], incorporating the latest GC-859 information in the Unified Database (UDB) and the Next Generation System

[1] UNF-ST&DARDS = Used Nuclear Fuel-Storage, Transportation & Disposal Analysis Resource and Data System

Analysis Model (NGSAM) to include other DOE-managed spent fuel and high-level waste.[2]

- Establish an outward-facing document archive in FY2022; the archive could be similar to CURIE[3].
- Expand the SFWD seminar series to include broader audiences.

b) ***NWTRB Recommended Action Item 1b:*** *Further enhance integration of R&D programs executed by DOE's Office of Environmental Management (DOE-EM), Office of Nuclear Energy (DOE-NE), and other DOE offices* to optimize collaboration, minimize duplication, and maximize the effectiveness of the effort.

i) Relevant Existing Activities:

- Integration of scientific R&D occurs regularly within and across the National Laboratories through execution of collaborative projects. For example, Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratories (SNL) collaborated to provide input to ARPA-E [4] for its workshop on advanced reactors in December 2020. ARPA-E has hosted additional coordination events (including workshops, industry days, meetings), where national labs, NE, EM, and the National Nuclear Security Administration (NNSA) have been invited to comment on program development and areas of technical and programmatic coordination.
- Staff from multiple laboratories support a range of programs for several DOE energy and science offices. The knowledge and experience gained in those programs can be leveraged to support SFWD objectives.
- The Disposal Research International Activities Program collaborates actively with science-based R&D disposal programs around the world.
- SFWD engages in direct communication with the other DOE-NE offices as well as with the DOE's Office of Environmental Management (DOE-EM), e.g., through DOE's Spent Nuclear Fuel Working Group, to discuss or collaborate on a variety of topics including:
  - Considerations for advanced fuels/reactors
  - Potential changes to High-Level Waste (HLW) glass compositions
  - Development and maintenance of DOE O 460.2B [5]
  - Operation of the National Transportation Stakeholders Forum (NTSF), primarily through conferences and webinars
  - Standard Canister design work

[2] These tools are currently used by NE to better understand the spent fuel component of the integrated waste management system.

[3] CURIE = Centralized Used-Fuel Resource for Information Exchange. CURIE is an information-sharing website, accessible to federal and laboratory partners, as well as other stakeholders that provides usable, collaborative document and data access. CURIE helps users find resources, upload documents, and work more efficiently.

[4] ARPA-E = Advanced Research Projects Agency - Energy

[5] DOE O 460.2B = DOE Transportation Order for Departmental Materials Transportation & Packaging Management

- The Hanford Lead Canister Project[6]
- The DOE Spent Nuclear Fuel (SNF) Packaging Demonstration

- Under the auspices of the DOE Spent Nuclear Fuel Working Group (SNFWG), DOE is integrating development of packaging and processing technologies not only to address aging SNF and SNF facilities but also to facilitate a seamless transition from DOE-regulated SNF management to an NRC-regulated nuclear waste management environment
- SFWD is contributing to development of fully remote Cold Spray Coating (CSC), Friction Stir Processing (FSP), and Friction Stir Welding (FSW) for small diameter standardized canisters which could be used on DOE Standard Canisters, and which could also be slightly modified to include Multi-Canister Overpacks (MCOs). The specific use cases are being considered are part of the DOE SNF Packaging Demonstration.

- SFWD collaborates with Energy Information Administration (EIA) on the Nuclear Fuel Data Survey Form GC-859 data collection process.
- SFWD has been expanding the Next Generation Systems Analysis Model (NGSAM) to be able to explicitly model individual assemblies of non-commercial SNF.

ii) Potential Future Actions

- In FY2022, SFWD will enhance collaboration with the DOE Office of Nuclear Fuel Cycle and Supply Chain (NE-4) and the DOE Office for Reactor Fleet and Advanced Reactor Deployment (NE-5) to address SNF and HLW waste management challenges from advanced reactors.
- Opportunities exist for additional integration through collaborations on subsurface characterization and modeling efforts. Specific opportunities include projects that utilize underground research labs (URLs) across the world.

c) ***NWTRB Recommended Action Item 1c:*** *Find ways to work with utilities, cask vendors, fuel manufacturers, and others in the nuclear industry in an ongoing manner, to more effectively develop and implement the nuclear waste management program.*

i) Relevant Existing Activities:

- The SFWD Program actively collaborates with nuclear industry organizations including utilities, cask manufacturers, fuel vendors, and others (e.g., Orano (formerly Transnuclear Inc.), Dominion Energy Virginia, Orano (formerly AREVA), Framatome (formerly AREVA), Westinghouse, NAC International, the Electric Power Research Institute (EPRI), and the Nuclear Energy Institute (NEI). The SFWD Program also coordinates with the U.S. Nuclear Regulatory Commission (NRC) and international nuclear agencies on a variety of research activities related to storage, transportation, or disposal of SNF. Examples include:

[6] This collaborative project seeks to transfer Cs/Sr capsules from the Waste Encapsulation and Storage Facility (WESF) into dry storage.

- The Canister Deposition Field Demonstration to run a field-based controlled study to measure the deposition of corrosive species (chloride salts) from marine coastal ambient air onto prototypic spent nuclear fuel (SNF) canisters.
- The large scale, long term, dry storage cask research and development project for spent nuclear fuel. That is the High Burnup (HBU) demo cask, currently on the pad at Dominion's North Anna storage facility, and the associated post-irradiation testing/characterization of the HBU fuel rods (sibling pins).
- Studies of Dual-Purpose Canister (DPC) direct disposal evaluating various processes including potential future basket/neutron absorber modifications. Associated corrosion testing of advanced neutron absorbers to gain knowledge in "other" repository environments to inform absorber selection. External review of the DPC studies includes industry staff.
- Rail Car Optimization
- The Studsvik Cladding Integrity Project (SCIP-IV) on SNF characterization/testing, the 1/3-scale drop test at the German Federal Institute for Materials Research and Testing (Bundesanstalt für Materialforschung und-prüfung, or BAM) facility in Germany, and the multimodal transportation test with the Korea Atomic Energy Research Institute (KAERI) of the Republic of Korea and ENSA (Equipos Nucleares S.A) of Spain.

- SFWD partners with EPRI for development of the Used Nuclear Fuel (UNF) standards and technology transfers.
- The GC-859 web-based application development effort is being conducted to allow utilities to easily provide information on spent fuel, and plans to incorporate their feedback based on pilot testing the application.
- SFWD collaborates with utilities to perform on-site and near-site transportation infrastructure evaluations.
- SFWD collaborates with the cask vendors on cask/canister-related data collection.
- SFWD collaborates with the railroad industry on the Association of American Railroads (AAR) Standard 2043 for railcar design and testing.

ii) Potential Future Actions:

- Work with vendors to develop "universal" transportation casks.
- As planned, support the 2022 NEI Used Fuel Conference.
- Possibility of future collaboration between DOE and cask vendors (and NRC) on a full-scale rail-sized cask package performance study.
- Collaborate with NEI and cask vendors on their performance margin-related efforts.
- Collaborate with utilities and cask vendors on developing dry cask loading that will support direct disposal.
- Collaborate with cask vendors in the areas of additive manufacturing of basket/canister/cask.

d) ***NWTRB Recommended Action Item 1d:*** *Find additional innovative ways of information sharing through DOE-led conferences or workshops that might encourage the different entities in the implementation matrix in Table 3-1 to improve communications and engagement.*

i) Relevant Existing Activities:

- Leading the development of the 2022 International High Level Waste Conference. Note that Sylvia Saltzstein (SNL) is the General Chair and both Rob Howard (PNNL) and Brady Hanson (PNNL) are technical program chairs.
- Funded the National Academy of Sciences (NAS) Study on Waste Aspects of Advanced Reactors.
- Annual SFWD meeting with industry/vendor/university/other agency collaborators.
- Leading the international DECOVALEX (DEvelopment of COupled Models and their VALidation Against EXperiments in Nuclear Waste Isolation) model validation initiative, which holds regular workshops twice a year.

ii) Potential Future Actions:

- Reconstitute and support the Ad Hoc Working Group on Transportation Communications.
- Develop plenary presentations for the 2022 National Transportation Stakeholders Conference.

2) NWTRB Recommendation #2: Anticipate Required Infrastructure and Personnel Needs

a) ***NWTRB Recommended Action Item 2a****: Develop and communicate an integrated plan regarding physical infrastructure, information technology, and personnel needs over the next decade.*

i) Relevant Existing Activities:

- SFWD Knowledge Management (KM) activities are directly related to preserving and making available to DOE-NE and associated Labs existing critical knowledge and information, including the tacit knowledge of individual staff members, for training, development, and succession planning of more junior staff.
- The SFWD cloud-based information technology (IT) platform is capable of supporting a full-scale generic nuclear waste management program with applications to support organizational and quality assurance (QA) requirements. This cloud-based solution could facilitate fully integrated program-wide collaboration with the ability to communicate and share easily between multiple remote locations and multiple participating parties. A sample of capabilities includes email, teleconferencing, document/records management, project management, data storage, legacy applications, and a project portal.
- A pilot program for development of geoscience expertise was initiated in fiscal year 2022 to educate, attract, develop and train early-career scientists to build a diverse next-generation workforce for disposal research in the U.S.

ii) Potential Future Actions

- Create a deliverable in FY2022 related to creation of a draft integrated plan.[7]

b) ***NWTRB Recommended Action Item 2b:*** *Formulate and implement research programs and other supporting infrastructure consistently to anticipate the effects of aging of facilities*

i) Relevant Existing Activities:

[7] DOE will likely need to develop a separate document for federal staffing needs.

- SFWD has several ongoing activities to address this sub-recommendation, for example:
  - Active R&D on aging of commercial SNF (CSNF) canisters at storage sites, including potential changes to the stored CSNF.
  - The high burnup (HBU) demo canister is a long-term test (fielded at North Anna facility) to study aging of stored HBU SNF.
  - The Canister Deposition Field Demonstration in the Spent Fuel and Waste Science and Technology (SFWST) R&D program has acquired and is instrumenting storage canisters for the Canister Deposition Field Demonstration.
- SFWD has supported several DOE Nuclear Energy University Program (NEUP)-funded Science & Technology projects. Examples include the Hanford Lead Canister project, Cold Spray Coating (CSC) and Friction Stir Welding (FSW).
- SFWD is developing railcars (Cask railcars, a buffer railcar, and a rail escort vehicle) all of which are designed for 50-year service lives from the time of manufacture.
- SFWD has studied the transportation infrastructure at and near to utility sites that will be the origin points for the transportation system with an understanding that local infrastructure may change over time, so there is a focus on major thoroughfares which not likely to change (mainline railroads, interstates, and navigable waterways) in our transportation planning activities.

c) ***NWTRB Recommended Action Item 2c:*** *Develop and maintain the capability to utilize DOE's leading-edge, high-performance computing (HPC) resources for the analysis and simulation of processes and systems related to the back-end of the fuel cycle.*

i) Relevant Existing Activities:

- The SFWST campaign utilizes HPC for the Geological Disposal Safety Assessment (GDSA) Framework[8]. The GDSA is used for system analyses as well as for subsystem work. Both the systems models and subsurface analyses (including uncertainty quantification and sensitivity analyses) rely on access to HPC resources, though they can be executed on less powerful platforms.

ii) Potential Future Actions:

- High performance computing can be applied to the Used Nuclear Fuel-Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS)[9]/COBRA-SFS[10].
- Collaborate with the National Laboratories to apply their HPC capabilities to data analytics, data visualization, machine learning, and artificial intelligence.

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[8] GDSA Framework (https://pa.sandia.gov) is an open-source software framework developed to leverage the US DOE's high-performance computing (HPC) resources. The availability of this unique computing capability enables appropriately detailed modeling of the coupled physical and chemical processes affecting repository evolution and radionuclide transport, implementation of model domains with geologic fidelity, forward simulation over the 10^4- to 10^6-year timescale typically required by regulation, and propagation of uncertainty over many realizations of the problem.

[9] ST&DARDS is thermal hydraulics code developed for steady-state and transient analysis of multi-assembly spent-fuel storage and transportation systems

[10] COBRA-SFS is a module within ST&DARDS that is devoted to spent fuel package thermal analysis. It is a thermal-hydraulics code developed for steady-state and transient analysis of multi-assembly spent-fuel storage and transportation system.

d) ***NWTRB Recommended Action Item 2d:*** *Develop infrastructure for and implement data management systems that can meet the needs for long-term and efficient retrieval of information from current and, to the extent possible, previous relevant R&D programs.*

i) Relevant Existing Activities:

- The SFWD Cloud Project has migrated all the key project applications and their functionality and document collections from previous active nuclear waste disposal programs to an integrated cloud platform. The migrated information includes all materials pertaining to the technical and regulatory aspects associated with licensing a facility. This action preserves and facilitates efficient utilization of information related to that program. In addition, the cloud project provides a platform that enables the same capabilities to operate under a future nuclear QA program.
- SFWD Knowledge Management (KM) activities are directly related to preserving and making available existing critical knowledge and information, including the tacit knowledge [11] of individual personnel, to train and develop more junior staff, as well as to conduct succession planning.[12] A taxonomy developed on the knowledge base of nuclear waste management has been implemented to tag this content with metadata facilitating enhanced search for the database user.

e) ***NWTRB Recommended Action Item 2e****: Address the challenges of an aging workforce by expanding mentorship of a new generation of staff through: technical training programs; more effectively targeting undergraduate scholarships, graduate fellowships, and post-doctoral fellowships in areas of need; establishing internships at underground research laboratories (URLs); and promoting careers in nuclear waste management as an opportunity to address this grand environmental challenge.*

i) Relevant Existing Activities:

- National Laboratories supporting SWFD have developed internal programs for succession planning.
- SFWD has a pilot program for more active recruitment of junior geoscience personnel into the disposal research (DR) field. This pilot program for workforce development leverages the International Activities and the Geologic Disposal System Analyses (GDSA) activities to encourage student and post-doc involvement to grow a more diverse workforce.[13]
- Senior- and mid-career staff commonly serve as Control Account Managers (CAMs) while early-career staff serve as work package managers (WPMs).
- When appropriate, senior- and mid-level staff are actively paired with junior-level staff on projects to facilitate knowledge transfer and promote staff development.
- Funding of dozens of NEUP projects annually includes technical points of contact assigned from SFWST junior- through senior-level technical staff.

[11] *Tacit knowledge* can be defined as skills, ideas and experiences that are possessed by people but are not codified and may not necessarily be easily expressed. With tacit knowledge, people are not often aware of the knowledge they possess or how it can be valuable to others.

[12] The KM Repository is designed to contain the multimedia datasets of many types and to make them easy to retrieve and use in multiple manners that are preferred by different users.

[13] The Workforce Initiative would focus on underrepresented groups and collaborate with minority-serving institutions.

- SFWD has recently hired and begun mentoring new technical staff to cover anticipated near-term and longer-term needs, including management of research work in the area of integrated waste management systems involving advanced reactor types, and consent-based siting.

ii) Potential Future Actions:

- SFWD will consider more active involvement with universities to prepare the next generation of researchers and engineers.
- SFWD plans to continue hiring new federal staff in FY22 to support new program areas and cover program areas where retirements are anticipated.

3) NWTRB Recommendation #3: Expand the Research Paradigm to Embrace Hypothesis Testing

a) ***NWTRB Recommended Action Item 3a:*** *Anticipate surprises or unexpected results that may arise during the R&D program and assure all research programs include ample provisions to accommodate possible changes in direction and focus.*

i) Relevant Existing Activities

- The SFWD research approach is aligned with this associated action item. Modeling and testing work includes hypothesis testing and provides for the possibility of unexpected results and changes in direction. For example:
  - The HBU demo cask testing work (and sibling pins characterization testing) was analyzed with thermal models prior to the setting up the demo cask at the North Anna facility. The thermal models were benchmarked against the thermal testing facility-controlled experiments. The data collection in the test resulted in key refinements to specific modeling constraints such as thermal boundary conditions and heat transfer characteristics that improved the accuracy of the models. [14]
  - The results from the above example as well as other storage and transportation (S&T) testing (e.g., the international multi-modal transportation test) have been used to revise the gap analyses and reprioritize the R&D programs.
  - Within Disposal Research (DR), models of bentonite buffer are corroborated and/or adjusted as needed based on results from field-scale tests and laboratory experiments.

b) ***NWTRB Recommended Action Item 3b:*** *Test alternative hypotheses using careful experimental design over multiple scales from laboratory to full-scale in-situ tests in a URL.*

i) Relevant Existing Activities

- The SFWD research approach is aligned with this associated action item as is our fundamental approach to the coupling of modeling and testing. Tests are performed from laboratory- to field-scale throughout the R&D activities. Specific examples include:
  - Field-scale S&T work on the North Anna HBU demo (refer to 3a for additional information) with coupled testing of sibling pins and thermal modeling. All of

[14] Ultimately this approach led to the understanding that prior models overestimated peak cladding temperatures of fuel rods within the canisters and provided an improved basis for assessing evolution of stored CSNF.

this work demonstrated conservatism of previous estimates and resulted in modification of thermal modeling approaches.

- The Brine Availability Test in Salt (BATS) (refer to 3d, 3e and 5ai for additional information) is the field-scale component of the Salt R&D program, which includes laboratory testing, coupled process modeling (e.g., TH, THM[15]), and refinement of constitutive models using all of the above to provide GDSA the bases and models for system-scale analyses.
- Testing on natural and engineered barriers, including different host rocks, bentonite buffers and cementitious materials, occurs from small-scale in the laboratories to field-scale measurements and long-term tests in international URLs. Processes are evaluated with models from the molecular-scale to the drift scale to evaluate model concepts and scaling issues.

c) ***NWTRB Recommended Action Item 3c:*** *Continue to make new measurements to build a database that tests the abilities of existing models to capture important processes and evaluate the possible need for new conceptual models to improve estimates of system properties and thus prediction accuracy.*

i) Relevant Existing Activities:

- The SFWD research approach is aligned with this associated action item as is our fundamental approach of the coupling of modeling and testing throughout the R&D activities.
- Each technical R&D area has various principal-investigator-created/managed databases utilized to test models and improve representations, for example:
  - Sandia and Lawrence Livermore National Laboratories manage thermochemical data obtained during geochemical studies and modeling.[16]
  - Argonne National Laboratory has constructed data sets for SNF characteristics to use for testing models and improving understanding.[17]

d) ***NWTRB Recommended Action Item 3d****: Use results of repeated testing of existing and evolving hypotheses to enhance the usefulness of models in performance assessment.*

i) Relevant Existing Actions:

- The SFWD research approach is aligned with this associated action item as is our fundamental approach of the coupling of modeling and testing throughout R&D activities. Examples discussed above include:
  - The HBU demo project on thermal conditions in storage and the evolution of CSNF fuel rods during storage and transportation.
  - The BATS research program conducted in bedded salt in the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico.
  - Research activities in underground research laboratories in our international collaborations as discussed under Recommendation #6 below.

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[15] THM = Thermal-Hydro-Mechanical

[16] The geochemical studies and modeling referenced are conducted under the disposal research (DR) program.

[17] The SNF data compilation referenced is conducted under the Science and Technology R&D program.

- The international DECOVALEX Project involves model comparison studies between research teams from multiple organizations for the purpose of hypothesis testing. DOE is a partner in the DECOVALEX Project and the project is chaired by a National Lab scientist.

e) ***NWTRB Recommended Action Item 3e****: Establish one or more dedicated domestic underground research laboratories that will provide the necessary opportunities for researchers and students to conduct in-situ investigations into sub-surface processes at scale, test models, and further international collaboration.*

i) Relevant Existing Activities:

- SFWD is conducting generic salt R&D testing in the underground at WIPP. This work, known as the Brine Availability Test in Salt (BATS), is evaluating heated salt beds to understand mobilization of brine during thermal perturbations. SFWST staff are leaders in the Nuclear Energy Agency (NEA) Salt Club and the BATS is being used as a data set for international model validation activities. Additional testing expansion is underway in this area.
- Work is ongoing in SFWD to refurbish and utilize a tunnel in unsaturated tuff as a URL for studies on generic unsaturated disposal systems.[18]

ii) Potential Future Actions

DOE considers the current utilization of underground research facilities (including the Waste Isolation Pilot Project in bedded salt, and participation with international partnerships such as research in argillite (Mt. Terri in Switzerland) and crystalline media (Grimsel Test Site in Switzerland)) adequate for current research needs. Establishing a dedicated domestic URL is not appropriate at this time, however, as the research program and repository program advances, DOE will consider additional research opportunities as appropriate in the future, such as:

- Supporting the collaborative establishment of a state-of-the-art borehole to advance subsurface science and technology. The borehole laboratory design is a flexible, multi-purpose configuration that enables one or more borehole utilizations for singular or multiple simultaneous experiments to study phenomena at all scales.
- Consider use of the Sanford Underground Research Facility (SURF)[19], URL located in Lead, South Dakota. There is potential to use this full-scale, crystalline rock URL to:
  - Develop and advance technologies for repository characterization that can improve the uncertainty quantification and sensitivity analyses for modeling efforts.
  - Develop and advance technologies for long-term and/or real-time monitoring of waste packages.
  - Design engineered processes and systems for applied energy and national security.

[18] The site infrastructure developments have been delayed by COVID. Planning for tests include underground passive monitoring of site gas movement and Muon detection in the subsurface.
[19] For more information on the SURF URL visit https://www.sanfordlab.org/

- Consider support of R&D activities associated with the Deep Vadose Zone (DVZ) Test Site.[20]

4) **NWTRB Recommendation 4: Apply an Iterative, Adaptive Approach in Developing and Managing the Nuclear Waste Management Program.**
   a) ***NWTRB Recommended Action Item 4a:*** *Iterate between testing individual components of the nuclear waste management program and testing integrated models of the entire waste management system, always being ready to adapt each approach based on what is learned from such testing.*
      i) Relevant Existing Activities:
         - This is a core, fundamental process of the coupling of modeling and testing throughout SFWD R&D activities. Please see above examples provided in Recommendation 3 for examples.
         - The development of the Geological Disposal Safety Assessment (GDSA) capabilities is inherently an iterative process of continued evaluation, addition, testing, refinement, and reassessment, both for understanding of process representations and for prioritization of next stages of R&D for disposal system analyses.
         - Systems analyses using the Next-Generation System Analysis Model (NGSAM), embraces this approach. System model representations of waste acceptance, transportation, storage, and disposal operations are developed iteratively.

      ii) Potential Future Actions:
         - The GDSA is currently focused on addressing generic repository systems in the SFWD program, but the capabilities are developed in a manner (both technical and documentation) that facilitates utilization in potential future application in other programs that may evolve to more site-specific focus.

   b) ***NWTRB Recommended Action Item 4b:*** *Be open and structured to adapt to surprises during all aspects of the nuclear waste management program and always be willing to reevaluate and rethink previous decisions.*
      i) Relevant Existing Activities:
         - SWFD is committed to proceeding in a manner that is inclusive, transparent, participatory, and responsive to new information and the suggestions and recommendations of communities, stakeholders, and the public.
         - This is a core, fundamental aspect of the coupling of modeling and testing throughout SFWD R&D activities, for example:
            - The HBU Demo cask studies used thermal measurements of a HBU SNF cask to update the understanding of model representations for boundary conditions and other conservative heat transfer process. Updated models led to improved,

[20] The DVZ Test Site is leveraged for development and demonstration of advanced monitoring technologies within consolidated and unconsolidated sediments and crystalline rock. The unique characteristics of this area allow for in-depth analysis and learning that can be applied to multiple sites and needs across the country.

more realistic representations and better understanding of the peak cladding temperatures in HBU casks.

In implementing its Strategic Framework for DOE-Managed Spent Nuclear Fuel (June 2021) DOE is reevaluating and validating or modifying, as appropriate, previously made decisions with respect to storage and disposition of DOE-managed SNF.

c) ***NWTRB Recommended Action Item 4c:*** *Establish mechanisms as part of on-going evaluations to facilitate and incentivize solicitation of input and feedback from all affected stakeholders, including: independent scientists and engineers outside of the nuclear waste management program; local, state, and tribal governments; nuclear utilities; and the interested public.*

i) Existing Relevant Activities:

- Integration of inputs/constraints from all relevant sources is a fundamental activity in the coupling of modeling and testing throughout the R&D activities within SFWD.

ii) Potential Future Actions:

- Develop and implement a Strategic and Comprehensive Stakeholder Engagement and Communications Plan that includes mechanisms to facilitate and solicit input from affected stakeholder groups and tribal representatives.

5) NWTRB Recommendation #5: Expand Engagement with the International Community to Benefit from Lessons Learned.

There are four sub-recommendations under Recommendation #5, however because there is an actively integrated collaborative international program, a single response to all four sub-recommendations is provided. The four sub-recommendations for NWTRB Recommendation #5 are as follows:

a) ***NWTRB Recommended Action Item 5a:*** *Build on current initiatives and continue to expand engagement with the international community, recognizing the need for global cooperation in science and technology in this world-wide grand environmental challenge.*

NWTRB Recommended Action Item 5b: *Sustain active engagement in international programs given the tangible benefits derived from close involvement.*

NWTRB Recommended Action Item 5c: Continue and *expand participation in collaborative international underground research laboratory activities. If, as recommended, DOE develops one or more underground research laboratories, it should encourage international participation, which could benefit the DOE program by incorporating broader perspectives and expertise.*

NWTRB Recommended Action Item 5d: *Emphasize engagement with countries that have advanced to the demonstration and/or construction authorization stages of repository development to enhance knowledge of these stages.*

Overall, SFWD believes that focus on international collaboration allows close integration with the international waste management R&D community in terms of best practices, new science advances, state of the art simulation tools, new monitoring and performance confirmation approaches, lessons learned, etc. SFWD has therefore established a broad range of international collaboration activities. The joint R&D with international researchers, the worldwide sharing of knowledge and experience, and the direct access to relevant

data/experiments from a variety of underground research laboratories and host rocks provides an improved understanding of the current technical basis for disposal in a range of potential host rock environments. Comparison with experimental data allows for testing and validating predictive computational models for evaluation of disposal system performance in a variety of generic disposal system concepts. Comparison of model results with other international modeling groups, using their own simulation tools and conceptual understanding, enhances confidence in the robustness of predictive models used for performance assessment. The possibility of linking model differences to particular choices in conceptual model setup provides guidance into "best" modeling choices and understanding the effect of model uncertainty. These outcomes, including improved predictive models and a deep understanding of conceptual model uncertainties, can be directly incorporated into GDSA activities.

i) Relevant Existing Activities:

- SFWD researchers actively participate in numerous international activities. See previous responses for some examples from the Storage and Transportation (S&T) R&D program as well as from the Disposal Research (DR) R&D programs.
- Disposal Research R&D includes projects in URLs from many countries as well as development of domestic URL programs. The SFWD BATS is a U.S.-based field test with international collaboration. Much of this collaborative international work is available in public reports, journal articles, and conference publications.
- SFWD has a balanced portfolio of international collaboration activities in DR and addresses relevant R&D challenges in near-field perturbation, engineered barrier integrity, radionuclide transport, and integrated system analysis. These activities form a central element of SFWD DR programs, and significant advances have been made across different host rock types and engineered barriers.
- SFWD recognizes that international collaboration enables (1) leveraging a deep knowledge base regarding alternative repository environments developed across the world, (2) utilizing international research facilities, especially operating underground research laboratories not available in the U.S., and (3) sharing the cost of major tasks such as full-scale *in situ* experiments or complex modeling efforts.
- SFWD currently has in place formal collaboration agreements with multiple international partners on several international initiatives, including the following:
    - The DECOVALEX Project[21]
    - The Mont Terri Project[22]
    - SKB Task Forces[23]

[21] The DECOVALEX project is an international research and model comparison collaboration, initiated in 1992, for advancing the understanding and modeling of coupled thermo-hydro-mechanical-chemical (THMC) processes in geological systems. https://decovalex.org/

[22] The Mont Terri Project is an international research project for the hydrogeological, geochemical, and geotechnical characterization of a clay formation (Opalinus Clay). Mont Terri is located in Switzerland. https://www.mont-terri.ch/

[23] SKB is the Swedish Nuclear Fuel and Waste Management Company that is tasked with finding solutions for the safe management of Sweden's radioactive waste. The SKB Task Force is an international collaboration that focuses on selecting and

- HotBENT[24]

- SFWD researchers are conducting several collaborative R&D activities that align with R&D priorities across most of the technical areas discussed in this section. In these collaborations, SFWD scientists contribute world class analyses, models, and data for both process understanding and system risk modeling and assessment (see e.g., Birkholzer and Faybishenko, 2021[25].
- Early efforts to develop a consent-based siting (CBS) approach to site a SNF repository and/or interim storage facility were built upon examples, experiences and lessons learned from countries such as Canada, Sweden, and Finland.

6) **NWTRB Recommendation #6: Embrace Openness, Transparency, and Engagement**
As noted in the 2017 *Draft Consent Based Process for Consolidated Storage and Disposal Facilities for Spent Nuclear Fuel and High-Level Radioactive Waste*, NE is committed to proceeding in a manner that is inclusive, transparent, participatory, and responsive to new information and the suggestions and recommendations of communities, stakeholders, and the public.
   a) **NWTRB *Recommended Action Item* 6a:** *Inform and engage the public and other affected stakeholders early in the planning and review of all aspects of the nuclear waste management program.*
      i) Relevant Existing Actions:
         - A DOE-NE Request for Information (RFI) was issued in December 2021, that seeks public input on several SFWD programs, including consent-based siting (CBS).
         - Much of the collaborative work generated within SFWD is available in public reports, journal articles, and conference publications.
         - SFWD and its National Lab partners regularly engage in public conferences and meetings with external entities in industry, regulatory agencies, and academia.
         - SFWD funds the Nuclear Energy University Program (NEUP), which has dozens of active projects.
         - Stakeholder feedback from earlier consent-based siting (CBS) efforts was a central component of designing the 2017 *Draft Consent-Based Siting Process for Consolidated Storage and Disposal Facilities for Spent Nuclear Fuel and High-Level Waste*. Over 10,000 pieces of correspondence, received by DOE via a variety of mechanisms, were

overseeing specific experiments to be performed at the Äspö Hard Rock Laboratory for parallel modeling by more than one participating team. Currently, the SKB Task Force is focused on two tasks: Task 8 is investigating the interface of engineered and natural barriers, and Task 9 seeks to develop more realistic models of solute flow and transport through fractured rock. https://www.skb.com/about-skb/our-task/

[24] HotBENT is a collaborative international effort to evaluate the effects of high temperatures on bentonite-based barriers and their safety functions. Field work for HotBENT takes place in Switzerland at the Grimsel Test Site URL. https://www.grimsel.com/gts-projects/hotbent-high-temperature-effects-on-bentonite-buffers/hotbent-introduction

[25] Birkholzer, J., and Faybishenko, B. 2021. International Collaboration Activities in Geologic Disposal Research: FY20 Progress, Spent Fuel Waste Science and Technology (SFWST), Milestone Report, M2SF-20LB010307012, LBNL-2001433, Lawrence Berkeley National Laboratory, Berkeley, CA USA, 333 pp.

carefully tracked, processed, and summarized using a language processing tool known as the Comment Response Management System (CRMS).[26]

- SFWD is engaged with Native Americans through the Nuclear Energy Tribal Working Group (NETWG) and the Tribal Radioactive Materials Transportation Committee (TRMTC), and with State governments through four State Regional Groups (SRGs) covering the continental US. SFWD funding to TRMTC and the SRGs supports the operation of their respective committees, as well as participation in DOE's National Transportation Stakeholders Forum (NTSF) and its associated topical ad hoc working groups.
- SFWD has operated multiple NTSF ad hoc working groups comprised of federal, State, and Tribal government representatives to address technical and policy topics related to spent nuclear fuel transport. The NTSF Rail/Routing ad hoc working group has worked with States, Tribes, the US Department of Transportation Federal Railroad Administration, and the railroad industry to understand railroad transport operations, regulatory structures, process for identifying transport routes for hazardous materials, and safety inspection practices. The group is currently collaborating on development of a railcar safety inspection protocol for future DOE shipments of spent nuclear fuel that could enable States and Tribes along a transportation route access to safety inspection information on spent nuclear fuel shipments, and enable an inspection reciprocity arrangement, similar to what is available for highway radioactive materials shipments through the Commercial Vehicle Safety Alliance's Level VI inspection.
- SFWD nuclear power plant infrastructure evaluations include participation from State and Tribal government representatives in the region of a plant to both seek local input and expertise on options and challenges for transporting spent nuclear fuel away from reactor sites as well as lend transparency to DOE's considerations for transport modal options, logistical operations, safety, and security.

ii) <u>Potential Future Actions:</u>

- One or more community Funding Opportunity Announcements (FOAs) may be issued in FY2022. The FOAs will allow communities that are potentially interested in hosting a consolidated interim storage facility (CISF) to apply for funding to learn more and develop outreach and engagement activities of their own.
- DOE plans to create opportunities to discuss the Draft Strategic Plan with stakeholders.
- In FY22, SFWD plans to resume operation of the NTSF Section 180(c) ad hoc working group to continue collaborations with State and Tribal governments and work toward a final Departmental policy for how DOE will provide funds to States and Tribes through whose jurisdictions DOE transports spent nuclear fuel and high-level radioactive waste, consistent with the intent of Section 180(c) of the NWPA.

b) ***NWTRB Recommended Action Item 6b:*** *Be transparent in decision-making and provide support for meaningful stakeholder participation.*

[26] The CRMS is a proven and effective knowledge management tool to provide a rapid and effective way to efficiently synthesize public and stakeholder comments at both large scales and broad scopes. It has been used successfully to process tens of thousands of comments, shortening agency response time, while facilitating consistency and ensuring comments and concerns are captured and incorporated into the decision-making process and record.

i) Relevant Existing Activities:

- Senior-level communications and environmental justice (EJ) personnel are being integrated into the design and implementation of a consent-based siting (CBS) process.
- SFWD is investing in the development of FACET[27] and related tools to develop meaningful engagement and outreach opportunities. FACET is a science-based framework for transparently evaluating tradeoffs among complex environmental, economic, and social issues. It offers support for policy and business decisions, resulting in risk-informed, socially equitable, and defensible evaluations for all stakeholders.

ii) Future Potential Actions:

- Restart bi-annual (every 6 months) Transportation Core Group Meetings.
- Reconvene and support Ad Hoc Working Groups on Transportation Communications.
- Strive to publicly release all fully developed reports and notify State, Tribal, and federal partners, as appropriate, when they are posted publicly.
- Design and implement a Comprehensive and Strategic Stakeholder Engagement and Communications Plan (See NWTRB Recommendation #6 opening paragraph, above).

c) ***NWTRB Recommended Action Item 6c:*** *Take account of lessons learned in other countries about listening to and informing the public, in order to improve communications, better understand community perspectives, and avoid unnecessary delays of the program.*

i) Relevant Existing Activities:

This recommended action item is aligned with SFWDs path forward on developing an integrated nuclear waste management system that includes a consent-based approach to siting waste management facilities. SFWD has consultants with experience from other nuclear waste management programs such as the Canadian Nuclear Waste Management Organization (NWMO) and plans to seek additional advice and lessons learned from international waste management programs, whenever possible.

d) ***NWTRB Recommended Action Item 6d:*** *Though not a license requirement for any new site selected for a repository, DOE should develop and make available a clear characterization of the facility early in the process that describes the waste management concept and its multiple barriers and other attributes that contribute to safety. DOE must also clearly acknowledge and communicate its commitment that the safety concept will be revised to update it as new information and input are received.*

i) Relevant Existing Activities:

- This recommended action item is aligned with SFWDs path forward on developing an integrated nuclear waste management system that includes a consent-based approach to siting waste management facilities. Multiple products need to be developed for a wide range of audiences to explain overall waste management system concepts and approaches, facilities, and safety features.

[27] FACET = The Framework for Assessment of Complex Environmental Tradeoffs
https://www.pnnl.gov/projects/environmental-justice/facet

e) ***NWTRB Recommended Action Item* 6e:** *Develop site-suitability criteria prior to the start of site selection so as to minimize any ambiguity and latitude in their interpretation, thus helping to ensure the objectivity of the process and public confidence in its outcome. If, at any point during the siting process, the criteria need to be changed, a transparent and meaningfully participatory process to do so needs to be followed.*

i) Relevant Existing Activities

- There is discussion of "Siting Considerations" for both repositories and a CISF in the 2017 *Draft Consent-Based Siting Process for Consolidated Storage and Disposal Facilities for Spent Nuclear Fuel and High-Level Radioactive Waste* document.

f) ***NWTRB Recommended Action Item 6f:*** *If, as recommended, the United States develops one or more underground research laboratories, these laboratories, in addition to their research function, should be utilized for outreach and public engagement, in order to provide access to the subsurface (a vague concept with the public) and to build public confidence and trust and engineering behind the safety concept, as well as in the operational capabilities for remote handling of waste underground.*

i) Relevant Existing Actions:

- URL work in the US is currently used for outreach, however the sites themselves have/may have restrictions regarding direct public access.
- Operational testing for disposal concepts goes well beyond generic disposal system R&D and may not be warranted in the R&D program until further progression into a disposal program timeline. Currently, the international collaboration provides insight into this area for generic disposal system R&D.

ii) Potential Future Actions:

- If DOE develops a specific underground research laboratory in the future to support repository development, DOE will consider the use of the URL for outreach, public engagement, and for testing operations as recommended.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

July 6, 2022

Dr. Kathryn Huff
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Dr. Huff:

On behalf of the U.S. Nuclear Waste Technical Review Board (Board), I would like to thank you for your recent responses to our letter of August 12, 2021, regarding the Board public meeting held May 12-13, 2021, and our report, *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward* (Six Recommendations Report; April 2021). We appreciate the time and effort that you and your team devoted to providing detailed and thoughtful replies to our recommendations. We particularly appreciate the format of the letter responding to the Six Recommendations Report in which you listed current activities and future actions that relate to our recommendations.

The Board believes that a continuing and candid discussion between our organizations is important and fruitful. Such communication can bolster the Department's research and development (R&D) program supporting the management and disposal of spent nuclear fuel and high-level radioactive waste as well as the Board's efforts to review and provide feedback on those activities.

Given what the Board believes is the importance of implementing the recommendations made in the Six Recommendations Report, and to further clarify key points contained in the report and DOE's responses to the Board's recommendations, I would like to arrange a follow-up meeting with you in the near future. I suggest a one-on-one meeting with you to discuss key points in the Six Recommendations Report, including the Department's R&D efforts, developing an integrated waste management system, and advancing a new consent-based siting program. Please let me know if and when you can support this meeting by sending your response to our Acting Executive Director, Mr. Daniel Ogg, at ogg@nwtrb.gov. Thank you. We look forward to hearing from you.

Sincerely,

{Signed by}

Jean M. Bahr
Chair

cc: Mx. Samuel Brinton, DOE-NE

Telephone: 703-235-4473 Fax: 703-235-4494 www.nwtrb.gov

Department of Energy
Washington, DC 20585

September 28, 2022

Dr. Jean M. Bahr
Chair
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Suite 1300
Arlington, Virginia 22201-3367

Dear Dr. Bahr:

The U.S. Department of Energy's (DOE) Office of Nuclear Energy appreciates your letter of January 7, 2022, which summarized the Nuclear Waste Technical Review Board's Fall 2021 Meeting. In that virtual meeting, held on November 3–4, 2021, information was presented by DOE and national laboratory participants on DOE's research and development (R&D) activities related to the Geologic Disposal Safety Assessment (GDSA) Framework.

DOE also provided the Board with an update on current efforts to implement a consent-based approach for siting a federal interim storage facility for spent nuclear fuel (SNF), and on the work DOE has been conducting to prepare for an integrated waste management system.

The Board's letter provided observations, findings, and recommendations on DOE's GDSA R&D activities, and included comments related to DOE's consent-based siting efforts.

The enclosure provides DOE's responses to the Board's specific observations, findings, and recommendations on the GDSA R&D activities. DOE would also like to thank you for the attention to and comments on DOE's consent-based siting efforts. We will be considering these comments as DOE moves forward with the consent-based siting process.

DOE appreciates the Board's input to our program and looks forward to future insight from the Board on DOE's activities related to the management and disposal of SNF and high-level radioactive waste.

If you have any questions, please feel free to contact Timothy Gunter, Disposal R&D Team, Office of Spent Fuel and Waste Science & Technology, Office of Nuclear Energy, at Timothy.Gunter@nuclear.energy.gov.

Sincerely,

Dr. Kathryn Huff
Assistant Secretary
for Nuclear Energy

Enclosure

U.S. Department of Energy (DOE) Response to the Nuclear Waste Technical Review Board (NWTRB) Report on the DOE's Research & Development Activities Related to the Geologic Disposal Safety Assessment (GDSA) Framework

Board findings, observations, and recommendations, and DOE responses:

1. The Board finds that DOE has a technically valid approach to developing its geologic disposal safety assessment capability that will enable it to evaluate the post-closure performance of potential SNF and HLW repositories in different host rocks and with different disposal options. DOE is competently carrying out the development of the GDSA Framework and is making great progress in this effort while recognizing some of the challenges.

The Board encourages DOE to continue its GDSA Framework development efforts.

DOE Response:

The DOE continues to work to ensure the geologic disposal safety assessment (GDSA) capability is applicable to disposal in a variety of host rocks and includes the features, events, and processes most relevant to the generic research and development program. GDSA Framework development leverages high-performance computing to enable process model integration, simulation of 3-D geometries, and probabilistic uncertainty and sensitivity analyses. Ongoing development will continue to implement new capabilities, address challenges, and respond to advances in understanding and methods.

2. The Board finds that DOE needs to more clearly define and articulate the near-term goals and applications of the GDSA Framework in order to better prioritize what needs to be incorporated into the software framework at different stages of the repository program.

The Board recommends that DOE define a clear strategy and intended outcome for the use of the GDSA Framework in the near term and systematically apply it to a broad suite of reference cases.

DOE Response:

The DOE SFWST Campaign endeavors continuously to improve the transparency and clarity regarding the goals for the GDSA Framework as applied to advancing the GDSA capabilities defined in detail (Mariner et al., 2021) and at higher level (Sassani et al., 2021). The SFWST Campaign is centered on developing the technical bases for, and the GDSA capabilities to represent, multiple generic repository concepts in various geologic systems. The primary focus is on expanding the process capabilities relevant to each of the generic concepts. The implementation into GDSA of added model complexity is managed in the GDSA Framework (Mariner et al., 2021 Section 3.1), as is the development of the Next Generation Workflow (Mariner et al., 2021 Section 3.2) that is

used to construct and execute the application of GDSA to reference cases and allows workflow automation and management of the GDSA analyses (i.e., Reference Cases). Such capabilities development is essential for all potential generic repository concepts and is a higher priority focus because of that broad applicability. Drawing conclusions about the relative performance of generic disposal concepts at this point is premature given the nature of such generic reference cases in this conceptual stage, which is focused on demonstrating the GDSA capabilities. The program has been, and plans to continue, using the GDSA Framework for developing Reference Cases for generic disposal concepts with a range of source inventories, and included features, events, and processes.

References:

Mariner et al., 2021, GDSA Framework Development and Process Model Integration FY2021, M2SF-21SN010304053, SAND2021-12626 R, Sandia National Laboratories, Albuquerque, NM.

Sassani et al., 2021, SFWST Disposal Research R&D 5-Year Plan – FY2021 Update, M2SF-21SN010304054, SAND2021-12491 R, Sandia National Laboratories, Albuquerque, NM.

3. The Board finds that the GDSA Framework currently does not have an adequate capability to assess the performance of engineered barriers, which may be necessary for evaluating engineered barrier capability and different disposal options.

The Board recommends that DOE expedite the development of the GDSA Framework such that it has sufficient capability to assess the performance of different engineered barriers. This capability is needed to assess different disposal options and to apply the GDSA Framework systematically to a broad suite of reference cases. The Board notes that in developing this capability, DOE also needs to take account of near-field processes that could affect the performance of engineered barriers.

DOE Response:

As presented by Sassani in the NWTRB Fall 2020 Board Virtual Meeting (December 2, 2020), the SFWST Campaign is in the very early stages of a generic repository program, that potentially may transition to another program (if appropriate congressional actions occur) that includes siting processes. Until that program exists, the focus of the current program is on developing technical bases and capabilities that apply to generic repository concepts, without assessing site-specific constraints for any of these. This broad approach creates planning and prioritization challenges associated with addressing process-level constraints and system-level analytical capabilities for multiple disparate geologic systems, as well as the variety of generic engineered barriers for each of those.

Given the extensive list of potential materials, processes, and generic repository configuration combinations, the SFWST Campaign leverages the work being conducted in international programs for their specific sites to inform the technical bases (data sets, process models, parameter values) for the primary identified engineered barrier system

(EBS) materials and potential configurations. This information is being used to identify and integrate the most relevant barriers into our generic repository concepts in our Reference Cases. However, additional process level R&D is also focused on developing capabilities to model/analyze the barriers at conditions potentially relevant only to the US program (e.g., higher temperatures) and to incorporate such aspects appropriately into the GDSA Reference Case (e.g., see section 3.1.3 of Mariner et al., 2021).

The SFWST work prioritizes the engineered barriers that are most common in multiple generic repository concepts, such as bentonite backfill. For example, there are process-level studies that incorporate data from international URL testing to develop models for evolution of bentonite that address a range of thermal conditions and near-field chemical evolution in both argillite and crystalline systems. These would be used to modify GDSA models of bentonite buffer behavior as appropriate for barrier capability evolution in future updates of those reference cases. In the international programs, specific engineered barrier designs for outer barriers of waste packages are developed and evaluated relative to their site-specific conditions and that data set provides clear starting points for engineered barriers for SFWST generic repository concepts.

Evaluation of design details of waste containers was included in the Roadmap Prioritization activity (DOE, 2012) and provided that "…specific design concepts and site environments are ultimately needed to evaluate waste container performance within the context of a fully coupled engineered barrier system." As such, the SFWST campaign priority (Sevougian et al., 2019) is to mine the literature data/models to constrain degradation rates, degradation products, and corrosion processes for container materials identified from prior studies to inform GDSA representation of failure processes/rates for waste packages (e.g., Sec. 3.1.3, Mariner et al., 2021). Further R&D on detailed engineered barrier design/evaluation/selection would likely occur within a program in the site-selection stage, so the SFWST focus is on incorporating important barrier capabilities into the GDSA Framework (e.g., variable timing for waste package failures) such that appropriate analyses are possible in such a future program.

References:

Mariner et al., 2021, GDSA Framework Development and Process Model Integration FY2021, M2SF-21SN010304053, SAND2021-12626 R, Sandia National Laboratories, Albuquerque, NM.

DOE, 2012, "Used Fuel Disposition Campaign Disposal Research and Development Roadmap", U.S. Department of Energy Used Fuel Disposition Campaign, FCR&D-USED-2011-000065 REV 1.

Sevougian, S. D., P. E. Mariner, L. A. Connolly, R. J. MacKinnon, R. D. Rogers, D. C. Dobson, and J. L. Prouty (2019). "DOE SFWST Campaign R&D Roadmap Update", Rev. 1. SAND2019-9033 R, July 22, 2019. Sandia National Laboratories, Albuquerque, New Mexico.

Sassani et al., 2021, SFWST Disposal Research R&D 5-Year Plan – FY2021 Update, M2SF-21SN010304054, SAND2021-12491 R, Sandia National Laboratories, Albuquerque, NM.

4. The Board finds that the development of the GDSA Framework can be improved by peer reviews by a broader spectrum of stakeholders.

The Board recommends that DOE solicit input on the development of the GDSA Framework from a broader spectrum of stakeholders, including the public and the regulator.

DOE Response:

The DOE agrees that peer review is important to development and credibility of the complex set of tools required for probabilistic performance assessment. The DOE's objective is to make the capabilities of GDSA Framework transparent and accessible to facilitate use by, and feedback from, external sources. To this end DOE has chosen open-source software as the building blocks of its framework and offers a variety of avenues for peer and public interaction with key components of GDSA Framework. GDSA team members publish and present at national and international public venues, lead and participate in international collaborations, and offer PFLOTRAN short courses frequently.

Since 2017, DOE has offered 8 PFLOTRAN short courses; audiences have included the academic community, the national lab community, and the international repository science community. DOE (with the national laboratories) maintains public-facing documentation of GDSA Framework and its components (pa.sandia.gov) and publishes multiple publicly available reports each year. Currently, the generic research and development program is not connected to a process that includes site selection (during which community outreach and dialogue would be beneficial) nor to any site characterization process (during which the Nuclear Regulatory Commission (NRC) may be more active/engaged). Therefore, stakeholder engagement currently reflects the limited specificity of this disposal R&D program. The DOE does intend to continue to publish, present, and share its safety assessment capabilities and tools, and to develop GDSA Framework in such a way that these can be readily migrated to a future program that includes site selection and beyond. Additionally, DOE will offer to engage on this topic with the NRC, however this will be dependent upon the NRC's current interest and priorities.

5. The Board observes that, although DOE has applied its own quality assurance (QA) program, the GDSA Framework, PFLOTRAN, and DAKOTA codes have not been developed under a Nuclear Quality Assurance (NQA-1)[1] or equivalent QA program. Yet this will be an important requirement for any future submission of a license to the NRC for repository construction. The Board believes that qualifying the computer codes using

[1] ASME NQA-1-2019, "Quality Assurance Requirements for Nuclear Facility Applications," American Society of Mechanical Engineers, New York, NY.

an acceptable QA program will be more costly, challenging, and time consuming the longer the implementation of the QA program is delayed.

The Board notes that it would be appropriate for DOE to start an assessment of what needs to be done to have all the components of the GDSA Framework NQA-1 qualified (or equivalent). Moreover, it appears to the Board that the capabilities of the DAKOTA code are not being utilized in model calibration to determine the values and associated uncertainties of parameters that appear in various models.

DOE Response:

The DOE recognizes that quality assurance is an important component of model and software development. Currently the Spent Fuel and Waste Science and Technology (SFWST) Campaign works to the requirements of DOE Order 414.1. PFLOTRAN development is carried out using change and version control, rigorous review of new code, automated regression and unit testing, publication of an online users' manual and theory guide, and software verification testing. The DOE intends to expand software quality assurance activities in the near-term to include a more complete suite of documentation compatible with potential future programs within an NQA-1 quality assurance environment. Such expansion includes additional documentation of software requirements and verification testing.

Currently, the development/documentation effort focuses on PFLOTRAN, the code in which the bulk of GDSA capability development occurs. As other purpose-built software matures, more complete documentation can be developed. Ultimately, any software quality assurance plan will be tied to facilitate potential transition for use in potential future, possibly externally regulated, programs.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
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December 14, 2022

Dr. Kathryn Huff
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Dr. Huff:

On behalf of the U.S. Nuclear Waste Technical Review Board (Board), I want to thank you and your staff, as well as the staff from the national laboratories, for supporting the Board's 2022 Summer Meeting, which was held on September 13–14, 2022, in Arlington, VA. The purpose of the meeting was to review information on the U.S. Department of Energy, Office of Nuclear Energy (DOE-NE) research and development (R&D) activities related to the geologic disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) in argillaceous host rocks[1] and R&D on clay-based engineered barriers. This letter presents the Board's findings, recommendations, and observations resulting from the meeting. The agenda, presentation materials, meeting transcript, and an archived recording of the webcast for the meeting are posted on the Board's website at https://www.nwtrb.gov/meetings/past-meetings/summer-2022-board-meeting---september-13-14-2022.

The Board also thanks the staff from DOE and the national laboratories for supporting a technical fact-finding meeting, which was held at Sandia National Laboratories on July 19, 2022. This fact-finding meeting enabled the Board to prepare for the Summer 2022 public meeting.

Background

Over the past several years, DOE has been conducting R&D activities related to the potential geologic disposal of SNF and HLW in several alternative host rock types, including argillaceous host rock formations. These argillaceous formations are considered to have properties beneficial to waste isolation, including low porosity and permeability, geochemically reducing conditions, capability to self-seal fractures, and the presence of minerals that strongly sorb some radionuclides. DOE also has been conducting R&D on clay-based engineered barriers, e.g., bentonite buffer and backfill, that are being considered for use in both argillaceous and

[1] Argillaceous rocks are rocks composed of clay or having a notable portion of clay in their composition. Argillaceous rocks include shale, argillite, and claystone. Argillite refers to a compact rock derived from mudstone (claystone or siltstone) or shale that has hardened via heat or pressure or introduction of a cementing material (American Geological Institute. 2011. *Glossary of Geology*, Fifth Edition, Revised, Alexandria, VA). DOE uses the terms clay, shale, and argillite for clay-bearing rock formations.

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crystalline host rock repository concepts.[2] These clay-based engineered barriers are intended to protect and isolate the waste canisters and to retain and retard radionuclides released from breached canisters. The objective of DOE's R&D activities is to develop models and generate experimental data for understanding and predicting the long-term performance of geologic repositories in argillaceous host rocks and that of clay-based engineered barriers. Although DOE presentations in previous Board meetings have touched upon some aspects of these R&D activities and the Board has commented on those in Board reports[3] or letters to DOE,[4,5] the September 2022 meeting was an opportunity for the Board to conduct a review focused on these efforts.[6]

At the meeting, the Board heard several presentations from the national laboratory researchers who are conducting the work for DOE. These presentations included an overview of R&D activities related to argillaceous host rocks and clay-based engineered barriers; details of the numerical models developed to assess the long-term integrity of argillaceous host rocks; information on numerical modeling and laboratory- and field-scale experiments that focus on understanding coupled processes in bentonite buffers at high temperatures; and details of how process-level models of argillaceous host rock and engineered barrier system behavior are integrated into the Geologic Disposal Safety Assessment Framework, which is used for performance assessment calculations.

The Board also heard presentations by Dr. Maria Victoria Villar, a research scientist at the Center for Energy, Environmental and Technological Research (CIEMAT) in Madrid, Spain, and by Dr. Chris Neuzil (U.S. Geological Survey, retired), a hydrogeologist with four decades of research experience on argillaceous rocks. Dr. Villar described laboratory studies focused on understanding coupled processes in clay-based engineered barriers and the technical challenges related to laboratory experiments at high temperatures. Dr. Neuzil discussed the technical issues related to characterizing argillaceous formations and the key technical gaps that need to be addressed to better understand behavior of argillaceous formations at dimensions comparable to those of a repository. Dr. Neuzil's presentation included issues such as validity of traditional Darcy's Law for a low-permeability medium like clay or bentonite and the need to better understand fluid pressure anomalies (e.g., due to glacial loading and unloading) that can occur over repository time scales (e.g., up to a million years).

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[2] Sassani, D. et al. 2021. SFWST Disposal Research R&D 5 Year Plan – FY2021 Update. SAND2021-12491 R. Albuquerque, New Mexico: Sandia National Laboratories. August.

[3] NWTRB. 2020. *Filling the Gaps: The Critical Role of Underground Research Laboratories in the U.S. Department of Energy Geologic Disposal Research and Development Program*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. January. https://www.nwtrb.gov/docs/default-source/reports/nwtrb-url-report.pdf?sfvrsn=9. (Accessed on December 8, 2022)

[4] Bahr, J.M. 2021. Board letter to Dr. Kathryn Huff with comments from December 2020 Board meeting (December 30, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb028.pdf?sfvrsn=4. (Accessed December 8, 2022)

[5] Bahr, J.M. 2022. Board letter to Dr. Kathryn Huff with comments from November 2021 Board meeting (January 7, 2022). https://www.nwtrb.gov/docs/default-source/correspondence/jmb039.pdf?sfvrsn=4. (Accessed December 8, 2022)

[6] Processes that may impact the performance of clay-based engineered barriers in crystalline host rocks, such as buffer erosion and colloid generation and transport, were outside the scope of the meeting.

Board Findings, Recommendations, and Observations

After discussing and examining the information presented at the meeting and supporting DOE reports, the Board has several observations, findings, and recommendations that are provided below. The Board notes that the meeting presentations were informative and addressed many of the questions the Board posed in the meeting agenda.

Technically valid R&D approach

As mentioned above, DOE's R&D activities seek to develop models and generate experimental data that can be used to predict the long-term performance of geologic repositories in argillaceous host rocks and that of clay-based engineered barriers. DOE's R&D activities have particular focus on understanding the host rock and engineered barrier behavior at high temperatures, which are conditions unique to the U.S. geologic disposal program.[7] The Board notes that DOE is using state-of-the-art modeling approaches and methods of analysis for evaluating and predicting long-term repository performance. The Board recognizes the technical challenges DOE faces related to field and laboratory studies needed to support and validate numerical models, but is encouraged by ongoing DOE efforts to collaborate with and leverage experience from disposal programs in other countries.

> *The Board finds that DOE has a technically valid approach to developing its modeling capability that will enable it to evaluate the post-closure performance of a potential SNF and HLW repository in an argillaceous host rock.*
>
> *The Board encourages DOE to continue its R&D efforts related to argillaceous host rocks and clay-based engineered barriers, including leveraging the experience of disposal programs in other countries.*

Need for self-assessment of DOE R&D progress

DOE has been conducting R&D activities related to argillaceous host rocks and clay-based engineered barriers since 2010. These activities include developing conceptual and numerical models, conducting laboratory- and field-scale experiments, and participating in international collaborative R&D programs. The technical accomplishments of these R&D activities were presented to the Board during its fact-finding and public meetings. However, the Board notes that some speakers, particularly those providing overview presentations, did not clearly articulate the knowledge gaps and how the results of R&D activities contributed to improving DOE's understanding of barrier capability and long-term repository performance. DOE reports relevant to argillaceous host rocks and clay-based engineered barriers provide detailed descriptions of the technical progress made in each R&D task, any updates to DOE's R&D priorities, and the

[7] The inventory of U.S. commercial SNF may be disposed of in large waste packages holding more than twice as much SNF, hence higher heat load, as any other country (Hardin, E. et al. 2012. *Repository Reference Disposal Concepts and Thermal Load Management Analysis*. U.S. Department of Energy, Office of Used Nuclear Fuel Disposition. FCRDUFD-2012-00219 Rev. 2; Hardin E. et al. 2015. "Investigations of Dual-Purpose Canister Direct Disposal Feasibility – 15106." WM2015 Conference, March 15–19, 2015, Phoenix, Arizona).

technical gaps that were being addressed. [8,9,10] However, these reports, as well as the presentations at the Board meeting, do not provide information on the progress of each R&D task toward meeting the R&D program objectives or addressing the technical gaps, how the R&D has improved the understanding of processes, and how the R&D has contributed to the development of DOE's modeling capability and to the evolution of DOE's argillite reference case. Documenting progress to achieving objectives or addressing gaps, especially for those R&D tasks that did not achieve the objectives or provided unexpected results, will preserve the institutional knowledge, and serve as a useful resource for future researchers, as well as provide a basis for communicating DOE's progress on its disposal R&D portfolio.[11] Moreover, by not clearly identifying whether the work conducted addressed a technical gap, DOE may be less able to focus its resources on remaining technical gaps.

> *The Board finds that DOE has not clearly articulated the progress of its R&D activities related to argillaceous host rocks and clay-based engineered barriers toward achieving its program objectives and addressing the technical gaps.*
>
> *The Board recommends that DOE assess the overall progress of its R&D activities relative to achieving the stated objectives and addressing the identified technical gaps and how each R&D task contributed to understanding processes in the natural and engineered barrier systems and to developing DOE's argillite reference case. This self-assessment could also serve as a tool for knowledge management and for clear and effective communication on its disposal options, including disposal in argillaceous rocks. Ongoing and future assessments could help refine the focus of DOE's R&D activities documented in the disposal R&D 5-year plan.*

Public and stakeholder engagement

The Board previously had recommended that DOE "take account of lessons learned in other countries about listening to and informing the public, in order to improve communications, better understand community perspectives, and avoid unnecessary delays" in moving the national waste program forward.[12] The Board expanded on that recommendation in its review of DOE's

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[8] Jové Colón, C.F et al. 2021. *Evaluation of Nuclear Spent Fuel Disposal in Clay-Bearing Rock – Process Model Development and Experimental Studies*. M2SF-21SN010301072. Albuquerque, NM: Sandia National Laboratories. August.

[9] Matteo, E.N. et al. 2021. *Evaluation of Engineered Barrier Systems FY21 Report*. M2SF-20SN010308043. Albuquerque, NM: Sandia National Laboratories. November.

[10] Sassani, D. et al. 2021. *SFWST Disposal Research R&D 5 Year Plan – FY2021 Update*. SAND2021-12491 R. Albuquerque, New Mexico: Sandia National Laboratories. August.

[11] Bahr, J.M. 2021. Board letter to Dr. Kathryn Huff with comments from December 2020 Board meeting (December 30, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb028.pdf?sfvrsn=6. (Accessed December 8, 2022)

[12] NWTRB. 2021. *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. April. https://www.nwtrb.gov/docs/default-source/reports/nwtrb-six-recommendations-report.pdf?sfvrsn=20. (Accessed on December 8, 2022)

disposal R&D program[13] and in its recent feedback on DOE's current efforts to employ a consent-based approach to siting federal consolidated interim storage facilities.[14] Given that DOE's vision for an integrated waste management system[15] includes facilities for interim storage and disposal, it would be beneficial for the insights and lessons learned from the consent-based siting process related to interim storage facilities to be fully integrated into DOE's current and future disposal program. Key topics could include fostering public and stakeholder engagement, risk communication and better understanding of community perspectives. The Board notes that several technical and programmatic issues related to both sets of activities are closely linked[16] and that better integration would be beneficial to both programs, especially as DOE considers its existing waste management strategy[17] and develops a draft integrated waste management program plan.

> *The Board finds insufficient integration between DOE activities related to consent-based siting of federal consolidated interim storage facilities and those related to geologic disposal.*
>
> *The Board recommends integration of DOE activities related to consent-based siting of federal consolidated interim storage facilities and those related to geologic disposal to enable effective public and stakeholder engagement.*

The Board had also previously recommended that DOE consider "compiling best practices, innovative approaches, and notable successes and failures in public outreach, engagement, and risk communication from the experiences of URL programs in other countries."[18] The Board commends DOE for already exploring how underground research laboratories (URLs) can play an important role in attracting and training the next generation of waste disposal scientists and engineers. Having a well-developed professional workforce will be vital to any future waste disposal program. The Board is encouraged by innovative programs such as the Next-Gen

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[13] Bahr, J.M. 2021. Board letter to Dr. Kathryn Huff with comments from December 2020 Board meeting (December 30, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb028.pdf?sfvrsn=6. (Accessed December 8, 2022)

[14] Bahr, J.M. 2022. Board letter to Dr. Kathryn Huff with comments from March 2022 Board meeting (June 7, 2022). https://www.nwtrb.gov/docs/default-source/correspondence/jmb041.pdf?sfvrsn=4. (Accessed December 8, 2022)

[15] DOE. "Integrated Waste Management" https://www.energy.gov/ne/consent-based-siting/integrated-waste-management. (Accessed on December 8, 2022).

[16] Bahr, J.M. 2021. Board letter to Dr. Kathryn Huff with comments from July 2020 Board meeting (January 11, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb026.pdf?sfvrsn=8. (Accessed on December 8, 2022)

[17] DOE. 2013. *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Waste*. January. https://www.energy.gov/sites/prod/files/Strategy%20for%20the%20Management%20and%20Disposal%20of%20Used%20Nuclear%20Fuel%20and%20High%20Level%20Radioactive%20Waste.pdf. (Accessed on December 8, 2022)

[18] NWTRB. 2020. *Filling the Gaps: The Critical Role of Underground Research Laboratories in the U.S. Department of Energy Geologic Disposal Research and Development Program*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. January. https://www.nwtrb.gov/docs/default-source/reports/nwtrb-url-report.pdf?sfvrsn=9. (Accessed on December 8, 2022)

Nuclear Waste Disposal Internship program,[19] but notes that, so far, projects in this program are limited to laboratory or modeling studies and do not yet include URL experiences.

Based also on international experience, it is apparent that URLs and other facilities (e.g., Waste Isolation Pilot Plant) can play an important role in public information, outreach, and engagement efforts. Providing the public opportunities to observe aspects of a waste program first-hand can facilitate communication with the public and enhance its understanding of nuclear waste issues in a way that websites, lectures, printed materials, and other means often cannot. With DOE's current efforts on a consent-based siting process for federal consolidated interim storage facilities, it is worth again emphasizing the potential role of URLs and other facilities in public outreach, communication, and information. DOE can, for example, evaluate whether the use of existing facilities, such as the Waste Isolation Pilot Plant, can be broadened without impacting their primary missions.[20]

> *The Board commends DOE for recognizing the importance of URLs in training the next generation of scientists and engineers.*
>
> *The Board recommends that DOE further consider how URLs and other DOE facilities could play a role in public information and community engagement efforts and in training programs. As DOE proceeds with its consent-based siting process for federal consolidated interim storage facilities, systematic consideration should be given to how URLs and other facilities might contribute. This should include systematically reviewing and learning from the experiences by other countries.*

Impact of bentonite buffer on repository performance

DOE's near-term R&D activities include understanding coupled thermal, hydrologic, mechanical, and chemical processes that may affect engineered barrier system performance. A focus of these R&D efforts is on understanding bentonite behavior when subjected to high temperatures.[21] In DOE's reference disposal concept for a repository in an argillite host rock, a bentonite buffer surrounds the waste package. DOE has used the Geologic Disposal Safety Assessment Framework to assess repository performance for this argillite reference case. The Board notes that DOE has not evaluated repository performance for alternative scenarios, for example, scenarios wherein the bentonite buffer is either absent or is replaced with a buffer made of crushed host rock. Analysis of these alternative scenarios can help clarify the relative importance of the bentonite buffer on repository performance in argillaceous rocks (e.g., if and by how much it reduces the dose to the receptor). The Board acknowledges that DOE's disposal

[19] Lawrence Berkeley National Laboratory. "Next-Gen Nuclear Waste Disposal Internship." https://sites.google.com/lbl.gov/eesa-student-opportunities/nextgen-nuclear-waste-disposal-internship. (Accessed on December 8, 2022)

[20] NWTRB. 2020. Filling the Gaps: The Critical Role of Underground Research Laboratories in the U.S. Department of Energy Geologic Disposal Research and Development Program. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. January. https://www.nwtrb.gov/docs/default-source/reports/nwtrb-url-report.pdf?sfvrsn=9. (Accessed on December 8, 2022)

[21] Sassani, D. et al. 2021. *SFWST Disposal Research R&D 5 Year Plan – FY2021 Update*. SAND2021-12491 R. Albuquerque, New Mexico: Sandia National Laboratories. August.

R&D program is in the early stages and that detailed analysis and evaluation of engineered barriers will be performed in the future.

> *The Board finds that additional analysis is required to clarify the relative importance of the bentonite buffer on the performance of a repository in an argillaceous host rock.*
>
> *The Board recommends that DOE assess the performance of argillite repositories with no buffer or with a crushed host rock buffer.*

Observations related to numerical models

Several DOE numerical models of groundwater flow in argillite host rock and bentonite buffer use equations based on the traditional Darcy's law. In his presentation, Dr. Neuzil discussed the potential inadequacy of Darcy's law, when applied to a low-permeability medium like clay or bentonite. The Board notes that DOE previously developed additional models to represent non-Darcian flow in both argillites and bentonite buffers.[22,23] The Board suggests that DOE clearly articulate the technical basis for the assumptions made in its numerical models for flow in the bentonite buffer and argillite host rock. DOE is planning to update features, events, and processes for generic repositories and the Board suggests that the applicability of Darcy's Law to low permeability media like argillites and bentonite buffers be evaluated as a part of this update.

Observations related to laboratory and field experiments

The presentations at the meeting indicated that several DOE R&D tasks involve developing numerical models and using data from laboratory- and field-scale experiments to quantify input and/or validate the models. The Board notes that direct interactions between numerical modelers and experimentalists can help (1) identify any changes that may be needed in the design or data collection method (e.g., frequency of collection or type of data collected) during the conduct of the experiment; (2) better explain measured data and/or model predictions that may seem counterintuitive; and (3) advance fundamental understanding of the processes that significantly impact barrier capabilities. The Board encourages DOE to consider incorporating frequent and ongoing interactions between modelers and experimentalists in its current and future tasks. The Board commends DOE's participation in the HotBENT Modeling platform[24] that provides this type of interaction.

Several presenters at the meeting (e.g., Neuzil, Rutqvist, Zheng) noted the challenges associated with monitoring and characterizing low permeability media like argillites. One of the challenges is accounting for uncertainties that can be quantified, such as errors associated with sensor measurements. The Board observes that DOE has not provided information on these quantifiable uncertainties (i.e., epistemic uncertainties) in DOE reports or presentations, especially when

[22] Liu, H.-H. and J. Birkholzer (2012). *On the relationship between water flux and hydraulic gradient for unsaturated and saturated clay*. Journal of Hydrology Vol. 475, pp. 242-247.

[23] Zheng, L. et al. 2015. *Investigation of Coupled Processes and Impact of High Temperature Limits in Argillite Rock*. United States. FCRD-UFD-2015-000362. LBNL-187644. Lawrence Berkeley National Laboratory. Berkeley. CA. July.

[24] Matteo, E.N. et al. 2021. *Evaluation of Engineered Barrier Systems FY21 Report*. M2SF-20SN010308043. Albuquerque, NM: Sandia National Laboratories. August.

comparing model predictions with laboratory and field data. The Board suggests that DOE include comparable information in its reports and presentations, if available, to better illustrate the capabilities and limitations of the numerical models. The Board acknowledges that, in some cases, the uncertainty and variability of the natural system may be significantly greater than such quantifiable uncertainties.

Thank you again, on behalf of the Board, for the participation of DOE-NE staff and technical experts from the national laboratories at our November meeting. We look forward to continuing our ongoing review of DOE's technical activities related to managing and disposing of SNF and HLW.

Sincerely,

{signed by}

Jean M. Bahr
Chair

cc: Dr. Kimberly Petry, DOE-NE
Dr. William Boyle, DOE-NE
Mr. Timothy Gunter, DOE-NE

Department of Energy
Washington, DC 20585
July 5, 2023

Dr. Nathan Siu
Chair
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Suite 1300
Arlington, VA 22201-3367

Dear Dr. Siu,

The U.S. Department of Energy's (DOE) Office of Nuclear Energy (NE) appreciates your letter of June 7th, 2022, which summarized the Nuclear Waste Technical Review Board's 2022 Winter Meeting. In that virtual meeting, held on March 1-2, 2022, information was presented by DOE and national laboratory participants on DOE's research and development (R&D) activities related to storage, transportation, and disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW). In the area of integrated waste management, DOE and supporting participants presented information on the development of decision-support tools used to assist in developing and managing an integrated waste management system. DOE also provided the Board with an update on efforts to develop a consent-based approach for siting one or more federal consolidated interim storage facilities for SNF.

The Board's letter provided observations, findings, and recommendations on these DOE activities. DOE appreciates the Board's input to our program and looks forward to its future insights on DOE's activities related to the management and disposal of SNF and HLW.

The enclosure provides the DOE's responses to the Board's specific findings and recommendations. If you have any questions on these responses, please contact Timothy Gunter (NE-81) at timothy.gunter@nuclear.energy.gov or Erica Bickford (NE-82) at erica.bickford@nuclear.energy.gov.

Sincerely,

Kathryn Huff
Assistant Secretary
For Nuclear Energy

Enclosure

U.S. Department of Energy (DOE) Response to the Nuclear Waste Technical Review Board (NWTRB) Report from the NWTRB 2022 Winter Meeting

NWTRB findings and recommendations, and DOE responses:

1. The Board finds that additional analyses and quantitative information regarding the potential pros and cons of the DPC direct disposal option will be useful to decision-makers.

To provide decision-makers with information about the pros and cons of direct disposal of DPCs versus repackaging of SNF assemblies currently in DPCs, the Board recommends that DOE complete quantitative assessments for both concepts spanning the waste management lifecycle. These assessments should include estimates of costs and radiation doses related to packaging (or repackaging) of SNF, transportation, interim storage, and repository operations, including the ramifications of disposal in alternative geological media.

DOE Response:

DOE agrees that the recommended assessments would be useful to decision makers and will consider these in the future. However, current activities are focused on whether direct disposal of dual-purpose canisters (DPCs) is even technically feasible. Additionally, these types of assessments would require much more detailed repository design information, all of which does not currently exist.

Some information has been developed. With regard to costs, SAND2019-6999 Rev 1 provides a quantitative comparison of life cycle costs for a single assumed repository type (a Yucca Mountain-like repository) for various options, including direct disposal and repackaging. A Yucca Mountain-like repository was chosen because the total system life cycle cost (TSLCC) (DOE 2008) provided reliable cost estimates for that specific repository design. There is insufficient information available for comparable size spent nuclear fuel (SNF)/high-level radioactive waste (HLW) repositories in other geologic media in the U.S., and extrapolation from international cost estimates and designs would not provide as reliable comparisons as is provided by the TSLCC cost information.

Regarding dose, SAND2022-15262PE (Slide 5) provides an estimate of collective worker dose from repackaging – ~250 mrem/canister for a wet handling facility and 220-393 mrem/canister for a dry handling facility, based on Weck (2013). For context, 10 CFR 63 limits worker dose to 5 rem/year. More detailed life cycle dose estimates would require more specific design information.

References:

DOE (US Department of Energy) 2008. *Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program, Fiscal Year 2007*. DOE/RW-0591. U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, DC.

Freeze, G., E.J. Bonano, E.A. Kalinina, J. Meacham, L. Price, P.N. Swift, A. Alsaed, D.A. Beckman, and P.G. Meacham 2019. *Comparative Cost Analysis of Spent Nuclear Fuel Management Alternatives*. SAND2019-6999 Revision 1. Sandia National Laboratories, Albuquerque, NM.

Freeze, G. 2022. *Dual-Purpose Canister (DPC) Direct Disposal – Operations, Engineering, and Thermal Management*. SAND2022-15262PE. Presented at EPRI ESCP Winter 2022 Meeting Direct Disposal Workshop, Charlotte, NC, November 7, 2022.

Weck, P.F. 2013. "Worker exposure for at-reactor management of spent nuclear fuel", *Radiation Protection Dosimetry, Vol. 156, No. 3*, pp. 386–393.

2. The Board finds that DOE has not yet provided evidence for making this conclusion [that DOE still believes that pressurized water reactor (PWR) data for high-burnup fuels bound boiling water reactor (BWR) behavior].

The Board recommends that DOE either demonstrate that existing data and modeling regarding the behavior of high burnup PWR SNF bound the behavior of BWR and ATF SNF and SNF containing IFBAs or complete the necessary testing and modeling for these fuel types.

DOE Response:

The DOE Spent Fuel and Waste Science and Technology (SFWST) Storage and Transportation R&D program is exploring options to obtain data to confirm that high burn-up (HBU) PWR behavior bounds HBU BWR behavior, accident tolerant fuel (ATF) SNF, and SNF containing integral fuel burnable absorbers (IFBAs). We are participating in the Studsvik Cladding Integrity Project (SCIP) IV program with a goal to obtain BWR data, as well as IFBA data. We are also considering obtaining HBU BWR SNF to perform testing in Oak Ridge National Laboratory (ORNL) hot cells. Additionally, we are collaborating within DOE's ATF program to plan future testing of ATF SNF within ORNL and/or Pacific Northwest National Laboratory (PNNL) hot cells.

3. The Board finds that DOE has not fully considered whether a different localized corrosion mechanism such as crevice corrosion could be a precursor process for initiation of CISCC in addition to pitting corrosion.

As DOE continues to develop the two full-scale canister demonstrations, the Board recommends that DOE consider whether localized corrosion such as crevice corrosion could be a precursor to CISCC and determine how that precursor mechanism could be assessed in the field demonstrations.

DOE Response:

The main goal of the full-scale canister demonstrations is to gain realistic data on deposition of dust on canister surfaces. However, DOE plans to incorporate a rack of material samples to evaluate corrosion near the canisters during the full-scale demonstrations. During the full-scale demonstrations, areas of the canister that might be candidates for crevice corrosion (e.g., contact with the rails) will not be

accessible for inspection. However, DOE plans to be able to evaluate the canisters for corrosion after the completion of the tests. Additionally, DOE will continue lab-scale testing to evaluate localized corrosion mechanisms.

4. As DOE conducts R&D to support its consequence assessment of canister failure, the Board recommends that DOE complete refinements that it has described for its aerosol transmission experiments, including conducting some experiments using a single effect approach to facilitate easier model development, validation, and interpretation of results. In the near-term, DOE should clearly define the events and processes that affect aerosol generation within a sealed cask that can lead to potential aerosol transmission when a crack forms to subsequently guide the R&D needed to realistically assess the consequence of a canister failure.

DOE Response:

DOE agrees that continuing refinements of aerosol transmission experiments, including conducting some experiments using a single effect approach to facilitate easier model development, validation, and interpretation, is important. Because of the importance of R&D to realistically assess the consequence of canister failure, DOE is funding such R&D at several National Laboratories and universities. Work is being done to better define events and processes that affect aerosol generation within a sealed cask, such as gathering spent fuel rod aerosol release data from the sibling pins project, and refining estimates of internal canister conditions, such as the amount of water remaining after drying and the subsequent effects on cladding degradation. Given the understanding of hypothetical aerosol releases into the canister interior developed from previous testing, additional SFWST R&D is being pursued to better define fuel-to-canister release fractions from fuel cladding failure. Complementary modeling of aerosol deposition inside dry storage systems is also ongoing and will be used to delineate internal aerosol sources and to evaluate potential aerosol release mechanisms.

5. The Board finds that there is value in expanding NGSAM capabilities and analyses to more completely address possible integrated waste management systems options and in renewing the development of MOEF as a part of understanding and addressing stakeholder objectives in support of consent-based-siting activities.

The Board recommends that DOE expand NGSAM capabilities and analyses to better address disposal of DPCs, including waste packaging operations and cost requirements, and that it include stakeholders involved in the consent-based siting process to inform NGSAM development and use.

DOE Response:

DOE fiscal year 2023 plans include applying the Next Generation System Analysis Model (NGSAM) capabilities towards analyzing scenarios involving direct disposal of DPCs, including analysis of cost and waste packaging considerations. DOE also plans to take into account stakeholder input received through the consent-based siting process to inform development and use of its system analysis tools and,

in turn, apply system analysis results to inform consent-based siting. We see this as an iterative process that facilitates communication and understanding between DOE and its external stakeholders.

6. The Board finds that there are additional opportunities for developing and using START as a training tool and to improve outreach using the knowledge bases of other agencies.

The Board recommends that DOE consider how START might be utilized as a resource to familiarize and train emergency response personnel for nuclear waste transport and as a component in tabletop exercises aimed at exploring emergency scenarios. Likewise, the Board recommends that DOE engage with other agencies involved in similar transportation efforts to leverage their experiences and approaches to stakeholder interactions and addressing hazards.

DOE Response:

DOE has spent the past 4 years working on migrating the Stakeholder Tool for Assessing Radioactive Transportation (START) to a new cloud server hosting platform at DOE headquarters that can better support expanded features and functions. Now that that migration is complete, the DOE Office of Integrated Waste Management (IWM) is returning to a backlog of planned updates to features and functions, as well as providing training opportunities. As part of the server migration, START is undergoing security testing that could allow for the removal of its official use only designation and enable START to be accessed by a wider audience of approved users. IWM staff hosted the first post-migration START training opportunity at the American Nuclear Society's International High-Level Radioactive Waste Management Conference in November 2022 and provided trainings for the Tribal Radioactive Materials Transportation Committee and the Council of State Governments Midwestern Radioactive Materials Transportation Committee in spring 2023.

IWM routinely engages with other radioactive material shipping programs to integrate lessons learned and best practices and to inform DOE's approaches to transport operations, public outreach, and emergency response training for future DOE shipments of SNF. IWM staff have spoken with program staff from the Office of Environmental Management's Waste Isolation Pilot Plant (WIPP) program about coordinating future training along any overlapping shipping corridors to avoid concentrating training resources in some areas while leaving gaps in others. START includes up-to-date data (updated every 6 months) on locations of personnel trained through DOE's Transportation Emergency Preparedness Program (TEPP). By overlaying transportation route layers with TEPP-trained responder layers, areas that may need additional training resources can be readily identified. IWM staff have also coordinated with personnel from the Naval Nuclear Propulsion Program on rail transportation operations and attended multiple Navy SNF transportation training exercises, which IWM plans to use as a model for future DOE SNF shipment training exercises. IWM is also considering proposing joint training exercises with both programs once DOE is closer to shipping. As a first step in coordination with those programs, IWM has added current highway shipping routes for WIPP and rail shipping routes for Navy SNF as layers in START. In the future, once DOE shipping routes begin to be identified, START can be used to see where there is overlap between DOE SNF shipping corridors and other shipping corridors and identify potential locations for joint training exercises. The START team also has plans to incorporate additional first responder information into START – expanding on the TEPP-trained personnel

information layer to include Tribal, State, and local personnel trained through other programs, using Federal Emergency Management Agency (FEMA) data for a more comprehensive understanding of where trained personnel are located or where additional training is needed. The START team also plans to look at including Tribal emergency operation center information to expand on Tribal readiness information.

7. The Board finds that there are additional actions that DOE could take to meet its stated commitments, learn from domestic siting experiences and from siting processes in other nations, and strengthen its overall consent-based siting effort.

Although the Board applauds DOE for undertaking significant consent-based siting activities, the Board recommends that DOE significantly strengthen and improve its efforts. A larger and broader range of participants should be engaged, and expanded efforts to include historically underrepresented communities should be undertaken. DOE should also make systematic use of the large body of scientific and technical literature in such fields as the social/behavioral sciences and the public health sciences. By informing all consent-based siting efforts with relevant outside scientific/technical knowledge and expertise on risk communication, risk perception, effective outreach, inclusiveness, and public engagement, DOE can identify ways to engage a broader range of participants, better understand public views and concerns, and improve the overall effectiveness and face validity of its consent-based siting work. The Board also recommends that DOE produce a candid "lessons learned" document on its deep borehole demonstration siting effort and review key lessons that have been learned from siting processes in other nations.

DOE Response:

The DOE consent-based siting process builds upon best practices from domestic and international siting cases, and DOE is continuing to examine how domestic and international siting experiences and/or collaborations can be used to support successful advancement of consent-based siting in the US. This includes lessons learned from DOE's siting efforts for the Deep Borehole Field Test from 2015 to 2017. Additionally, DOE leverages international collaboration by participating in many international forums and technical meetings, engaging in bi-lateral collaborations and discussions to exchange information, sharing best practices, and identifying areas for more in-depth collaboration.

To reach a broader range of participants, DOE has issued a $26 million funding opportunity to provide resources for communities interested in learning more about consent-based siting, management of spent nuclear fuel, and interim storage facility siting considerations. The award recipients will help DOE to advance mutual learning, provide ease of access to information, foster mutual understanding, and lay the foundations for wider-reaching community participation and engagement. The awardees will also help to reduce barriers to participation by providing grants to community organizations and partners. Additionally, DOE is expanding its strategy to develop relationships and build trust with historically underrepresented communities. For example, work is underway to fund partnerships with Tribal-serving Institutions, Historically Black Colleges and Universities, and a Hispanic Serving Institution.
The Department has conducted extensive literature reviews to understand and implement the rich and diverse social/behavioral science literature from a range of fields and disciplines, with recommendations

developed from this research to aide DOE's process design, engagement practices, and communication strategies. Additionally, DOE has hired social scientists with subject matter expertise in these fields who are implementing and operationalizing lessons learned from the scientific literature. Finally, in addition to the analysis of the 225 responses to the 2021 *Request for Information on Using a Consent-Based Siting Process to Identify Federal Interim Storage Facilities (86 FR 68244)* (see *Consent-Based Siting Request for Information Comment Summary and Analysis*), DOE is conducting wide-ranging research to better understand public perceptions and concerns, including analyses of national surveys, traditional media, social media, citizen science, and information gathering from diverse groups.

Department of Energy
Washington, DC 20585
August 21, 2023

Dr. Nathan Siu
Chair
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
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Dear Dr. Siu,

The U.S. Department of Energy's (DOE) Office of Nuclear Energy appreciates your letter of December 14th, 2022, which summarized the Nuclear Waste Technical Review Board's 2022 Summer Meeting. In that meeting, held on September 13-14, 2022 in Arlington, Virgina, information was presented by DOE and national laboratory participants on DOE's research and development (R&D) activities related to the geologic disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) in argillaceous host rocks and R&D on clay-based engineered barriers.

The Board's letter provided findings and recommendations on these DOE's activities. DOE appreciates the Board's input to our program and looks forward to its future insights on DOE's activities related to the management and disposal of SNF and HLW.

The enclosure provides the DOE's responses to the Board's specific findings and recommendations. If you have any questions on the responses, please contact Timothy Gunter at timothy.gunter@nuclear.energy.gov.

Sincerely,

Kathryn Huff
Assistant Secretary
For Nuclear Energy

Enclosure

U.S. Department of Energy (DOE) Response to the Nuclear Waste Technical Review Board (NWTRB) Report from the NWTRB 2022 Summer Meeting

NWTRB findings and recommendations, and DOE responses:

Board Comment #1:

The Board finds that DOE has a technically valid approach to developing its modeling capability that will enable it to evaluate the post-closure performance of a potential SNF and HLW repository in an argillaceous host rock.

The Board encourages DOE to continue its R&D efforts related to argillaceous host rocks and clay-based engineered barriers, including leveraging the experience of disposal programs in other countries.

DOE Response #1:

Investigations of deep geologic disposal in argillaceous host rocks, and clay-based engineered barriers, are fundamental components of the DOE Spent Fuel and Waste Science and Technology (SFWST) disposal research program and are planned to continue. These activities necessarily leverage the experience and expertise developed in international disposal research efforts. The SFWST R&D program, combined with international collaboration in related research areas, brings to bear a broad and multi-faceted range of expertise and experience to the DOE disposal research program.

Board Comment #2:

The Board finds that DOE has not clearly articulated the progress of its R&D activities related to argillaceous host rocks and clay-based engineered barriers toward achieving its program objectives and addressing the technical gaps.

The Board recommends that DOE assess the overall progress of its R&D activities relative to achieving the stated objectives and addressing the identified technical gaps and how each R&D task contributed to understanding processes in the natural and engineered barrier systems and to developing DOE's argillite reference case. This self-assessment could also serve as a tool for knowledge management and for clear and effective communication on its disposal options, including disposal in argillaceous rocks. Ongoing and future assessments could help refine the focus of DOE's R&D activities documented in the disposal R&D 5-year plan.

DOE Response #2:

Since the end of fiscal year 2022, a concerted effort has been made to more clearly articulate progress made, significance of activities undertaken, outstanding technical challenges, and prospective work in major SFWST work package milestone reports. Going forward, major milestone reports will contain a more detailed Executive Summary section that includes an Executive Summary abstract. This abstract will describe the importance of the corresponding work, accomplishments for the most recent year, key

findings of the work, and future R&D activities envisioned for both the near and far-term. For milestones with limited scope, the abstract may be the entire Executive Summary. For milestones with extensive scope and/or results, the body of the Executive Summary will cover further details of the work executed and results accomplished. The development and rollout of the milestone report abstract in the Executive Summary is due to a request from DOE-NE leadership that such a detailed abstract be included in major milestone report deliverables. It also results in part from a comment from the NWTRB at the July 2022 fact-finding meeting at Sandia National Laboratories. It is the intention of the DOE that progress, importance, key findings, and prospective work are more readily apparent by the inclusion of the Executive Summary abstract in major milestone report deliverables.

The detailed summaries will be useful when research priorities, and associated resource allocations, are developed and assessed each year, and will also form a basis for the progress in control accounts reported in updates to the Disposal Research 5-year Plan. Having concise summaries of R&D activities, challenges, accomplishments, and potential future work will further enable the assessment of program progress and the development of practical research goals for the near and far-term. These aspects are expected to prove useful, particularly for activities supporting disposal research in argillaceous rocks and clay-based engineered barriers.

Board Comment #3:

The Board finds insufficient integration between DOE activities related to consent-based siting of federal consolidated interim storage facilities and those related to geologic disposal.

The Board recommends integration of DOE activities related to consent-based siting of federal consolidated interim storage facilities and those related to geologic disposal to enable effective public and stakeholder engagement.

DOE Response #3:

The work being done in DOE's Disposal R&D program assumes that a geologic disposal facility is an integral part of any waste management program, supports the future use of a consent-based siting approach for future siting of a geologic disposal facility, and communicates about the ongoing R&D activities in Disposal Research. The DOE Disposal R&D program focuses on generic disposal concepts and the technical bases and constraints of these generic repository concepts to develop the tools for evaluating the post-closure safety of such systems. The SFWST Storage and Transportation R&D program and the Disposal Research R&D program maintain awareness of activities focused on consent-based siting for consolidated interim storage, both in the U.S. program and in international nuclear waste management efforts. Activities supporting the International Collaborations Disposal Research work package aim to stay abreast of approaches and outcomes in other countries so that those lessons learned can be applied to the U.S. program.

DOE management and staff leads in the Office of Integrated Waste Management (which includes Consent-Based Siting) and the Office of Spent Fuel and Waste Science and Technology (including Storage, Transportation and Disposal R&D) meet weekly or more often to maintain awareness and integrate activities between the two offices. DOE and SFWST staff are considering how consent-based siting could be adapted for siting deep geologic repositories in the future. However, because Congress has not authorized DOE to pursue consent-based siting for disposal, the primary focus currently remains on federal consolidated interim storage.

Board Comment #4:

The Board commends DOE for recognizing the importance of URLs in training the next generation of scientists and engineers.

The Board recommends that DOE further consider how URLs and other DOE facilities could play a role in public information and community engagement efforts and in training programs. As DOE proceeds with its consent-based siting process for federal consolidated interim storage facilities, systematic consideration should be given to how URLs and other facilities might contribute. This should include systematically reviewing and learning from the experiences by other countries.

DOE Response #4:

The use and leveraging of Underground Research Laboratories (URLs), both internationally and at the U.S. Waste Isolation Pilot Plant (WIPP) (a geologic disposal facility for transuranic defense waste), are fundamental aspects of the U.S. geologic disposal R&D program. DOE utilizes the WIPP facility for public outreach activities, such as tours of the site and the underground, although this can only be done in a limited fashion because site visits must be scheduled around WIPP operations. This results in somewhat limited opportunity for visits to the site by the public. But as an example, the Fall 2022 DECOVALEX (DEvelopment of COupled models and their VALidation against EXperiments) workshop held in Albuquerque, New Mexico, included a site visit to the WIPP site with a tour of the underground.

To evaluate the potential uses of a U.S. URL for geologic disposal R&D, as well as for public outreach, a new 2023 SFWST disposal research work package has been established to investigate the range of issues related to establishing a new U.S. URL. There are two components of this work package. The first component, led by Sandia National Laboratories, will evaluate the potential of a generic URL for the U.S. waste disposal program. This evaluation will include an assessment of the resource needs in establishing a URL, its maintenance requirements and operating costs once established, as well as optimal development timing for the facility within the disposal program evolution paradigm. Such a URL, located in the U.S., could prove advantageous for public outreach, communication, and information sharing.

The second component of the new URL work package, led by Lawrence Berkley National Laboratory, will consist of a detailed review of international collaborative activities in existing URLs. Although the U.S. is currently participating in numerous international URL activities throughout the world, this review will evaluate the involvement in additional URL testing and modeling activities. It will also consider primary disposal R&D benefits and associated costs, as well as ancillary benefits such as public outreach, of such additional activities.

Board Comment #5:

The Board finds that additional analysis is required to clarify the relative importance of the bentonite buffer on the performance of a repository in an argillaceous host rock.

The Board recommends that DOE assess the performance of argillite repositories with no buffer or with a crushed host rock buffer.

DOE Response #5:

Several performance assessment (PA) activities under the Geologic Disposal Safety Assessment (GDSA) framework are focused on developing a set of sensitivity analyses and virtual tracers that can be used to help quantify the performance contributions for specific Features, Events, and Processes (FEPs). GDSA evaluations could be done to quantify the performance contribution of a range of backfill/buffer materials, including crushed host rock, with respect to peak annual dose. However, because the answer would also depend to a large extent on the site-specific properties of the host rocks, with self-healing clays likely having less reliance on the bentonite buffer than a fractured brittle argillite formation, the Board's recommended assessment would be more relevant at a point where the program moves into a focus on specific sites. The primary objectives of PA development to date have been 1) adding capabilities to the PFLOTRAN model so that more FEPs are included in reference cases, 2) developing the reference cases to simulate nominal repository designs, 3) developing methods and techniques for including and propagating uncertainty in models, 4) developing sensitivity analyses for specific input parameters, and 5) performance quantification associated with specific FEPs, such as waste packages, waste forms, buffer, repository, geosphere, dispersion, decay, etc. The SFWST program is adjusting how FEPs for each generic repository concept are integrated with the R&D control accounts, defining the technical bases for each concept such that additional analyses of barrier function/reliance would be facilitated.

Board Comment #6:

The Board notes that DOE previously developed additional models to represent non-Darcian flow in both argillites and bentonite buffers. The Board suggests that DOE clearly articulate the technical basis for the assumptions made in its numerical models for flow in the bentonite buffer and argillite host rock. DOE is planning to update features, events, and processes for generic repositories and the Board suggests that the applicability of Darcy's Law to low permeability media like argillites and bentonite buffers be evaluated as a part of this update.

DOE Response #6:

Recent GDSA activities have supported the development of two reduced-order models in PFLOTRAN aimed at investigating the impact of fluid/rock interactions beyond traditional Darcy-law modeling. The two reduced-order models aim to represent the impact of bentonite swelling on disturbed rock zone permeability and rock-material dependent permeability for rocks that transform type (e.g., smectite to illite). Temperature-dependent capillary pressure and relative-permeability functions have also been implemented in PFLOTRAN. However, these have not yet been widely utilized in PA reference cases as their implementations are quite recent and there is significant additional computational overhead

associated with them for tightly coupled systems. An assessment of the applicability and suitability of Darcy's Law to low permeability media is a priority of PFLOTRAN FEPs analysis activities.

GDSA activities for the argillite case have been focused on the development of sensitivity analysis and uncertainty quantification for geological parameters, waste package degradation, and waste package breach time distribution.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
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August 24, 2023

Dr. Kathryn Huff
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Dr. Huff:

The U.S. Nuclear Waste Technical Review Board (Board) is charged with evaluating the technical and scientific validity of activities undertaken by the U.S. Department of Energy (DOE) in implementing the Nuclear Waste Policy Act and with reporting its findings, conclusions, and recommendations related to the management and disposition of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) to Congress and the Secretary of Energy. In discharging these responsibilities, the Board holds public meetings two or three times each year and then, offers its feedback to DOE in writing. This letter provides the Board's feedback on the topics discussed during the Spring 2023 Board Meeting, which was held on March 28, 2023, in Orlando, Florida.

On behalf of the Board, I want to thank you and your staff, as well as the staff from the national laboratories, for supporting the Spring 2023 Board Meeting. The Board especially appreciated your participation from Idaho at an early hour. The purpose of the meeting was to review information regarding the DOE, Office of Nuclear Energy (DOE-NE) activities to evaluate the future removal of commercial SNF from nuclear power plant sites. Other topics included the activities of the DOE-NE Office of Integrated Waste Management (IWM) related to a consent-based siting (CBS) process supporting the development of one or more federal interim storage facilities, as well as updates on transportation research and development (R&D) including site infrastructure evaluations, systems analysis tools, and railcar development. The agenda, presentation materials, meeting transcript, and an archived recording of the webcast for the meeting are posted on the Board's website at https://www.nwtrb.gov/meetings/past-meetings/winter-2022-board-meeting---march-28-2023.

The Board also thanks the staff from DOE and the national laboratories for supporting a technical fact-finding meeting, which was held at the DOE offices in Washington, D.C., on February 9, 2023. This fact-finding meeting enabled the Board to better prepare for the Spring 2023 public meeting.

Background

Over the past several years, DOE has been conducting R&D to enable storage, transportation, and eventual disposal of SNF and HLW from existing and future nuclear fuel cycles and to support planning for an IWM system. The DOE Office of IWM has sponsored the development

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of new railcars for transporting commercial SNF, and has implemented systems analysis tools, such as the Used Nuclear Fuel-Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS) tool and the Next Generation Systems Analysis Model, which support evaluation of different alternatives for an IWM system. The Office of IWM has also proposed, but not yet received funding for, a full-sized rail cask test known as the Package Performance Study as a means of demonstrating to the public the robustness of such rail casks and gathering technical data related to validating package performance.

DOE recently re-initiated efforts to use a CBS approach to support the development of one or more federal interim storage facilities for commercial SNF. Part of this effort includes providing funding to states, Tribes, and local communities to facilitate information exchange and mutual learning between DOE and interested parties. Regarding Tribal outreach, DOE has actively sponsored and engaged Tribes through various working groups such as the National Transportation Stakeholders' Forum (NTSF), the Nuclear Energy Tribal Working Group (NETWG), and the Tribal Radioactive Materials Transportation Committee (TRMTC).

DOE's transportation R&D activities include conducting site infrastructure evaluations for operating nuclear power plant sites and shutdown nuclear power plant sites, as well as sponsoring initial de-inventory reports for selected sites.[1] The site infrastructure evaluations have been conducted by a team of researchers at Pacific Northwest National Laboratory (PNNL) since 2012. The initial site-specific de-inventory reports have been produced by contractor Areva, now Orano USA (and sometimes, in partnership with other contractors), since 2015. These reports build upon the information provided by the PNNL team and include a multi-attribute utility analysis (MUA) as the basis for evaluating transportation modes and routes for removal of SNF from each site. These reports are intended to present a contractor's first look at operational details and recommendations for SNF handling and transportation, but do not necessarily represent DOE agreement with the recommended operations.

Summary of the Spring 2023 Board Meeting

Prior to the Board's public meeting, members of the Board and staff along with some DOE staff and contractors, toured the SNF storage facility at the shutdown Crystal River Nuclear Plant site. DOE has already completed a site evaluation for the Crystal River site and released an initial de-inventory report this year.[2]

The first portion of the Board's meeting included an overview of the activities of the DOE Office of IWM. DOE updated the Board on the IWM system transportation R&D activities, including the proposal for a Package Performance Study. DOE staff members also described their efforts to use a CBS process for one or more federal interim storage facilities. Next, DOE described the activities to evaluate the future removal of commercial SNF from nuclear power plant sites.

[1] Eleven initial site-specific de-inventory reports are available at: Initial Site-Specific De-Inventory Reports | CURIE (pnnl.gov) (last accessed 8/24/2023).

[2] Orano Federal Services LLC, 2023. *Initial Site-Specific De-Inventory Report for Crystal River*, Report No: RPT-3022488-001.

During the second half of the meeting, representatives from three Tribal nations provided their perspectives on DOE's transportation and CBS efforts. They noted the support provided by DOE to maintain several Tribal working groups (described above) and they stated their appreciation for the opportunity to engage with DOE. Regarding the path forward on IWM, the Tribal representatives discussed what they perceive to be the key challenges for future transportation of commercial SNF, meaningful engagement during DOE's CBS activities, and developing adequate emergency preparedness and response programs.

National laboratory staff then presented DOE-sponsored analyses of as-loaded commercial SNF canisters using the UNF-ST&DARDS tool, including a comparison of the analysis results with the regulatory limits in the Certificate of Compliance (CoC) for transportation for different SNF canister systems. DOE also provided updates and the path forward for the Atlas and Fortis railcar projects. The Board appreciates the thorough presentations given by DOE as well as the detailed responses to questions throughout the public meeting.

The final presentation of the meeting was from a representative of the U.S. Nuclear Regulatory Commission (NRC), who presented key takeaways from NRC's 2021 transportation readiness review.[3] NRC's work focused on transportation of commercial SNF by commercial entities (i.e., not DOE) to one or more NRC-licensed consolidated interim storage facilities, which are not federal interim storage facilities. The NRC effort identified information needs and recommended enhancements for SNF transportation, provided roadmaps of the roles and responsibilities of various federal agencies for transportation of commercial SNF from existing to new storage facilities, and highlighted differences between commercial and DOE transportation of commercial SNF.[4]

Board Conclusions, Findings, and Recommendations

Based on the information presented at the public meeting, the fact-finding meeting, and in related technical reports, the Board developed several findings, conclusions, and recommendations on DOE's IWM program, transportation R&D activities, and CBS program. The Board also developed observations on topics that may be outside of DOE's control but impact how DOE implements its activities. The Board's findings, conclusions, and recommendations follow. The enclosure provides more background and details regarding the meeting topics, and again presents the Board's findings, conclusions, and recommendations.

[3] U.S. Nuclear Regulatory Commission (NRC), 2021. "NRC's Regulatory Readiness for Oversight of Large-Scale Commercial Transportation of Spent Nuclear Fuel." October 22, available at: https://www.nrc.gov/docs/ML2129/ML21298A164.pdf (last accessed 8/24/2023).

[4] The Nuclear Waste Policy Act (NWPA) established requirements, in section 180, for DOE-directed shipments of SNF and HLW to a repository or a monitored retrievable storage facility (the federal facility equivalent to a commercial consolidated interim storage facility). This includes advance shipment notifications and financial support for training to the states and Tribes through whose jurisdictions DOE plans to transport SNF and HLW. Those NWPA conditions do not apply to commercial transportation of SNF to a commercial (privately-owned) consolidated interim storage facility.

IWM Program Overview and Future Priorities

Finding 1a: The Board finds that DOE is making progress in its IWM program, particularly in three major cross-cutting areas: (i) transportation preparations, (ii) storage design and regulatory considerations, and (iii) systems analysis tools and integration. The Board recognizes that DOE activities related to CBS of a federal interim storage facility are in the early stages of a multi-year effort.

Finding 1b: The Board finds that incorporating public feedback in the early development of a Package Performance Study is important; the Board previously encouraged DOE to engage early with stakeholders in developing a plan.[5] To date, DOE has obtained limited feedback from a few groups, but has not yet received broad public feedback on its proposal for a Package Performance Study.

Recommendation 1: If DOE pursues a Package Performance Study, the Board recommends that DOE first determine what the public's major safety concerns are, how public participants would like to be involved, and how meeting this goal can be integrated with regulatory testing goals. This will better enable DOE to identify the key issues to be addressed and to set clear outcomes for any demonstration. Further, planning for the demonstration should include a strategy for effective communication of test goals, expectations, and results to the public, and for a post-demonstration assessment of how well the test met its goals.

DOE's State and Tribal Engagement

The Board commends DOE for continuing to work closely with Tribes, and finds that the Office of IWM emphasis on making Tribal government engagement a priority is a positive step for CBS efforts. The Board also commends DOE for working to identify practical steps to enhance full participation, including efforts to engage with Tribes through its NTSF section 180(c) ad hoc working group, and with Tribal governments through NETWG and TRMTC.

The Board commends DOE for looking into developing metrics (i.e., ways to measure and evaluate Tribal engagement and progress) to assess or track the extent to which such efforts have been successful, as each Tribal government is independent and will be facing a variety of situations that are unique to its Tribe. The Board looks forward to seeing more detailed information about such metrics at future Board meetings.

The Board observes that some Tribes may lack adequate resources for emergency preparedness and response programs, which could hamper the Tribes' ability to support DOE activities to plan for future SNF transportation. However, as noted above, the Board recognizes DOE for its ongoing preparedness work with the Tribes, primarily through its renewed efforts relative to section 180(c) of the Nuclear Waste Policy Act. The Board believes that, through Tribal

[5] Bahr, J.M. 2022. Board letter to Dr. Kathryn Huff with comments from March 2022 Board meeting (June 7, 2022), available at: https://www.nwtrb.gov/docs/default-source/correspondence/jmb041.pdf?sfvrsn=4 (last accessed 8/24/2023).

engagement, DOE can help Tribes plan for the necessary emergency preparedness and response, technical expertise, and capabilities.

DOE's Evaluation of the Future Removal of Commercial SNF from Nuclear Power Plant Sites

The Board observes that DOE has used the initial site-specific de-inventory reports (supported by the MUAs) during early engagement with Tribal, state, and local representatives on the possible modes and routes for SNF transportation from each site. These engagements appear to be a useful starting point for DOE's planning for future SNF transportation. As DOE's IWM system matures, the Board expects that DOE decision makers and external stakeholders will be involved in further, more detailed discussions about preferred modes and routes of SNF transportation from each site. The Board notes that these discussions can be enhanced by considering lessons from analogous situations (e.g., shipments of low-level radioactive waste), revisiting the weighting of attributes (potentially going beyond pairwise comparisons in some cases) in each MUA, and addressing uncertainties in the MUAs.

Finding 2: The Board finds that the DOE-sponsored site evaluations provide a good opportunity for DOE to meet with onsite staff and discuss technical details, including SNF condition, anomalies, and canister loading maps.

Recommendation 2: During future site infrastructure evaluation visits, the Board recommends that DOE engage with site personnel and cask vendors regarding the NRC-approved transportation CoCs that apply to SNF in dry storage and assess whether the stored SNF will meet the requirements in the NRC-approved transportation CoCs. Site personnel and cask vendors who know the specific SNF contents for each storage canister and the approved contents for the transportation cask could potentially identify whether amendments or exemptions to the transportation CoCs will be needed prior to transportation.

As-Loaded Analyses to Determine Transportability of Commercial SNF Canisters

The Board commends DOE for sponsoring the as-loaded analyses needed to understand which commercial SNF canisters can meet the requirements of the corresponding transportation CoCs and which cannot, without an amendment or exemption to the NRC-approved CoC.

The Board observes that access to UNF-ST&DARDS would be valuable to the nuclear industry for analyses of SNF canisters for loading, storage, and transportation scenarios.

Finding 3: The Board finds that DOE can enhance its IWM system planning by engaging early with the NRC regarding the need for amendments or exemptions to the transportation CoCs for SNF canisters that do not currently meet the CoC requirements.

Recommendation 3: The Board recommends that DOE work with the NRC to identify the number and scope (including potential technical challenges) of amendments or exemptions to transportation CoCs that will be needed to allow the transportation of the affected SNF canisters.

Finding 4: The Board finds that there may be some technical difficulties with meeting the 10 CFR Part 72 requirements for SNF storage following the transportation of SNF, governed by 10 CFR Part 71. For example, 10 CFR Part 72 requires the licensee to demonstrate that the SNF cladding can meet its intended confinement function before placing the SNF into dry storage; but it is unclear how the licensee will demonstrate adherence to this requirement for SNF inside a welded canister.

Recommendation 4: The Board recommends that DOE expand its engagement with the NRC to understand the technical difficulties with respect to meeting the 10 CFR Part 72 requirements for storage following the transport of commercial SNF, subject to 10 CFR Part 71 requirements. Recognizing that the issues could be different and unique for each specific SNF cask loading and for each cask or canister design, this action should commence well in advance of starting a large-scale transportation campaign, such as one that DOE may start in support of a new federal interim storage facility.

Thank you again, on behalf of the Board, for the participation of DOE-NE staff and technical experts from the national laboratories at our February fact-finding meeting and our subsequent public meeting in March. In closing, the Board looks forward to hearing more about CBS and the CBS planning process in the upcoming Summer Board meeting. We look forward to continuing our ongoing review of DOE's activities related to managing and disposing of SNF and HLW.

Sincerely,

{signed by}

Nathan Siu
Chair

Enclosure

cc: Dr. Kimberly Petry, DOE-NE
Dr. Erica Bickford, DOE-NE

Enclosure

March 2023 Board Meeting Summary and
Board Findings, Conclusions, and Recommendations

This enclosure summarizes the public meeting presentations, provides background and details regarding the meeting topics, and presents the Board's findings, conclusions, and recommendations. [Topics addressed have underlined text, **Board findings and conclusions are presented in bold text,** and *Board recommendations are presented in italicized text*.]

U.S. Department of Energy (DOE) Integrated Waste Management (IWM) Program Overview and Future Priorities

Regarding the IWM program, DOE presented information that shows progress is being made in several activities that support key future decision-making on transportation planning for removing commercial spent nuclear fuel (SNF) from nuclear power plant sites. DOE has completed several infrastructure evaluation reports, which help identify options for transporting SNF and greater-than-Class-C low-level waste from nuclear power plant sites. DOE has published initial site-specific de-inventory reports,[6] which provide information that may be useful for planning the future removal of SNF from specific sites. Also, DOE has completed the development of the 12-axle Atlas railcar, which will undergo multi-car testing with the buffer railcar and the rail escort vehicle this year. The 8-axle Fortis railcar has been designed and is being fabricated. DOE is also developing plans for a Package Performance Study, which, if funded, would involve a full-sized rail cask package test, with the goals of building public trust and confidence in the safety of SNF transportation casks and SNF transportation by rail and gathering data to validate computer models. In addition, DOE has made progress in developing design functions and requirements, as well as reference design concepts for a federal interim storage facility for commercial SNF. DOE has developed data management and systems analysis tools, including Stakeholder Tool for Assessing Radioactive Transportation, Next Generation Systems Analysis Model, Used Nuclear Fuel Storage, Transportation & Disposal Analysis Resource and Data Systems (UNF-ST&DARDS), and Performance Assessment of Strategy Options. These tools are being used to inform DOE's planning and decision-making related to an IWM system for SNF and high-level radioactive waste (HLW).

As a part of DOE's transportation-related efforts and based on the recommendations by the National Academy of Sciences (NAS)[7] and the Blue Ribbon Commission (BRC),[8] the Office of IWM is proposing to conduct a Package Performance Study. According to DOE, actual testing

[6] Eleven initial site-specific de-inventory reports are available at: Initial Site-Specific De-Inventory Reports | CURIE (pnnl.gov) (last accessed 8/24/2023).

[7] *Going the Distance?: The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States*, 2006, available at: https://nap.nationalacademies.org/catalog/11538/going-the-distance-the-safe-transport-of-spent-nuclear-fuel (last accessed 8/24/2023).

[8] *Blue Ribbon Commission on America's Nuclear Future: Report to the Secretary of Energy*, 2012, available at: https://www.osti.gov/servlets/purl/1133851 (last accessed 8/24/2023).

will depend on funding availability, which has been requested for fiscal year 2024. Also, DOE is planning to invite the U.S. Nuclear Regulatory Commission (NRC) to collaborate in this effort.

In 1999, the NRC began, but did not complete a project also referred to as the Package Performance Study. The NRC's study had an enhanced public participatory process that was used to collect public comment, including comments on the draft testing protocols.[9] One of the main purposes of the NRC project was to demonstrate the inherent safety of SNF package design with public outreach constituting a significant element. Work on the NRC Package Performance Study ceased because of the high cost and because the proposed Yucca Mountain repository project had been halted. DOE stated that the Package Performance Study it is considering would include non-regulatory tests (e.g., train collision, waterbody retrieval demonstration, etc.) in addition to regulatory tests (e.g., impact onto unyielding surfaces).

In the NAS report, the authors provided a critical assessment of package performance with respect to the information from the NRC's public outreach work related to NRC's Package Performance Study and the package performance standards developed by the International Atomic Energy Agency. The authors stated that "… package performance under severe accident conditions is a major concern for transportation safety among many members of the public, especially those who live and work along shipping routes. Finding a way to resolve this issue continues to be a challenge to regulators in the United States and may eventually become a challenge for DOE and the private sector in their commercial spent fuel transportation programs." The NAS report contains technical findings and recommendations on the type of full-scale testing that it endorsed, which involved both regulatory and credible "extraregulatory" conditions.[10] One of the report's principal findings and recommendations on package performance is reproduced below:

> "[NAS] Finding: The committee strongly endorses the use of full-scale testing to determine how packages will perform under both regulatory and credible extraregulatory conditions. Package testing in the United States and many other countries is carried out using good engineering practices that combine state-of-the-art structural analyses and physical tests to demonstrate containment effectiveness. Full-scale testing is a very effective tool both for guiding and validating analytical engineering models of package performance and for demonstrating the compliance of package designs with performance requirements. However, deliberate full-scale testing of packages to destruction through the application of forces that substantially exceed credible accident conditions would be marginally informative and is not justified given the considerable costs for package acquisitions that such testing would require."
>
> "[NAS] Recommendation: Full-scale package testing should continue to be used as part of integrated analytical, computer simulation, scale-model, and testing programs to

[9] See *Package Performance Study: Developments Since PATRAM13*, available at: https://inis.iaea.org/collection/NCLCollectionStore/_Public/37/088/37088721.pdf?r=1 (last accessed 8/24/2023) and *Full-Scale Accident Testing in Support of Used Nuclear Fuel Transportation*, 2014, SAND2014-17831, available at: http://large.stanford.edu/courses/2017/ph241/watson2/docs/sand2014-17831r.pdf (last accessed 8/24/2023).

[10] Extraregulatory conditions refer to accidents that impose thermal or mechanical loads on transportation packages that are different from those generated in the hypothetical accident conditions specified in 10 CFR Part 71.

validate package performance. Deliberate full-scale testing of packages to destruction should not be required as part of this integrated analysis or for compliance demonstrations."

In the BRC's report, one of the recommendations for transportation that specifically refers to a Package Performance Study is reproduced below:

> [BRC Recommendation] "DOE and other federal agencies should reexamine and address those recommendations from the 2006 NAS *Going the Distance?* Study that have not yet been implemented. As part of this reexamination, the NRC should reassess its plans for the Package Performance Study without regard to the status of the Yucca Mountain project, and if it is found to have independent value, funding should be provided from the Nuclear Waste Fund so that the NRC can update these plans and proceed with those tests."

A 2014 DOE-funded report,[11] which served as part of the re-examination recommended by the BRC and the reassessment requested by DOE, identified several important concepts. The authors noted that because full-scale testing is expensive, an evaluation of the added value of such testing on public perceptions and public acceptance is important. They stated that the first phase of a package performance study would need to determine the type of information and level of participation that the public desires in order for them to evaluate the safety of SNF transportation.

In 2018, the Western Interstate Energy Board, which represents eleven western states and two Canadian Provinces, published a Position Paper[12] encouraging DOE to conduct full-scale cask testing. The Position Paper recommends, among other things, that "[d]emonstration testing [i.e., extraregulatory testing] is acceptable only in conjunction with regulatory testing," and "[s]takeholders should be involved in the testing program."

The Board agrees with the views expressed in the 2014 report and the 2018 Position Paper. The Board notes that important aspects of a full-scale test that DOE will need to make clear in its early planning and in its communications with the public are 1) whether extraregulatory tests will be included and 2) the extent to which the results of testing of one package design apply to the performance of other package designs.

The Board is interested in hearing more about the updated CBS process and updated DOE strategy for managing nuclear waste, the IWM program plan, the status of DOE's critical decision process, the DOE's plans for interacting with awardees of the Funding Opportunity Announcement, and consideration of a Package Performance Study in the upcoming Summer 2023 Board meeting. For example, the Board is interested in understanding DOE's underlying principles, approaches, and requirements for its CBS process, with evidence to support their validity, and how DOE has charted its path forward to meet the requirements. The Board is also interested in hearing how states and Tribes will be addressed in DOE's CBS activities and

[11] *Full-Scale Accident Testing in Support of Used Nuclear Fuel Transportation*. SAND2014-17831, available at: http://large.stanford.edu/courses/2017/ph241/watson2/docs/sand2014-17831r.pdf (last accessed 8/24/2023).

[12] Western Interstate Energy Board. 2018. "*High-Level Radioactive Waste Committee Position Paper, Full-Scale Cask Testing, Number 2018-2*."

decision processes, including the relationship of the CBS activities to the requirements in the Nuclear Waste Policy Act (NWPA) for participation of states and Indian Tribes [see NWPA Section 141(h)]. How DOE will communicate the differences between the commercial and federal consolidated interim storage efforts for commercial SNF is another area the Board is interested in hearing about in the Summer 2023 Board meeting.

Finding 1a: The Board finds that DOE is making progress in its IWM program, particularly in three major cross-cutting areas: (i) transportation preparations, (ii) storage design and regulatory considerations, and (iii) systems analysis tools and integration. The Board recognizes that DOE activities related to CBS of a federal interim storage facility are in the early stages of a multi-year effort.

Finding 1b: The Board finds that incorporating public feedback in the early development of a Package Performance Study is important; the Board previously encouraged DOE to engage early with stakeholders in developing a plan.[13] To date, DOE has obtained limited feedback from a few groups, but has not yet received broad public feedback on its early plans for a Package Performance Study.

Recommendation 1: If DOE pursues a Package Performance Study, the Board recommends that DOE first determine what the public's major safety concerns are, how public participants would like to be involved, and how meeting this goal can be integrated with regulatory testing goals. This will better enable DOE to identify the key issues to be addressed and to set clear outcomes for any demonstration. Further, planning for the demonstration should include a strategy for effective communication of test goals, expectations, and results to the public, and for a post-demonstration assessment of how well the test met its goals.

DOE's State and Tribal Engagement

In addition to the technical side of planning the CBS process, the Board heard about a parallel track for DOE's CBS plans that involves re-invigorating public engagement. DOE described the expertise of new staff and how the Office of IWM has been reorganized. One staff team, the CBS team, will focus on socio-political and socio-technical issues associated with CBS and the other, the Cross-Cutting Initiatives team, will focus more on technical issues. One point that DOE emphasized in discussing its CBS process is the idea of creating a "level playing field" (in terms of knowledge, to allow for willing and informed decisions) for those communities that are interested in the CBS process.

Section 180(c) of the NWPA states "The Secretary [of Energy] shall provide technical assistance and funds to States for training for public safety officials of appropriate units of local government and Indian tribes through whose jurisdiction the Secretary plans to transport spent nuclear fuel or high-level radioactive waste [to a NWPA-authorized facility]. Training shall cover procedures required for safe routine transportation of these materials, as well as procedures for dealing with emergency response situations." The Board notes that DOE has actively sponsored and engaged Tribes through various working groups such as the National

[13] Bahr, J.M. 2022. Board letter to Dr. Kathryn Huff with comments from March 2022 Board meeting (June 7, 2022), available at: https://www.nwtrb.gov/docs/default-source/correspondence/jmb041.pdf?sfvrsn=4 (last accessed 8/24/2023).

Transportation Stakeholders' Forum (NTSF), the Nuclear Energy Tribal Working Group (NETWG), and the Tribal Radioactive Materials Transportation Committee (TRMTC). DOE's efforts to engage states and Tribes on issues related to section 180(c) are relevant to efforts DOE may take with states, Tribes, and communities in its CBS effort. Understanding how DOE will implement a program that meets the requirements of section 180(c) is likely to be an important consideration for communities and Tribes that are participating, or contemplating participating, in the CBS process.

The Board looks forward to hearing more about how DOE will ensure greater Tribal and stakeholder engagement in its CBS process during the upcoming Summer 2023 Board meeting.

The Board commends DOE for continuing to work closely with Tribes, and finds that the Office of IWM emphasis on making Tribal government engagement a priority is a positive step for CBS efforts. The Board also commends DOE for working to identify practical steps to enhance full participation, including efforts to engage with Tribes through its NTSF section 180(c) ad hoc working group, and with Tribal governments through NETWG and TRMTC.

The Board commends DOE for looking into developing metrics (i.e., ways to measure and evaluate Tribal engagement and progress) to assess or track the extent to which such efforts have been successful, as each Tribal government is independent and will be facing a variety of situations that are unique to its Tribe. The Board looks forward to seeing more detailed information about such metrics at future Board meetings.

The Board observes that some Tribes may lack adequate resources for emergency preparedness and response programs, which could hamper the Tribes' ability to support DOE activities to plan for future SNF transportation. However, as noted above, the Board recognizes DOE for its ongoing preparedness work with the Tribes, primarily through its renewed efforts relative to section 180(c) of the Nuclear Waste Policy Act. The Board believes that, through Tribal engagement, DOE can help Tribes plan for the necessary emergency preparedness and response, technical expertise, and capabilities.

DOE's Evaluation of the Future Removal of Commercial SNF from Nuclear Power Plant Sites

DOE described its site infrastructure evaluations (sometimes called site evaluations), which have been conducted since 2012, and initial site-specific de-inventory reports, which have been conducted since 2015 at shutdown and operating nuclear power plants. For the site infrastructure evaluations, DOE contractors (led by PNNL) gathered data on site SNF inventories and the condition of on-site and nearby transportation infrastructure. The team identified information needs from each site (and continues to update the data) that could inform key future decisions for planning to remove commercial SNF from nuclear power plant sites. In many cases, it is envisioned that rail will be the primary mode of transportation for shipping commercial SNF. According to DOE, every site that has been evaluated so far has at least one option for mode of transportation (rail, heavy-haul truck, barge, etc.) for removing SNF. DOE noted that the infrastructure evaluations conducted by PNNL included input from site personnel, local Tribes/states, U.S. Department of Transportation, Federal Railroad Administration, and other stakeholders.

As part of the DOE-sponsored site evaluations, the PNNL team gathers available data on SNF types, SNF canister types and modifications, and other information that may affect the transportability of the SNF. Transportability can be determined by comparing the loaded SNF storage canister contents with the allowable contents listed in the corresponding transportation Certificate of Compliance (CoC). Learning from site personnel and cask vendors about which transportation cask CoCs may need to be amended or need an exemption to the NRC transportation regulation could enhance DOE's future planning and preparations for removing SNF from the sites.

DOE representatives explained how they are building on the information gathered during the site infrastructure evaluations by contracting with Orano USA to conduct more detailed assessments of needed infrastructure upgrades, equipment needs, time required, costs, etc. to remove commercial SNF from nuclear power plant sites. These assessments are documented in "initial site-specific de-inventory reports." The assessments are completed by experts in nuclear operations and SNF handling who make use of available documented information, without visiting the sites or consulting with site personnel or stakeholders. The intent of de-inventory reports is to obtain an expert opinion regarding "…the tasks, equipment, and interfaces necessary for the complete de-inventory of the [nuclear power plant site's] independent spent fuel storage installation (ISFSI)."[14] During the Board meeting, DOE noted that these reports are preliminary and represent the opinions of the contractor (not DOE), and that DOE expects to conduct new and updated assessments of the best approach for transporting SNF from nuclear power plant sites, when the timing for such transportation is closer at hand.

DOE also explained that Orano USA utilized multi-attribute utility analysis (MUA) as a key component of each de-inventory report. MUA is a well-established, general methodology for comparing different alternatives that may be considered in making a particular decision. The MUA process used by Orano USA employs an expert panel to identify attributes of each alternative, assign weighting factors to each attribute and then, compare the alternatives in a pairwise fashion. This was used to compare the pros and cons of the different modes and routes of SNF transportation away from each nuclear power plant site, culminating in Orano USA's recommendation for each site. For more details about how the MUA methodology was applied in support of the initial site-specific de-inventory reports, see Chapter 5 of any one of the reports (e.g., the report for Maine Yankee, listed in footnote 14).

The Board observes that DOE has used the initial site-specific de-inventory reports (supported by the MUAs) during early engagement with Tribal, state, and local representatives on the possible modes and routes for SNF transportation from each site. These engagements appear to be a useful starting point for DOE's planning for future SNF transportation. As DOE's IWM system matures, the Board expects that DOE decision makers and external stakeholders will be involved in further, more detailed discussions about preferred modes and routes of SNF transportation from each site. The Board notes that these discussions can be enhanced by considering lessons from analogous situations (e.g., shipments of low-level radioactive waste), revisiting the weighting of attributes

[14] AREVA Federal Services LLC, 2017. *Initial Site-Specific De-Inventory Report for Maine Yankee*, Report No.: RPT-3016127-002.

(potentially going beyond pairwise comparisons in some cases) in each MUA, and addressing uncertainties in the MUAs.

Finding 2: The Board finds that the DOE-sponsored site evaluations provide a good opportunity for DOE to meet with onsite staff and discuss technical details, including SNF condition, anomalies, and canister loading maps.

Recommendation 2: During future site infrastructure evaluation visits, the Board recommends that DOE engage with site personnel and cask vendors regarding the NRC-approved transportation CoCs that apply to SNF in dry storage and assess whether the stored SNF will meet the requirements in the NRC-approved transportation CoCs. Site personnel and cask vendors who know the specific SNF contents for each storage canister and the approved contents for the transportation cask could potentially identify whether amendments or exemptions to the transportation CoCs will be needed prior to transportation.

<u>As-Loaded Analyses to Determine Transportability of Commercial SNF Canisters using UNF-ST&DARDS</u>

DOE, through its national laboratories, has been using UNF-ST&DARDS—which provides an SNF database and integrated analysis tools—for assessing dose limits and criticality safety for as-loaded commercial SNF canisters. These analyses differ from the analyses conducted to support NRC approvals of SNF storage and transportation in that the former analyses use realistic (as-loaded) SNF parameters (e.g., initial loading of uranium, burnup, cooling time, axial power distribution) while the latter analyses use bounding (conservative) values for parameters that affect doses and criticality.

DOE initiated these new analyses in an effort to find a solution to known dose rate and criticality safety challenges regarding currently loaded canisters holding commercial SNF. For example, while these SNF canisters are approved by the NRC for safe and secure storage, some of the canisters are known to contain types of SNF that will not allow the canister to meet the dose rate or criticality safety requirements for transportation, as documented in the corresponding CoC for transportation (Clarity et al., 2017).[15]

A staff member at PNNL explained how UNF-ST&DARDS is being used to determine the number of SNF canisters at storage sites that cannot meet the transportation CoC requirements (the so-called "cannot ship list"), pursuant to Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), without NRC-approved amendments or exemptions to the CoCs. Particular CoC requirements that can be challenging for transportation are those for dose rates and criticality safety. Then, using realistic parameter values (rather than conservative bounding values) for commercial SNF as well as some assumptions about applying "burnup credit," PNNL presented several analyses demonstrating that many (but not all) of the affected SNF canisters can meet the dose rate and criticality safety requirements for transportation. These analyses would have to be

[15] Clarity, J.B., K. Banerjee, H.K. Liljenfeldt, W.J. Marshall. 2017. "As-Loaded Criticality Margin Assessment of Dual-Purpose Canisters Using UNF-ST&DARDS." *Nuclear Technology*, 199:3, 245–275, September 1.

formalized, submitted to the NRC as part of new CoC amendments, and then reviewed and approved by the NRC to allow transportation of the affected SNF canisters.

DOE representatives also described plans to conduct validation and uncertainty quantification work, as well as the path for commercialization of UNF-ST&DARDS. An important issue is the accuracy of the UNF-ST&DARDS base data and the derived parameters. Remaining data limitations (e.g., characteristics of damaged fuel and reactor side information) and analysis assumptions may limit the fidelity of the calculations performed to date. The Board plans to follow up with DOE on its efforts to verify and validate UNF-ST&DARDS.

As discussed by NRC in a previous Board meeting in June 2018,[16] there may be some technical difficulties with meeting the 10 CFR Part 72 requirements for SNF storage following the transportation of SNF, governed by 10 CFR Part 71. For example, 10 CFR 72.122(h)(1) requires the licensee to demonstrate that the SNF cladding can meet its intended confinement function (i.e., protected against gross rupture) before storage, and if not, the SNF must otherwise be confined (e.g., be placed inside a can for damaged fuel). In practice, it is unclear how the licensee will demonstrate adherence to this requirement when the SNF arrives at a new storage site following transportation (inside a welded canister).

In a future fact-finding meeting or public meeting, the Board looks forward to hearing more in-depth information on how data and information is being updated in DOE's various systems analysis and data integration tools, and how DOE's analysis results and preferences for SNF management strategies address and could be impacted by conditions other than the best-case (or near-best case) assumptions DOE often uses.

The Board commends DOE for sponsoring the as-loaded analyses needed to understand which commercial SNF canisters can meet the requirements of the corresponding transportation CoCs and which cannot, without an NRC-approved amendment or exemption to the CoC.

The Board observes that access to UNF-ST&DARDS would be valuable to the nuclear industry for analyses of SNF canisters for loading, storage, and transportation scenarios.

Finding 3: The Board finds that DOE can enhance its IWM system planning by engaging early with the NRC regarding the need for amendments or exemptions to the transportation CoCs for SNF canisters that do not currently meet the CoC requirements.

Recommendation 3: The Board recommends that DOE work with the NRC to identify the number and scope (including potential technical challenges) of amendments or exemptions to transportation CoCs that will be needed to allow the transportation of the affected SNF canisters.

Finding 4: The Board finds that there may be some technical difficulties with meeting the 10 CFR Part 72 requirements for SNF storage following the transportation of SNF,

[16] Darrell Dunn, NRC, presentation at June 13, 2018 public Board meeting, "NRC Perspective on a National Program to Transport Spent Nuclear Fuel and Radioactive Materials," available at: https://www.nwtrb.gov/docs/default-source/meetings/2018/june/dunn.pdf?sfvrsn=4 (last accessed 8/24/2023).

governed by 10 CFR Part 71. For example, 10 CFR Part 72 requires the licensee to demonstrate that the SNF cladding can meet its intended confinement function before placing the SNF into dry storage; but it is unclear how the licensee will demonstrate adherence to this requirement for SNF inside a welded canister.

Recommendation 4: The Board recommends that DOE expand its engagement with the NRC to understand the technical difficulties with respect to meeting the 10 CFR Part 72 requirements for storage following the transport of commercial SNF, subject to 10 CFR Part 71 requirements. Recognizing that the issues could be different and unique for each specific SNF cask loading and for each cask and canister design, this action should commence well in advance of starting a large-scale transportation campaign, such as one that DOE may start in support of a new federal interim storage facility.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

April 24, 2024

The Honorable Patricia Murray
Chair
Subcommittee on Energy and Water Development
Committee on Appropriations
United States Senate
Washington, DC 20510

The Honorable John N. Kennedy
Ranking Member
Subcommittee on Energy and Water Development
Committee on Appropriations
United States Senate
Washington, DC 20510

Dear Chair Murray and Ranking Member Kennedy:

The U.S. Nuclear Waste Technical Review Board (Board), an independent federal agency in the executive branch, performs independent technical and scientific peer review of the U.S. Department of Energy's activities related to managing and disposing of spent nuclear fuel (SNF) and high-level radioactive waste (HLW), and reports its findings and recommendations to Congress and the Secretary of Energy. The Board hopes the Committee will consider the Board a technical resource and will feel free to call on the Board to address technical and scientific questions related to SNF and HLW management and disposal.

The enclosed letter contains the Board's evaluation, findings, and recommendations to DOE regarding DOE's efforts to develop a consent-based siting process for a federal consolidated interim storage facility for SNF and provides two observations (see page 7) that can inform Congressional decision-making regarding the path forward on the management and disposal of SNF and HLW.

We would like to brief you or your staff on the letter and we would be happy to answer the questions that you may have. Please let us know a good day and time for an in-person or virtual meeting. We look forward to hearing from you.

Sincerely,

Nathan Siu
Chair

Enclosure

Telephone: 703-235-4473 Fax: 703-235-4495 www.nwtrb.gov

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

April 24, 2024

Dr. Kathryn Huff
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Dr. Huff:

The U.S. Nuclear Waste Technical Review Board (Board) is charged with evaluating the technical and scientific validity of activities undertaken by the U.S. Department of Energy (DOE) in implementing the Nuclear Waste Policy Act (NWPA). The Board is also required to report its findings, conclusions, and recommendations related to the management and disposition of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) to Congress and the Secretary of Energy. In discharging these responsibilities, the Board holds public meetings two or three times each year and then transmits its feedback to DOE in writing. This letter provides the Board's feedback on the topics discussed during the International Workshop on Siting of Radioactive Waste Facilities and Summer Board Meeting that the Board held on August 29-30, 2023, in Idaho Falls, Idaho.

On behalf of the Board, I want to thank you and your staff, as well as the staff from the national laboratories, for supporting these meetings. One purpose of the workshop was to obtain information that may be applicable to the DOE, Office of Nuclear Energy (DOE-NE) efforts to develop one or more federal interim storage facilities for commercial SNF using a consent-based siting process. The other purpose was to hear how DOE has addressed, or plans to address, the Board's previous recommendation to incorporate lessons learned into its consent-based siting efforts. The purpose of the Summer Meeting was to hear about DOE-NE's activities in the areas of consent-based siting, high burnup SNF (HBF),[1] and advanced reactor SNF and HLW disposition. Materials from the workshop and Summer Meeting are available online.[2]

The Board also thanks the staff from DOE as well as the staff from the national laboratories, for supporting technical non-public fact-finding meetings on June 29, 2023, and July 17, 2023. These fact-finding meetings enabled the Board to better prepare for the workshop and Summer Meeting.

[1] Fuel burnup is a measure of the thermal energy generated in a nuclear reactor per unit mass of nuclear fuel as initially loaded in the reactor and is typically expressed in units of gigawatt-days per metric ton of uranium (GWd/MTU). In the U.S., the U.S. Nuclear Regulatory Commission defines nuclear fuel utilized beyond 45 GWd/MTU as high burnup fuel.

[2] The agenda, presentations, transcript, public comments submitted online during the Summer Meeting, and an archived recording of the webcast for the meeting are at https://www.nwtrb.gov/meetings/past-meetings/summer-2023-board-meeting---august-30-2023. The same materials for the workshop and an independent consultant's report, are at https://www.nwtrb.gov/meetings/past-meetings/summer-2023-workshop---august-29-2023.

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Background

Over the past decade, DOE has been conducting research and development (R&D) activities to enable the storage, transportation, and eventual disposal of SNF and HLW from existing and potential future nuclear fuel cycles. In addition, DOE's Office of Integrated Waste Management (IWM) mission is to construct one or more federal interim storage facilities, using a consent-based siting process, ready to receive commercial SNF as soon as practicable. The Board has previously reviewed DOE's activities on its consent-based siting process and found that there were additional actions DOE could consider to further strengthen its consent-based siting effort, including learning from domestic siting experiences and siting processes in other nations.[3] DOE's recent efforts to use a consent-based siting approach included development and release of a consent-based siting process for federal consolidated interim storage of SNF. Also, DOE funded twelve awardees (i.e., consent-based siting consortia) from its funding opportunity announcement to serve as information, engagement, and resource hubs. DOE has conducted research to learn from past siting activities and environmental justice[4] practices and developed digital tools for engagement. IWM has been conducting technical activities related to transportation preparations, storage implementation (e.g., storage facility design), and system analysis needed for implementation of a federal consolidated interim storage facility within an integrated waste management system that includes disposal.

DOE's HBF R&D has focused on developing a better understanding of the characteristics of HBF to determine the performance and potential degradation of HBF during extended storage and subsequent transportation. DOE's efforts include the High Burnup Spent Fuel Data Project (or "Demo Project") that includes a demonstration cask that stores HBF assemblies from pressurized water reactors. That project also included detailed examinations of 25 HBF "sister" rods (aka sibling pins) withdrawn from assemblies in the demonstration cask or assemblies similar to those in the cask. The Board has evaluated DOE's efforts,[5] most recently at the Board's Winter 2022 meeting on March 1-2, 2022.[6] Examination of the 25 sister rods is ongoing but nearly complete. DOE plans to examine SNF from the demonstration cask after it is transported to a hot cell facility in 2027.

In addition to the HBF related projects, DOE completed a preliminary R&D gap analysis for the performance of accident tolerant fuels and other advanced fuels, including metallic and TRISO

[3] Bahr, J.M. 2022. Board letter to DOE following March 2022 meeting (June 7, 2022). https://www.nwtrb.gov/docs/default-source/correspondence/jmb041.pdf?sfvrsn=4. (last accessed April 4, 2024).

[4] As described by DOE, environmental justice is the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, Tribal affiliation, or disability with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

[5] NWTRB. 2021. *Evaluation of the Department of Energy's Research Program to Examine the Performance of Commercial High Burnup Spent Nuclear Fuel During Extended Storage and Transportation*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. July.

[6] Bahr, J.M. 2022. Board letter to DOE following March 2022 meeting (June 7, 2022). https://www.nwtrb.gov/docs/default-source/correspondence/jmb041.pdf?sfvrsn=4. (last accessed April 4, 2024).

(tri-structural isotropic) fuels, during storage and transportation.[7] The Board reviewed DOE's R&D activities related to advanced nuclear fuels for light water reactors, including accident tolerant fuels, and the impact of these fuels on SNF management and disposal.[8] DOE's advanced reactor SNF and HLW disposition R&D efforts were recently accelerated due to dedicated funding in fiscal years 2022 and 2023. DOE is seeking information from advanced reactor developers necessary to address regulatory and legal issues (such as, with the Standard Contract[9]) and to identify storage, transportation and disposal R&D gaps related to SNF and HLW that could be generated by advanced reactors.

Overview of the International Workshop and Summer Meeting

The workshop included presentations, facilitated panel discussions and an open house at the conclusion of the workshop.[10] Presentations by invited speakers from Canada (remotely), Sweden, and Switzerland (in person) focused on those country's siting processes for nuclear waste repositories and the lessons from those activities. An invited US speaker addressed lessons from past US waste facility siting attempts and the efforts of the Office of the Nuclear Waste Negotiator. The morning session ended with a facilitated discussion among the Swedish, Swiss, and US speakers. In the afternoon, DOE staff described how DOE is incorporating international siting and domestic best practices and lessons into their consent-based siting activities. Next, they described how DOE is using best practices and lessons from environmental justice. A facilitated discussion among the Swedish, Swiss, and US speakers and DOE staff followed.

The morning session of the Summer Meeting focused on DOE's consent-based siting activities. DOE staff provided an activities update, addressed how they are incorporating environmental justice and social science in consent-based siting, and described how they are developing digital tools for engagement.

During the afternoon, DOE and national laboratory staff provided an update on their HBF R&D. The speakers summarized the Phase I sibling pin test campaign and provided an overview of the draft Phase II test plan. DOE staff described how they are addressing back-end management of SNF and HLW from advanced reactors. The national laboratory staff described a detailed R&D gap analysis that is under development for accident tolerant fuels, high burnup/higher enrichment fuels, and advanced reactor SNF and waste forms for storage and transportation. DOE staff

[7] Honnold, P. et. al. 2021. *High Level Gap Analysis for Accident Tolerant and Advanced Fuels for Storage and Transportation*. Albuquerque, New Mexico: Sandia National Laboratories. April https://www.osti.gov/servlets/purl/1813674 (last accessed April 4, 2024).

[8] Bahr, J.M. 2022. Board letter to DOE following May 2021 meeting (August 12, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb035.pdf?sfvrsn=6. (last accessed April 4, 2024).

[9] The *Standard Contract for Disposal of SNF and/or HLW* ("DOE Standard Contract") establishes the terms and conditions under which DOE will make available nuclear waste disposal services to the owners and generators of SNF and HLW. DOE will take title to, transport, and dispose of SNF and/or HLW delivered to DOE by those owners or generators who execute the contract.

[10] DOE displayed three-dimensional (3-D) models of storage and transportation equipment, written materials describing DOE's consent-based siting efforts, and an immersive 3-D virtual reality tour of an SNF interim storage facility. These materials were the focus of the open house and remained available during the Summer Meeting.

stated that they plan to conduct an analysis of features, events, and processes for these same materials to identify the R&D gaps for disposal applications. The Board appreciates the thorough presentations given by the DOE and national laboratory speakers as well as their detailed responses to the Board's questions throughout the workshop and Summer Meeting.

Board Conclusions, Findings, and Recommendations

Based on the information presented at the workshop, Summer Meeting, the June 29, 2023, and July 17, 2023, fact-finding meetings, and in related technical reports, the Board has developed several conclusions, findings, and recommendations on DOE's consent-based siting activities and its HBF and advanced reactor waste disposition R&D. The Board has also developed a number of observations on topics that are outside of DOE's control under the NWPA, as amended, but are likely to impact DOE efforts to construct one or more federal interim storage facilities using a consent-based siting process. These conclusions, findings, recommendations, and observations follow. The enclosure provides more background and details regarding the meeting topics, the Board's evaluation, and again presents the Board's conclusions, findings, recommendations, and observations.

DOE's Activities on Consolidated Interim Storage Facilities for Commercial SNF

DOE's current consent-based siting efforts, which began in 2021, are still relatively new. Nevertheless, it is apparent that there has already been significant forward movement, especially in building capacity.[11] The Board commends DOE for its important, continuing efforts to assemble the needed consent-based siting scientific and technical personnel and expertise. For this extended process, which is currently estimated to last more than 10 years,[12] the Board has identified several areas that DOE could strengthen as it moves ahead:

- Access to scientific and technical information.
- Communication of complex scientific and technical information.
- Building capacity and incorporating scientific and technical information from the disciplines of public health, medicine, emergency management, and health physics.
- Measuring and evaluating progress toward achieving goals.
- Addressing intergenerational issues.

Finding 1: The Board finds that effectively meeting public information needs is an important component of consent-based siting. For interested parties to be informed about and empowered

[11] "Building capacity" is the process of developing and strengthening the skills, abilities, processes, and resources that DOE needs to implement a consent-based siting process, including the provision of funding to interested parties. DOE describes building capacity as including federal funding that would be provided to interested parties to learn more, increase engagement, and strengthen their capacity to participate in the consent-based siting process. (DOE. 2023. *Consent-Based Siting Process for Federal Consolidated Interim Storage of Spent Nuclear Fuel*. Washington, DC: U.S. Department of Energy. April.)

[12] DOE. 2023. *Consent-Based Siting Process for Federal Consolidated Interim Storage of Spent Nuclear Fuel*. Washington, DC: U.S. Department of Energy. April.

in the siting process,[13] *they need consistent and timely access to scientific and technical information. Providing such information will support effective engagement, help inform understanding of the many complex consent-based siting issues, and foster trust between the public and DOE.*

Recommendation 1: The Board recommends that consent-based siting-related information that will be produced by DOE and the consent-based siting consortia be made available to the public in as timely a manner as practicable.

Finding 2: The Board finds that the communication of complex scientific and technical information is a crucial part of consent-based siting efforts, and notes that DOE is contemplating various efforts to disseminate such information. In successful siting cases for radioactive waste facilities in Sweden and Switzerland, members of the public often preferred communication and information to come directly from scientists and engineers involved in the program rather than from public affairs or public relations staff. To meet this need, some program scientists and engineers engaged directly with the public, and worked to become more adept at explaining complex scientific and technical information about radioactive waste management facilities in clear, jargon-free language. The vital communication role played by scientists and engineers in successful siting efforts is consistent with what is also known from research and experience. The International Radiation Protection Association considers this a best practice.[14]

Recommendation 2: The Board recommends that DOE use successful siting cases for radioactive waste facilities in other countries, results from research, and best practices to explore what training or other efforts would be most helpful in preparing various scientists and engineers associated with the U.S. consolidated interim storage program to be able to engage in sustained and effective dialog with members of the public.

Finding 3a: The Board commends DOE for incorporating a wide range of social and behavioral science disciplines into its consent-based siting efforts. At the same time, the Board finds that additional cutting-edge work in radiation risk communication and related topics has taken place in such fields as public health, medicine, emergency management, and health physics. These fields need to regularly interact and communicate with members of the public about radiation, uses of radioactive and nuclear materials and technologies, and radiation safety and health. The Board finds that DOE has not yet fully incorporated this important, additional cutting-edge work in radiation risk communication and related topics into its consent-based siting efforts.

Finding 3b: The Board finds that although DOE has been able to successfully increase consent-based siting capacity and staffing, additional sustained resources and personnel (including full-time staff with expertise in such areas as risk communication) would further strengthen the

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[13] NWTRB. 2015. *Designing A Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: An Overview and Summary*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. November.

[14] International Radiation Protection Association. 2020. *Practical Guidance for Engagement with the Public on Radiation and Risk*. https://www.irpa.net/members/IRPA%20Guidance%20Public%20Engagement.pdf. (last accessed April 4, 2024).

consent-based siting process as it proceeds. By not having such expertise, important and directly relevant work could be missed or repeated unnecessarily by DOE.

Recommendation 3: As DOE continues to assemble needed expertise and information related to consent based siting, the Board recommends that DOE take steps to broaden its approach, such as: a) ensuring a high level of expertise and experience in such areas as risk communication, and b) systematically including technical literature and research from the disciplines of public health, medicine, emergency management, and health physics. Likewise, the Board recommends that when DOE gives public presentations on its consent-based siting activities, insights from these fields and publications describing key sources of information informing project efforts be included in slides.

Finding 4: The Board finds that as part of successful siting programs in Sweden and other countries, different evaluation approaches, methodologies, and metrics have been employed by each country to help assess the effectiveness of consent-based siting efforts. For example, in Sweden, the implementer collected, analyzed, and reviewed data over an extended time on the percent of the population willing to engage as part of the overall evaluation strategy. DOE described that in fiscal year 2024 it will be looking at potential metrics that could be applied to its communications and to its consent-based siting program. Likewise, the Board finds that such methods and metrics could be used by DOE, for example, to analyze which program-related activities are working well and which ones need to be strengthened, to measure whether consent-based siting program communications are effective, and to assess the extent to which different interested groups are being reached and engaged.

Recommendation 4: As DOE's consent-based siting effort continues to develop, the Board recommends that DOE identify state-of-the-art evaluation approaches, methods, indicators, and metrics that can be utilized to gauge the extent to which key goals are being achieved.

Finding 5: Consent-based siting issues have important implications not only for the present but also for the future (siting could take a decade or more and the transportation of SNF and storage at a sited facility could last decades). Thus, it will be important to understand key intergenerational issues and include the perspectives of younger people in the process. The Board finds that as DOE develops its own consent-based siting process, it would be valuable to identify and implement effective mechanisms to directly engage young people and gain a better understanding of intergenerational aspects of siting decisions.

Observations on Implementing Consolidated Interim Storage

As stated at the beginning of this letter, the Board's mandate is to evaluate the technical and scientific validity of activities undertaken by DOE. However, as a result of its past and ongoing reviews, the Board has come to recognize two key societal challenges that will likely affect DOE's efforts to successfully implement a consolidated interim storage program. These challenges are: 1) the need for timely progress toward the long-term solution of disposal of SNF

and HLW in an underground geologic repository;[15] and 2) the need for a legal and regulatory framework that is fully supportive of a consent-based siting approach, including the satisfactory treatment of the key role that states have in decision-making.[16] Solutions to these challenges will likely require budgetary and policy decisions by policymakers.

In keeping with the Board's technical mandate, the Board takes no position on whether a new effort should be undertaken to site either the country's first or second repository, or how to implement a consent-based siting approach; policymakers will make those decisions. The Board offers the following two observations that can inform Congressional decision-making regarding a path forward on SNF and HLW management and disposal *if* policymakers decide to move forward.

Observation 1: Information from the Board's past and recent reviews (including the experiences from other countries) show that timely progress on a geologic disposal program for SNF and HLW is needed now to provide confidence that storage of SNF at a federal consolidated storage facility will be interim and not permanent. Such confidence will be necessary for consent from states, Tribes, and communities.

Observation 2: If a consent-based siting approach is used for a federal consolidated interim storage facility or a repository, a consultation and concurrence approach with states and Tribes, rather than the consultation and cooperation approach currently embodied in the NWPA, as amended, will likely need to be explored both in terms of the timing (for example, when does consultation and concurrence begin and end) and extent (for example, what issues are subject to concurrence and who are the responsible concurring parties).

<u>High Burnup SNF</u>

DOE's R&D has focused on better understanding the characteristics of HBF, including the fuel's cladding, to determine the performance and potential degradation of HBF during extended storage and subsequent transportation. The Phase I testing of HBF sibling pins is ongoing, and largely complete. DOE has completed an extensive multi-modal transportation test with surrogate SNF. The mechanical loads expected during transportation are well within the capacity of the fuel cladding to resist degradation. The cladding temperatures and hoop stresses in the HBF rods examined have been determined to be too low to cause potentially damaging radial hydride formation within the cladding. As a result, our opinion is that many of the information gaps on issues of potential importance to HBF performance during storage and transportation can be closed. However, the Board notes that DOE has not addressed all the Board's 2021 recommendations on HBF.[17] The Board understands, from discussions at a

[15] NWTRB. 2021. *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. April.

[16] NWTRB. 2015. *Designing A Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Detailed Analysis*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. November.

[17] NWTRB. 2021. *Evaluation of the Department of Energy's Research Program to Examine the Performance of Commercial High Burnup Spent Nuclear Fuel During Extended Storage and Transportation*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. July.

February 28, 2024, fact-finding meeting, that DOE may soon make significant changes to its HBF storage and transportation R&D program and that the start of Phase II testing has been put on hold. The Board will provide, in a separate letter, the Board's assessment of the status of DOE's current R&D efforts relative to the Board's 2021 recommendations on HBF.

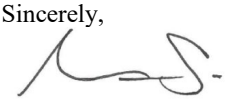
Advanced Reactor Waste Disposition

The NWPA, as amended, stipulates that an operating license for a reactor cannot be issued by the U.S. Nuclear Regulatory Commission unless the applicant has entered into a contract with the Secretary of Energy for the disposal of SNF and HLW generated from the reactor's operation.[18] DOE will need enough data, describing the characteristics of both the initial fuel and the discharged SNF and HLW and operations (e.g., storage canister design and what constitutes "failed fuel"), from a potential applicant to allow DOE to determine whether to enter such a contract.

Finding 6: DOE has initiated an effort to assess the potential impacts of various advanced nuclear fuels on storing, transporting, and disposing of SNF and HLW by requesting data from advanced reactor vendors. DOE is also developing a strategy to identify knowledge gaps and outline areas where further research would contribute to a well-defined disposition pathway for SNF and HLW resulting from advanced reactor operations. This effort will inform DOE decisions concerning how to proceed and how to deal with the impacts. The Board commends DOE for initiating this assessment and strongly endorses the effort.

Thank you again, on behalf of the Board, for the participation of DOE staff and technical experts from the national laboratories at our June and July 2023, and February 2024, fact-finding meetings and at the workshop and Summer Meeting in August 2023. We look forward to continuing our ongoing evaluation of the technical and scientific validity of DOE's activities related to managing and disposing of SNF and HLW.

Sincerely,



Nathan Siu
Chair

Enclosure

cc: Mr. Paul Murray, DOE-NE
Mr. Tim Gunter, DOE-NE
Dr. Erica Bickford, DOE-NE
Ms. Marla Morales, DOE-NE

[18] The *Standard Contract for Disposal of SNF and/or HLW* ("DOE Standard Contract") establishes the terms and conditions under which DOE will make available nuclear waste disposal services to the owners and generators of SNF and HLW. DOE will take title to, transport, and dispose of SNF and/or HLW delivered to DOE by those owners or generators who execute the contract.

Enclosure

International Workshop on Siting of Radioactive Waste Facilities and Summer 2023 Board Meeting

Evaluation Findings, Conclusions, Recommendations, and Observations

This enclosure summarizes U.S. Department of Energy's (DOE's) presentations at the Summer Meeting and the workshop, provides background and details regarding the meeting topics, and presents the Board's evaluation of DOE's activities and the Board's findings, conclusions, and recommendations. [**Topics** (all words are initial uppercase and bold) and subtopics (first word is uppercase) are underlined, *Board findings and conclusions are presented in italics*, and **Board recommendations are presented in bold text]**.

This enclosure also includes an analysis of topics that are outside of DOE's control under the Nuclear Waste Policy Act (NWPA), as amended,[19] but are likely to impact DOE efforts to construct one or more federal interim storage facilities for commercial spent nuclear fuel (SNF) using a consent-based siting process. The Board's analysis and **two observations** (**in bold text**) provide policymakers with information that is relevant to DOE's efforts and the potential for success.

DOE's Activities on Consolidated Interim Storage Facilities for Commercial SNF

As part of its Winter (March 1-2) 2022 meeting, the Board reviewed DOE's activities on the consent-based siting process for federal interim storage facilities for commercial spent nuclear fuel (SNF). The Board found that that there were additional actions that DOE could take to learn from domestic siting experiences and siting processes in other nations and to strengthen its overall consent-based siting effort.[20] The Board also heard an update on DOE's consent-based siting activities at its Spring (March 28) 2023 meeting. The Board commended DOE for starting to look into developing metrics (i.e., ways to measure and assess efforts to engage Tribal nations) to systematically evaluate the extent to which such engagement efforts have been successful, and stated it looked forward to seeing more detailed information about such metrics at future Board meetings.[21] Consistent with its mandate for an ongoing review of DOE's activities, the Board

[19] Hereafter in the enclosure the use of NWPA means the NWPA, as amended, except in direct quotations or where the NWPA of 1982 is noted.

[20] Bahr, J.M. 2022. Board letter to DOE following March 2022 meeting (June 7, 2022). https://www.nwtrb.gov/docs/default-source/correspondence/jmb041.pdf?sfvrsn=4. (last accessed April 4, 2024). DOE response to the Board letter: Huff, K. 2023. DOE Response to the Nuclear Waste Technical Review Board (NWTRB) Report from the NWTRB 2022 Winter Meeting (July 5, 2023). https://www.nwtrb.gov/docs/default-source/correspondence/doe_aug-21-2023.pdf?sfvrsn=6). (last accessed April 4, 2024).

[21] Siu, N. 2023. Board letter to DOE following March 2023 meeting (August 24, 2023). https://www.nwtrb.gov/docs/default-source/correspondence/nos008vf---board-letter-march-28-meeting.pdf?sfvrsn=4. (last accessed April 4, 2024).

utilized the August 2023 workshop and Summer Meeting to continue its review of DOE's consent-based siting activities.[22]

The Board organized its latest review of this topic around the following subtopics.

- Access to scientific and technical information.
- Communication of complex scientific and technical information.
- Building capacity and incorporating scientific and technical information from the disciplines of public health, medicine, emergency management, and health physics.
- Measuring and evaluating progress toward achieving goals.
- Addressing intergenerational issues.

Access to scientific and technical information

In the workshop, DOE staff described how they are incorporating international siting and domestic best practices and lessons learned into DOE's consent-based siting activities. DOE staff stated that during fiscal years 2023 and 2024, they are conducting literature reviews and completing in-depth case studies of international experiences and documenting these along with the status of each country's SNF management program.[23] These "case study" documents provide both insights into the current and historical sociopolitical environment of these countries and basic technical information. DOE staff stated that these case studies and associated single-page summaries ("fact sheets") were developed for use by DOE and national laboratory staff. DOE staff stated that they did not develop the documents with the public in mind and had not intended for the documents to be publicly available.

DOE staff described in the workshop how they are identifying lessons learned in a variety of sectors[24] (non-nuclear as well as nuclear) from previous domestic cases of siting facilities that have encountered a large amount of social scrutiny. The results, to be documented in in six exemplar reports,[25] will reflect a mixture of case studies and interviews from people who were involved. DOE plans to gather best practices and lessons learned from the exemplar studies that could be applicable to its own effort and consolidate that knowledge in a summary report. DOE

[22] The Board's visits over the last 10 years to Sweden, Switzerland, and Canada have also informed our review. For example, in October 2023, the Board visited Ontario Canada to exchange information with key scientific and technical nuclear waste management organizations and a potential repository host community and to gain an understanding of potential activities that the Canadian implementer and DOE may conduct jointly on consent-based siting.

[23] The country reports for fiscal year 2023 address Canada, the United Kingdom, Switzerland, Finland, and Germany.

[24] A sector is an area of the economy in which businesses share the same or related business activity, product, or service.

[25] In 2022, the Board had suggested that DOE look at high-risk, as perceived by the public, facilities, such as a biosafety level 4 facility, as part of their plans for evaluating domestic siting experience. DOE has completed case studies for the Office of the Nuclear Waste Negotiator, a biosafety level 4 facility, and a solar energy project. DOE plans to complete, in fiscal year 2024, exemplar studies in the wind sector, petrochemical manufacturing sector, and another in the nuclear sector (i.e., Western Uranium & Vanadium mill).

staff stated that they did not develop the exemplar reports with the public in mind and had not intended for the documents to be publicly available. In response to questions from the Board, the DOE staff stated that they could consider making the reports public, eventually.

In the workshop, DOE staff described the different facets of environmental justice and how DOE is using best practices and lessons learned from the field. DOE staff indicated that procedural justice, a part of environmental justice, includes the notion of meaningful involvement. Procedural justice addresses the equitable access of stakeholders and entities to the processes of decision making, including provision of access to information. DOE staff stated that it had completed an environmental and energy justice literature review, which is non-public, for its consent-based siting program. In describing its environmental justice efforts in the Summer Meeting, DOE staff discussed the development and use of a digital tool known as CURIE.[26] This resource management database includes access-restricted libraries in which materials are not available to the public. DOE has developed a resource library in CURIE for the consent-based siting consortia that is access restricted but allows DOE and consortia members to add resources to the library. DOE is limiting the materials it is adding to the resource library in CURIE for the consortia to avoid overwhelming the consortia.

The Board commends DOE for its efforts to identify and incorporate lessons learned from domestic and international siting efforts into its consent-based siting program and acknowledges DOE's rapid progress in a short period. However, the Board notes that access to scientific and technical information developed in DOE's studies and information generated by the consortia is valuable not only to DOE but also to the public.

Finding 1: The Board finds that effectively meeting public information needs is an important component of consent-based siting. For interested parties to be informed about and empowered in the siting process,[27] they need consistent and timely access to scientific and technical information. Providing such information will support effective engagement, help inform understanding of the many complex consent-based siting issues, and foster trust between the public and DOE.

Recommendation 1: The Board recommends that consent-based siting-related information that will be produced by DOE and the consent-based siting consortia be made available to the public in as timely a manner as possible.

Communication of complex scientific and technical information

At the workshop, presentations by invited speakers from Canada, Sweden, and Switzerland focused on their country's siting processes and the lessons learned from those activities. The Board observes that in successful siting cases in Sweden and Switzerland, members of the public

[26] CURIE is the Resource Portal for DOE Nuclear Waste Management Information and is at https://curie.pnnl.gov/. (last accessed April 4, 2024)

[27] NWTRB. 2015. *Designing A Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: An Overview and Summary*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. November.

often preferred face-to-face communication and preferred that information come directly from scientists and engineers working on the project rather than from public affairs or public relations staff. Public information specialists certainly had a role to play; but hearing directly from scientists and engineers was an essential component in fostering genuine dialog and understanding and in establishing credibility and trust. As explained by the Swedish and Swiss speakers, scientists and engineers engaged directly with the public, and worked to become more adept at explaining complex scientific and technical information associated with radioactive waste facilities in clear, jargon-free language. The vital communication role played by scientists and engineers in successful siting efforts is consistent with what is also known from research. Scientists tend to rank highly in terms of public trust and confidence (even though there are variations across countries and populations).[28] This means the public looks to individuals with relevant scientific and technical expertise for information, particularly in relation to technically complex topics.[29] Indeed, the International Radiation Protection Association has described direct engagement of technical experts with the public as a best practice. In its benchmarks of good practice, the International Radiation Protection Association advises that communication not be left only to non-specialists; rather, it is particularly important for knowledgeable professionals with scientific and technical expertise about radioactive materials, safety, and risk to engage directly with the public.[30]

Finding 2: The Board finds that the communication of complex scientific and technical information is a crucial part of consent-based siting efforts, and notes that DOE is contemplating various efforts to disseminate information. In successful siting cases for radioactive waste facilities in Sweden and Switzerland, members of the public often preferred communication and information to come directly from scientists and engineers involved in the program rather than from public affairs or public relations staff. To meet this need, some program scientists and engineers engaged directly with the public, and worked to become more adept at explaining complex scientific and technical information about radioactive waste management facilities in clear, jargon-free language. The vital communication role played by scientists and engineers in successful siting efforts is consistent with what is also known from research and experience. The International Radiation Protection Association considers this a best practice.[31]

Recommendation 2: The Board recommends that DOE use successful siting cases for radioactive waste facilities in other countries, results from research, and best practices to explore what training or other efforts would be most helpful in preparing various scientists

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[28] See for example, National Science Board (NSB), National Science Foundation. 2022. "Science and Technology: Public Perceptions, Awareness, and Information Sources." *Science and Engineering Indicators* 2022. NSB-2022-7. Alexandria, VA. https://ncses.nsf.gov/pubs/nsb20227 (last accessed April 4, 2024).

[29] See, for example, Lang, J.T. and W.K. Hallman. 2005. "Who does the public trust? The case of genetically modified food in the United States." *Risk Analysis* 25(5): 1241-1252.

[30] International Radiation Protection Association. 2020. *Practical Guidance for Engagement with the Public on Radiation and Risk*. https://www.irpa.net/members/IRPA%20Guidance%20Public%20Engagement.pdf. (last accessed April 4, 2024).

[31] Ibid.

and engineers associated with the U.S. consolidated interim storage program to be able to engage in sustained and effective dialog with members of the public.

Building capacity and incorporating scientific and technical information from other disciplines

The Board recognizes that DOE is early into the multi-year consent-based siting enterprise. DOE's consent-based siting efforts to date include hiring new federal staff to work on multi-disciplinary issues such as those that intersect with social and behavioral sciences, and environmental justice.[32] DOE has also developed its consent-based siting process document[33] and has funded twelve consent-based siting consortia that serve as information, engagement, and resource hubs. Both DOE's staffing efforts and the consortia are integral parts of building capacity and collaboration that DOE believes it will need to implement its consent-based siting process.

In the Summer Meeting, DOE staff presented an update on its consent-based siting activities and an overview of environmental justice in consent-based siting. DOE staff stated that the consortia (whose participants are located across the nation and many of them associated with universities) will conduct robust engagement activities in their communities and enable mutual learning. The collaboration with communities and building capacity within and between the consortia will occur over the course of 18 to 24 months, which is the period of performance for the cooperative agreements with the individual consortia.[34] DOE staff stated that the consortia resources to be developed are critical in allowing interested communities the opportunity to learn more about nuclear waste, the management of commercial SNF, and the role that a consolidated interim storage facility may have in their community.

DOE staff also described how they are incorporating social science into consent-based siting and developing digital tools for engagement. As of August 2023, the DOE consent-based siting staff included three social scientists (i.e., a psychologist, a cultural anthropologist, and a social scientist) and a physical scientist with a degree in health physics.[35] The DOE staff stated that the

[32] DOE staff described that the development of StoryMaps, one of their digital tools for engagement, has brought the social scientists together with the other technical staff to develop communication products on technical topics that are accessible and appealing to the public. DOE social scientists are working with other technical staff on some of the transportation studies and assessments, including the preparations for a potential package performance demonstration.

[33] DOE. 2023. *Consent-Based Siting Process for Federal Consolidated Interim Storage of Spent Nuclear Fuel*. Washington, DC: U.S. Department of Energy. April.

[34] In August 2023, DOE had not finalized any of the cooperative agreements. Currently all consortia have signed agreements and have begun implementing their proposed activities. Under the agreements the consortia will organize, lead, and maintain meaningful, inclusive community and stakeholder engagement processes related to nuclear waste management. The second task required under the agreements is that the consortia will map public values, interests, concerns, and goals to promote and enable effective collaboration and community-driven feedback. Finally, DOE requires the consortia to develop, implement, and report on outcomes, strategies and activities that support mutual learning among the DOE, stakeholders, communities, and experts on nuclear waste-related topics. DOE's intent is to use the information learned from the consent-based siting consortia to revise or adjust its consent-based siting process.

[35] DOE's physical scientist on the consent-based siting team, whose expertise included risk communication, left the agency in September 2023.

three social scientists "cover anthropology, science and technology studies, geography, psychology, behavioral science, science communication, and risk communication which includes risk perception." DOE staff acknowledged that there is considerable research in risk analysis and risk perception and understanding what influences how people perceive risks.

The Board notes that a draft literature review authored by national laboratory staff on social science and SNF that addressed consent-based siting did not appear to include recent studies (such as those on the Fukushima Dai-ichi crisis and its aftermath). These recent studies addressed a range of topics related to risk, risk communication, community engagement, and radiation. For example, in responding to DOE's social science presentation, a Board member explained that considerable new and innovative work about citizen science has been performed in the aftermath of the crisis at Fukushima Dai-ichi.[36] The DOE staff stated that although they were not aware of that literature it could be an exciting avenue to explore. In the Summer Meeting, a Board member also stated that several journals[37] that are directly relevant to the work DOE is conducting are not indexed in social science indices and that DOE could be missing important, relevant work.

Finding 3a: The Board commends DOE for incorporating a wide range of social and behavioral science disciplines into its consent-based siting efforts. At the same time, the Board finds that additional cutting-edge work in radiation risk communication and related topics has taken place in such fields as public health, medicine, emergency management, and health physics. These fields need to regularly interact and communicate with members of the public about radiation, uses of radioactive and nuclear materials and technologies, and radiation safety and health. The Board finds that DOE has not yet fully incorporated this important, additional cutting-edge work in radiation risk communication and related topics into its consent-based siting efforts.

In the Summer Meeting, DOE staff stated they have limited resources and are relying on the staff they have, with support from national laboratory staff with backgrounds in public health, to address knowledge in risk communication and related topics. The Board again notes the importance of communication of complex scientific and technical information to the public in face-to-face situations and the need for DOE to explore training or other efforts that would be most helpful in preparing its scientists and engineers for that type of communication.[38] Having DOE staff expertise in risk communication available to the consent-based siting team could

[36] There is now a growing literature that discusses citizen science, citizen radiation monitoring, citizen engagement, and related topics after the Fukushima Dai-ichi crisis. Examples include: Kenens J. 2020. "Changing perspectives: tracing the evolution of citizen radiation measuring organizations after Fukushima." *Radioprotection* 55(HS2); Brown A. *et al*. 2016. "Safecast: successful citizen-science for radiation measurement and communication after Fukushima." *J. Radiol. Prot.* 36(S82); and van Oudheusden M., J. Kenens, G. Yoshizawa, and N.Mizushima. 2019. *Learning from citizen science after Fukushima: probing the role and potential of citizen science in nuclear science and technology governance in Japan and Belgium*. Brussels: SCK CEN (The Belgian Nuclear Research Centre).

[37] These journals include British Medical Journal, Prehospital and Disaster Medicine, American Journal of Public Health, and Health Physics. The Board notes that DOE's draft report on social science and SNF did not cite any of these journals.

[38] The Board previously recommended that DOE anticipate required personnel needs in the Board's *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward* report. NWTRB 2021. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. April.

better enable DOE to assess its training needs, define and evaluate the support provided by the national laboratories, and facilitate evaluation of the materials developed by the consent-based siting consortia.

Finding 3b: The Board finds that although DOE has been able to successfully increase consent-based siting capacity and staffing, additional sustained resources and personnel (including full-time staff with expertise in such areas as risk communication) would further strengthen the consent-based siting process as it proceeds. By not having such expertise, important and directly relevant work could be missed or repeated unnecessarily by DOE.

Recommendation 3: As DOE continues to assemble needed expertise and information related to consent based siting, the Board recommends that DOE take steps to broaden its approach, such as: a) ensuring a high level of expertise and experience in such areas as risk communication, and b) systematically including technical literature and research from the disciplines of public health, medicine, emergency management, and health physics. Likewise, the Board recommends that when DOE gives public presentations on its consent-based siting activities, insights from these fields and publications describing key sources of information informing project efforts be included in slides.

Measuring and evaluating progress toward achieving goals

At the Board's March 28, 2023, meeting, DOE staff stated that it would be looking into developing metrics (i.e., ways to measure and systematically evaluate Tribal nation engagement and progress) to assess or track the extent to which such engagement efforts have been successful. The Board stated it looked forward to seeing more detailed information about such metrics at future Board meetings.[39] During the workshop and Summer Meeting, invited experts from other countries and DOE staff discussed the topic of measuring and evaluating progress toward achieving goals of siting programs for radioactive waste management facilities. DOE staff stated that in fiscal year 2024, they would be developing evaluation strategies and metrics. DOE's task is challenging because it needs to assess its own efforts, the work conducted by the national laboratories, and the efforts of the consortia. DOE's intent is to use the information learned from the consent-based siting consortia to revise or adjust its consent-based siting process.

Developing an appropriate evaluation strategy will require considerable thought regarding what to assess, what data to gather, what methods to employ (e.g., quantitative, qualitative, mixed), and how to involve stakeholders and other entities, outside experts, and others in the evaluation process. In some cases, evaluation strategies and metrics from international experience may be useful. In other cases, different approaches and methods might be needed for the U.S. context. Evaluations of previous DOE siting and engagement efforts could be useful, as could evaluation-related documents used in other parts of DOE. Other federal agencies, including those that deal with issues related to safety, health, and environment, have well-developed evaluation guides

[39] Siu, N. 2023. Board letter to DOE following March 2023 meeting (August 24, 2023). https://www.nwtrb.gov/docs/default-source/correspondence/nos008vf---board-letter-march-28-meeting.pdf?sfvrsn=4. (last accessed April 4, 2024).

that may be relevant.[40] Since a centrally important component of evaluating a consent-based siting effort involves assessing the effectiveness of engagement efforts, it will be important to consult evaluation literature and handbooks specifically focused on that topic.

Finding 4: The Board finds that as part of successful siting programs in Sweden and other countries, different evaluation approaches, methodologies, and metrics have been employed by each country to help assess the effectiveness of consent-based siting efforts. For example, in Sweden, the implementer collected, analyzed, and reviewed data over an extended time on the percent of the population willing to engage as part of the overall evaluation strategy. DOE described that in fiscal year 2024 it will be looking at potential metrics that could be applied to its communications and to its consent-based siting program. Likewise, the Board finds that such methods and metrics could be used by DOE, for example, to analyze which program-related activities are working well and which ones need to be strengthened, to measure whether consent-based siting program communications are effective, and to assess the extent to which different interested groups are being reached and engaged.

Recommendation 4: As DOE's consent-based siting effort continues to develop, the Board recommends that DOE identify state-of-the-art evaluation approaches, methods, indicators, and metrics that can be utilized to gauge the extent to which key aims are being achieved.

Addressing intergenerational issues

DOE staff stated in both the workshop and Summer Meeting that it is conducting an analysis of intergenerational justice and intergenerational equity.[41] The purpose of this analysis is to identify best practices for understanding these issues and to identify mechanisms for achieving restorative justice while ensuring the well-being of future generations. DOE is also funding the national laboratories to develop guidance and a draft recommendation to DOE for addressing intergenerational justice. DOE is considering a potential intergenerational council in response to public feedback. DOE has also begun to look at the practicalities (e.g., how to recruit people, what ages are optimal, etc.) of including youth in an intergenerational council. The Board commends DOE for its initial efforts to analyze intergenerational justice and equity and to explore the possibility of an intergenerational council.

[40] Clinical and Translational Science Awards Consortium, Community Engagement Key Function Committee, and Task Force on the Principles of Community Engagement. 2011. *Principles of Community Engagement.* Agency for Toxic Substances and Disease Registry, Centers for Disease Control and Prevention, NIH publication 11-7782. June. https://stacks.cdc.gov/view/cdc/11699 (last accessed April 4, 2024). For an extensive and detailed compilation of specific tools, resources and instruments for assessing whether engagement is succeeding, whether communities feel engaged, and ways that engagement can be improved see *Assessing Meaningful Community Engagement*. National Academy of Medicine, National Academies of Sciences, Engineering, and Medicine. https://nam.edu/programs/value-science-driven-health-care/assessing-meaningful-community-engagement/ (last accessed April 4, 2024).

[41] DOE (2023) lists and describes the values and principles that will guide their consent-based siting process. DOE. 2023. *Consent-Based Siting Process for Federal Consolidated Interim Storage of Spent Nuclear Fuel*. Washington, DC: U.S. Department of Energy. April.

The Canadian implementer, the Nuclear Waste Management Organization (NWMO), relies on several advisory bodies to assist its siting efforts for a geologic repository.[42] One such council, the Council of Knowledge Holders, formerly the Council of Youths and Elders, is focused on Indigenous peoples. It provides counsel on the application of Indigenous knowledge in the implementation of adaptive phased management, the plan for radioactive waste management the Canadian government adopted and that NWMO is implementing. In addition, the council provides advice on issues that could enhance the development and maintenance of good relations with Indigenous communities. In the workshop, DOE staff stated it had signed a bilateral agreement focused on SNF management with NWMO. The purpose of the agreement, a statement of intent, is to support mutual learning, information exchange on consent-based siting processes, science and technology programs, engagement activities, and joint technical studies. This agreement could allow DOE to learn more from NWMO on incorporating youth perspectives in the siting process.

Finding 5: Consent-based siting issues have important implications not only for the present but also for the future (siting could take a decade or more and the transportation of SNF and storage at a sited facility could last decades). Thus, it will be important to understand key intergenerational issues and include the perspectives of younger people in the process. The Board finds that as DOE develops its own consent-based siting process, it would be valuable to further explore the idea of youth advisory boards, intergenerational councils, and other similar mechanisms more fully as ways to include young persons in the process and gain a better understanding of intergenerational aspects of siting decisions.

The Board looks forward to evaluating the scientific and technical validity of DOE's continued progress on the topic of consolidated interim storage facilities for commercial SNF, including its consent-based siting activities. The Board acknowledges DOE's substantial efforts to address the Board's recommendation to learn from domestic siting experiences and siting processes in other nations and to strengthen its overall consent-based siting effort. The Board has also developed observations (immediately below) on topics that are outside of DOE's control under the NWPA but are likely to impact DOE efforts to construct one or more federal interim storage facilities using a consent-based siting process.

Observations on Implementing Consolidated Interim Storage

As stated at the beginning of this letter, the Board's mandate is to evaluate the technical and scientific validity of activities undertaken by DOE. However, as a result of its past and ongoing reviews, the Board has come to recognize two key societal challenges that will likely affect DOE's efforts to successfully implement a consolidated interim storage program. These challenges are: 1) the need for timely progress toward the long-term solution of disposal of SNF and HLW in an underground geologic repository;[43] and 2) the need for a legal and regulatory framework that is fully supportive of a consent-based siting approach, including the satisfactory

[42] NWTRB. 2022. *Survey of National Program for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: 2022 Update*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. July.

[43] NWTRB. 2021. *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. April.

treatment of the key role that states have in decision-making.[44] Solutions to these challenges will likely require budgetary and policy decisions by policymakers.

The Board notes that a geologic repository for SNF and HLW is needed whether a federal consolidated interim storage facility for commercial SNF is part of the integrated waste management system or not. The Board has found that disposal of radioactive waste in deep boreholes does not eliminate the need for a mined, geologic repository.[45] Advanced reactors or recycling facilities also do not eliminate the need for a geologic repository. As described in Advanced Reactor Waste Disposition section of this letter, in section 302(b) of the NWPA, the advance contracting requirement stipulates that DOE can accept for disposal (in a repository) SNF and HLW generated from an advanced reactor's (or from a recycling facility) operation provided the applicant for the U.S. Nuclear Regulatory Commission license for the facility has entered into a contract with the Secretary of Energy.[46] Thus, timely progress toward the long-term solution—disposal in a deep underground repository—is still a matter of urgency.[47]

Others have also noted that timely progress toward disposal in a deep geologic repository is a key issue that will impact DOE's potential for success in its consent-based siting effort. Commenters on DOE's consent-based process[48] and information provided in the workshop highlighted that progress on a geologic disposal program is needed as part of any federal effort on consolidated interim storage of SNF. Regarding the role of a federal consolidated interim storage facility in an integrated waste management system, DOE found that a greater number of people opposed developing federal consolidated interim storage than those who supported moving forward with storage.[49] Many of those opposed cited a concern that such facilities could become de facto permanent disposal sites given the lack of progress in developing a repository. Several commenters also noted that measurable and publicly visible progress toward a repository

[44] NWTRB. 2015. *Designing A Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Detailed Analysis*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. November.

[45] The Board (NWTB 2016) found that "although deep boreholes might provide a disposal option for certain types of DOE-managed waste, … disposal of radioactive waste in deep boreholes does not eliminate the need for a mined, geologic repository." NWTRB. 2016. *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development*. Regarding commercial SNF stored in the U.S., the Board (NWTRB 2016) noted that "DOE also has indicated that commercial SNF is not being considered for deep borehole disposal, mainly because of its size".

[46] As DOE described in the Board's Summer Meeting only one entity has provided enough information on its waste characteristics (e.g., form, quantity, packaging, etc.) to allow DOE to state that the U.S. Nuclear Regulatory Commission's applicant is actively and in good faith negotiating with the Secretary of Energy for a contract. That applicant is Kairos Power LLCs in its construction permit application for the Hermes Test Reactor.

[47] NWTRB. 2021. *Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. April.

[48] DOE. 2022. *Consent-Based Siting: Request for Information Comment Summary and Analysis*. Washington, DC: U.S. Department of Energy. September. On December 1, 2021, DOE issued a request for information (RFI) on "Using a Consent-Based Siting Process to Identify Federal Interim Storage Facilities" (86 FR 68244). DOE received 225 submissions in response to the RFI from a wide variety of commenters, including Tribal, state, and local governments; non-governmental organizations; members of academia and industry; other stakeholders; and individual commenters.

[49] Ibid.

would alleviate these concerns. Many commenters felt that progress on a repository should be simultaneous with efforts to develop consolidated interim storage. They emphasized that progress on both fronts is critical to restore trust and gain community consent to host a storage facility.[50] At the workshop, Swedish and Swiss experts, whose countries have selected sites for geologic repositories, stated that success in siting a federal consolidated interim storage facility in the U.S. is less likely without an active geologic disposal program or a path to a repository.[51] For example, the Canadian speaker stated that Canada's success was due, in part, to their government assuming the responsibility for final disposal "now, because it's not acceptable to leave the burden of the waste we created to future generations." Also, the Swiss speaker concurred with the Canadian speaker and stressed the importance of addressing the disposal of the SNF now.

The NWPA authorized the DOE to site, construct, and operate a monitored retrievable storage (MRS) facility (equivalent to a federal consolidated interim storage facility) using two alternative paths for siting the facility. Siting could occur by a DOE-directed survey-and-evaluation process [originally specified in Subtitle C of Title I of the NWPA of 1982]. Alternatively, siting could occur through the efforts of the Nuclear Waste Negotiator, whose office was established for that purpose in the Nuclear Waste Policy Amendments Act of 1987.[52] In 1992, the NWPA was amended again and reset the termination date of the Office of the Nuclear Waste Negotiator.[53] Thus, DOE's consent-based siting efforts are limited to the authorities and limitations, in particular, those affecting states and DOE's consultation and cooperation with them, under Subtitle C of Title I of the NWPA.

DOE's current consent-based siting process will have to be consistent with the NWPA.[54] DOE's process does not include states in the decision process for a consent-based sited facility in a potential host community until site selection, some six to ten years after DOE's siting process

[50] Ibid.

[51] The Swiss consultant's report to the Board also addressed this topic. *Short report containing observations and suggestions for improvements in the U.S. Department of Energy's (DOE) consent-based siting process for one or more consolidated interim storage facilities for spent nuclear fuel*. https://www.nwtrb.gov/docs/default-source/meetings/2023/august/zuidema_report.pdf?sfvrsn=4 (last accessed April 4, 2024).

[52] DOE. 1991. *Preliminary Site Requirements and Considerations for a Monitored Retrievable Storage Facility*. https://curie.pnnl.gov/system/files/documents/not%20yet%20assigned/MRS_Preliminary_Site_Requirements.pdf (last accessed April 4, 2024).

[53] The Office shall cease to exist not later than 30 days after the date 7 years after the date of the enactment of the Nuclear Waste Policy Amendments Act of 1987. P.L. 102–486, 106 Stat. 2923 (1992).

[54] "Current law, including Subtitle C of Title I of the NWPA of 1982, as amended, allows the Department to proceed with a consent-based siting process, negotiate an agreement with a host community, and design and seek a license for an interim storage facility. … The consent-based siting process will follow applicable provisions in the NWPA concerning Tribes, states, and affected units of local government." DOE. 2023. *Consent-Based Siting Process for Federal Consolidated Interim Storage of Spent Nuclear Fuel*. Washington, DC: U.S. Department of Energy. April.

started.[55] Under Section 146 of the NWPA, state participation in a consolidated interim storage facility siting decision is limited to an allowance to submit a notice of disapproval to Congress.

The Board notes the nation's past lack of success in siting, constructing, and operating a consolidated interim storage facility or a repository for SNF and HLW is generally understood—for example by DOE, the Blue Ribbon Commission on America's Nuclear Future and the Board—to be related to an inadequate accounting of the pivotal role and power that states have in decision-making within their borders. In 1990, DOE stated in its briefing paper for the Nuclear Waste Negotiator, the failed "MRS siting experience at Oak Ridge illustrates the need for any discussions with a potential host to include both the local community (or Tribe) **and** [bold in the original] the State, as well as other affected stakeholders."[56] In the August 2023 workshop, DOE staff described lessons learned from the efforts of the Office of the Nuclear Waste Negotiator. DOE staff described that creating a process that shifts agency to states and provides funding to enable the shift will increase the chance of success.[57] The Blue Ribbon Commission on America's Nuclear Future stated that it believed "that states and tribes should retain—or where appropriate, be delegated—direct authority over aspects of regulation, permitting, and operations where oversight below the federal level can be exercised effectively and in a way that is helpful in protecting the interests and gaining the confidence of affected communities and citizens."[58] In its analysis of past siting efforts for deep geologic repositories, the Board[59] addressed the pivotal role and power that states have in decision-making within their borders and how strong forms of consent-based siting do not find a hospitable environment in the United States. The Board also discussed the difference between the consultation and cooperation approach adopted in the NWPA and a consultation and concurrence approach that would be

[55] See Figure 1 and Tables 2-6 in DOE (2023). Nonetheless, "throughout the consent-based siting process, DOE will also seek to engage and communicate with Tribes and states adjacent to the host." DOE. 2023. *Consent-Based Siting Process for Federal Consolidated Interim Storage of Spent Nuclear Fuel*. Washington, DC: U.S. Department of Energy. April.

[56] DOE also noted that the "Supreme Court let stand without review the U.S. Court of Appeals decision that NWPA did not require DOE to consult with any state before DOE submits the proposal [proposed site for MRS] to Congress." DOE also stated that "recognizing the difficulty of DOE-directed siting through national or regional screening, the DOE prefers an MRS facility that is sited through the efforts of the Nuclear Waste Negotiator." DOE noted that a negotiated site would avoid the institutional issues [dealing with states and Tribes] associated with a DOE-directed siting process. DOE. 1990. *MRS Siting Briefing*. https://curie.pnnl.gov/system/files/documents/not%20yet%20assigned/siting%20history.pdf (last accessed April 4, 2024).

[57] The Board notes that a DOE-funded draft report on the lesson learned characterized this concept as that state-level elected officials need to be able to 'win' in the eyes of their constituents, which means having some element of control over the process and make gains for the state.

[58] Blue Ribbon Commission on America's Nuclear Future. 2012. *Report to the Secretary of Energy*. Washington, DC. The Commission focused on an independent organization implementing a consent-based siting program and stated that "a new waste management organization must find ways to address state concerns while at the same time capitalizing on local support for proposed facilities." The Commission also stated that "it will be important to define the roles, responsibilities, and authorities of host state, tribal, and local governments both throughout the siting and licensing process and once a facility is operational."

[59] NWTRB. 2015. *Designing A Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Detailed Analysis*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. November.

more suited for the development of a consent-based siting process.[60] The Board notes that consultation and concurrence is likely to be more successful based upon domestic history and international experiences of nuclear waste described in the workshop. Based on past experiences, the Board believes these limitations—the lack of a repository program and a legal and regulatory framework that is inconsistent with obtaining consent from states—likely will impact DOE's potential success in siting, constructing, and operating a federal consolidated interim storage facility.

In keeping with the Board's technical mandate, the Board takes no position on whether a new effort should be undertaken to site either the country's first or second repository or whether to, or how to implement a consent-based siting approach; policymakers will make those decisions. The Board offers the following two observations that can inform Congressional decision-making regarding a path forward on SNF and HLW management and disposal *if* policymakers decide to move forward.

Observation 1: Information from the Board's past and recent reviews (including the experiences from other countries) shows that timely progress on a geologic disposal program for SNF and HLW is needed now to provide confidence that storage of SNF at a federal consolidated storage facility will be interim and not permanent. Such confidence will be necessary for consent from states, Tribes, and communities.

Observation 2: If a consent-based siting approach is used for a federal consolidated interim storage facility or a repository, a consultation and concurrence approach with states and Tribes, rather than the consultation and cooperation approach currently embodied in the NWPA will likely need to be explored both in terms of the timing (for example, when does consultation and concurrence begin and end) and extent (for example, what issues are subject to concurrence and who are the responsible concurring parties).

High Burnup SNF

DOE's HBF R&D has focused on better understanding the characteristics of HBF, including the fuel's cladding, to determine the performance and potential degradation of HBF during extended storage and subsequent transportation. DOE's efforts include the High Burnup Spent Fuel Data Project (or "Demo Project") that includes a demonstration cask ("demo cask") that stores HBF assemblies from pressurized water reactors. The project also includes detailed examinations of 25 HBF "sister rods" (aka sibling pins) withdrawn from assemblies in the demo cask or from assemblies similar to those in the cask.

At the Board's August 2023 Summer Meeting, national laboratory staff described DOE's gap analysis to support extended storage and transportation,[61] DOE's storage and transportation 5-

[60] Ibid. Metlay (2013) explores further the concept of consultation and concurrence. Metlay, D. 2013. *Consent-Based Siting: What Have We Learned?* Radwaste Solutions, Vol. 20, No. 3, pp. 28-36. https://www.nwtrb.gov/docs/default-source/staff/dsm-radwaste.pdf?sfvrsn=6 (last accessed April 4, 2024).

[61] Teague, M., S. Saltzstein, B. Hanson, K. Sorenson, and G. Freeze. 2019. *Gap Analysis to Guide DOE R&D in Supporting Extended Storage and Transportation of Spent Nuclear Fuel: An FY2019 Assessment*. SAND2019-15479R. Sandia National Laboratories. Albuquerque, NM. December.

year R&D plan,[62] and DOE's Demo Project. The presentation focused on DOE's HBF sibling pin test campaign. The Phase I testing[63] of sibling pins is ongoing, but largely complete, and DOE completed an extensive multi-modal transportation test with surrogate SNF. Key conclusions include 1) the cladding temperatures and hoop stresses in the HBF rods examined are too low to cause potentially damaging radial hydride formation within the cladding and 2) the mechanical loads expected during transportation are well within the capacity of the fuel cladding to resist degradation. As a result, many of the information gaps on issues of potential importance to HBF performance during storage and transportation can be closed.

The Board notes that DOE is well on the way to completing Phase I of its efforts to address issues related to the long-term storage and transportation of HBF. DOE has made substantial and beneficial progress in this regard and has essentially closed out many issues previously believed to be important. However, the Board notes that DOE has not addressed all the Board's 2021 recommendations on HBF.[64]

The national laboratory staff stated that as a follow-on to the Phase I testing, DOE and the national laboratories are proposing additional (Phase II) testing to gather additional data from the remaining HBF sibling pins. A national laboratory speaker described the Draft Phase II test priorities and prioritization approach. DOE funded development of, and the national laboratories have completed, a Phase II test plan.[65] The speaker described that the national laboratories reassessed gaps from the existing gap analysis on extended storage and transportation to help determine priorities for Phase II testing. One factor that the investigators considered in determining priorities for the Phase II program was testing to higher temperatures (to address potential industry actions to load hotter SNF for storage, which would raise overall cask and fuel temperature). A second factor, in which the U.S. Nuclear Regulatory Commission staff expressed interest, was addressing potential annealing and creep in SNF cladding because Phase I test results indicated reduced cladding yield strengths.

The Board held a follow-up technical fact-finding meeting with DOE and national laboratory staff on February 28, 2024, related to DOE's HBF R&D. The Board understands from discussions at the fact-finding meeting that DOE may soon make significant changes to its HBF storage and transportation R&D program. The Board also understands that the start of HBF Phase II testing is now on hold. The Board thanks DOE for discussing its high burnup SNF R&D and planning effort for its future R&D at the fact-finding meeting on February 28, 2024. The Board will provide, in a separate letter, the Board's assessment of the status of DOE's

[62] Saltzstein, S., B. Hanson, G. Freeze, and K. Sorenson. 2020. *Spent Fuel and Waste Science and Technology Storage and Transportation 5-Year R&D Plan*. SAND2020-9310R. Sandia National Laboratories. Albuquerque, NM. August.

[63] S. Saltzstein et al., *Visualization of the High Burnup Spent Fuel Rod Phase 1 Test Plan*, SAND2018-8042-O, 2018.

[64] NWTRB. 2021. *Evaluation of the Department of Energy's Research Program to Examine the Performance of Commercial High Burnup Spent Nuclear Fuel During Extended Storage and Transportation*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. July.

[65] Bignell, J. et. al. 2023. *High-Burnup Spent Fuel Data Project: Sister Rod Final Phase II Test Plan*. Albuquerque, New Mexico: Sandia National Laboratories. September https://www.osti.gov/servlets/purl/2204271 (last accessed April 4, 2024). At the time of the Summer Meeting, the report was still in draft form and not yet public.

current R&D efforts relative to the Board's 2021 recommendations on HBF.[66] The Board's updated assessment of DOE's HBF R&D could help DOE in its ongoing program reprioritization.

Other SNF topics

During the discussion of DOE's HBF R&D at the Board's August 2023 Summer Meeting, the Board raised other issues that are applicable to all commercial SNF, not just HBF. Previously the Board has addressed DOE's efforts related to potential repackaging of SNF from current containers into different packages and post-closure repository evaluations of potential criticality related to SNF disposal. At the Board's March 1-2, 2022, meeting, national laboratory staff described DOE's SNF cladding degradation modeling efforts applicable to a geological repository environment. DOE is developing the cladding degradation model, in part, to support post-closure repository evaluations of potential criticality related to SNF disposal in dual-purpose (storage and transportation) canisters. The Board noted that degradation of cladding, SNF assembly hardware (e.g., grid spacers), and baskets within a dual-purpose canister will affect the potential for criticality and that short-term testing indicates that the grid spacers would degrade faster than cladding. At the meeting, DOE recognized that partial grid collapse may occur for horizontally emplaced dual-purpose canisters, which could permanently obviate criticality. The Board observed that this partial grid collapse scenario deserves attention because it could reduce the probability of criticality, but that DOE could need additional knowledge of grid material properties and stresses.[67]

Fuel rod assembly mechanical behavior could affect other aspects of the management of SNF, such as potential repackaging of SNF from current containers into different packages. The Board recently completed an evaluation of DOE's R&D on the disposition of commercial SNF in dual-purpose (storage and transportation) canisters.[68] The evaluation addressed repackaging of SNF from current containers (e.g., dual-purpose canisters) into different packages and post-closure repository evaluations of potential criticality. In that report, the Board noted that using a risk approach, which considers both the probability and potential consequences, rather than solely focusing on detailed analyses of consequences could allow DOE to determine whether such detailed analyses are needed.[69] The Board notes that considering both the probability and consequences can be a basis for defining the scope of DOE's high burn SNF R&D program and individual activities.

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[66] NWTRB. 2021. *Evaluation of the Department of Energy's Research Program to Examine the Performance of Commercial High Burnup Spent Nuclear Fuel During Extended Storage and Transportation*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. July.

[67] Bahr, J.M. 2022. Board letter to Dr. Kathryn Huff with comments from March 2022 Board meeting (June 7, 2022), available at: https://www.nwtrb.gov/docs/default-source/correspondence/jmb041.pdf?sfvrsn=4 (last accessed April 4, 2024).

[68] NWTRB. 2024. *Evaluation of the U.S. Department of Energy Research and Development Activities on the Disposition of Commercial Spent Nuclear Fuel in Dual-Purpose Canisters*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. February.

[69] Bahr (2022) more fully discusses this approach. Bahr, J.M. 2022. Board letter to DOE following March 2022 meeting (June 7, 2022). https://www.nwtrb.gov/docs/default-source/correspondence/jmb041.pdf?sfvrsn=4. (last accessed April 4, 2024).

As discussed in the February 2024 fact-finding meeting, one source of information for fuel rod assembly mechanical behavior could be industry sources (e.g., fuel assembly vendors). The Board also notes that DOE's planned transport of the demo cask to a hot cell facility in 2027 and subsequent examination of HBF offer another opportunity to obtain data on fuel assembly mechanical behavior because the demo cask contains complete SNF assemblies.

Advanced Reactor Waste Disposition

In its May 12-13, 2021, public meeting the Board reviewed DOE's R&D activities related to advanced nuclear fuels for light water reactors, including accident tolerant fuels ("advanced nuclear fuels" henceforth), and the impact of these fuels on SNF management and disposal. By that point, DOE had completed a preliminary, high-level, R&D gap analysis regarding the performance of advanced fuels [including metallic and TRISO (tri-structural isotropic) fuels during storage and transportation].[70] At the meeting, DOE staff stated that significantly different fuel systems (e.g., TRISO, metallic fuels) may require a new storage, transportation, and disposal container design. The Board recommended that DOE expand the scope of its efforts beyond storage and transportation to include disposal of SNF resulting from the use of advanced nuclear fuels in the next update to DOE's gap analysis report for SNF management.[71]

More recently, DOE's advanced reactor waste disposition R&D efforts accelerated due to dedicated funding in fiscal years 2022 and 2023. At the Board's Summer Meeting, DOE staff described how they are addressing back-end management of SNF and HLW from advanced reactors. DOE is seeking information from advanced reactor developers necessary to address regulatory and legal issues (such as, with the Standard Contract) and to identify storage, transportation, and disposal R&D gaps related to the SNF and HLW generated by advanced reactors. DOE is pursuing two efforts to address the waste from advanced reactors.

First, section 302(b) of the NWPA is the advance contracting requirement related to the disposal of SNF and HLW generated from the reactor's operation that involves the Secretary of Energy.[72]

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[70] Honnold, P. et. al. 2021. *High Level Gap Analysis for Accident Tolerant and Advanced Fuels for Storage and Transportation*. Albuquerque, New Mexico: Sandia National Laboratories. April https://www.osti.gov/servlets/purl/1813674 (last accessed April 4, 2024).

[71] Bahr, J.M. 2022. Board letter to DOE following May 2021 meeting (August 12, 2021). https://www.nwtrb.gov/docs/default-source/correspondence/jmb035.pdf?sfvrsn=6. (last accessed April 4, 2024). DOE responded to the Board letter. Griffith, A. 2022. DOE Response to the Nuclear Waste Technical Review Board (NWTRB) Comments and Recommendations on Advanced Nuclear Fuels and Accident Tolerant Fuels Spring 2021 NWTRB Meeting (April 7, 2022). https://www.nwtrb.gov/docs/default-source/correspondence/doe04072022.pdf?sfvrsn=6. (last accessed April 4, 2024).

[72] "(1) (A) The Commission shall not issue or renew a license to any person to use a utilization or production facility under the authority of section 103 or 104 of the Atomic Energy Act of 1954 (42 USC 2133, 2134) unless– (i) such person has entered into a contract with the Secretary under this section; or (ii) the Secretary affirms in writing that such person is actively and in good faith negotiating with the Secretary for a contract under this section. (B) The Commission, as it deems necessary or appropriate, may require as a precondition to the issuance or renewal of a license under section 103 or 104 of the Atomic Energy Act of 1954 (42 USC 2133, 2134) that the applicant for such license shall have entered into an agreement with the Secretary for the disposal of high-level radioactive waste and spent nuclear fuel that may result from the use of such license."

As DOE staff described it, DOE will need enough data, describing the characteristics of both the initial fuel and the discharged SNF and HLW and SNF and HLW operations (e.g., fuel irradiation time and storage canister design), from a potential applicant to allow DOE to determine whether to enter such a contract. DOE's Office of Nuclear Energy is developing a report for each new reactor design that is based on proprietary data provided by the reactor vendor. Each report will address back-end management of SNF and HLW for each reactor and the report will be provided to DOE's Office of General Counsel (OGC) for review and action (e.g., OGC can decide to send a letter to the applicant affirming that it is actively and in good faith negotiating with the Secretary for a contract—the applicant can then use the DOE letter in the U.S. Nuclear Regulatory Commission licensing process). DOE staff stated it needs four to six months to develop a report that contains the technical assessment of the feasibility of storage, transportation, and disposal of the advanced reactor's fuel and HLW, if any.

Second, DOE is developing a report that addresses advanced reactors SNF and wastes,[73] including the storage, transportation, and disposal of SNF and HLW from TRISO- and metallic-fueled reactors and molten salt reactors. The national laboratory staff described an effort to develop a detailed R&D gap analysis for accident tolerant fuels, high burn/high enrichment fuels, and advanced reactor SNF and waste forms for storage and transportation in fiscal year 2024 and beyond. The national laboratories plan to conduct a features, events, and processes analysis, at the same time, for the same materials to identify the R&D gaps for disposal.

Finding 6: DOE has initiated an effort to assess the potential impacts of various advanced nuclear fuels on storing, transporting, and disposing of SNF and HLW by requesting data from advanced reactor vendors. DOE is also developing a strategy to identify knowledge gaps and outline areas where further research would contribute to a well-defined disposition pathway for SNF and HLW resulting from advanced reactor operations. This effort will inform DOE decisions concerning how to proceed and how to deal with the impacts. The Board commends DOE for initiating this assessment and strongly endorses this effort.

[73] Matteo, E. et al. 2023. *Advanced Reactors Spent Fuel and Waste Streams Disposition Strategies*. Albuquerque, New Mexico: Sandia National Laboratories. June.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
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May 28, 2024

Dr. Michael Goff
Acting Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Dr. Goff:

On behalf of the U.S. Nuclear Waste Technical Review Board (Board), I want to thank you and your staff, as well as the staff from the national laboratories, for supporting a recent technical fact-finding meeting related to the U.S. Department of Energy (DOE) research on commercial high burnup spent nuclear fuel (HBF). The meeting was held in-person (and virtually) in the Board's offices on February 28, 2024. The Board requested the fact-finding meeting to discuss DOE's activities related to examining and testing HBF, which is part of the DOE-sponsored High Burnup Spent Fuel Data Project (HBF Data Project). These activities include DOE's plans for examining the irradiated pressurized water reactor (PWR) HBF that is now in dry storage in a specially modified TN-32B cask (the HBF Demo Cask).

The following discussion is organized in the same order as the Board recommendations from the Board HBF report.[1] For reference, a full listing of the findings and recommendations from the HBF Report are included in Attachment 1.

General.

HBF Report Recommendation 1.a., regarding documentation that summarizes the results of DOE research and development (R&D): The Board understands, through staff-to-staff interactions, that DOE continues to document the results of its HBF sister rod[2] research and is working to produce a single summary report regarding factors affecting fuel rod integrity during storage and transportation. The Board looks forward to seeing the new summary report and encourages DOE to focus its efforts on building the sound technical bases that will be needed to support future NRC licensing of HBF storage, transportation, and disposal activities. When DOE publishes the summary report, the Board will consider HBF Report Recommendation 1.a. closed.

[1] NWTRB. 2021. *Evaluation of the Department of Energy's Research Program to Examine the Performance of Commercial High Burnup Spent Nuclear Fuel During Extended Storage and Transportation*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. July.

[2] A sister rod (or sibling pin) is a rod that has similar characteristics to one that is stored in the HBF Demo Cask. There were two fuel assembly types that served as donors for sister rods: (1) assemblies having similar designs and operating histories to those assemblies chosen for storage in the HBF Demo Cask; or (2) actual fuel assemblies selected for storage in the cask.

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HBF Report Recommendation 1.b., regarding collaboration with research activities at the Electric Power Research Institute (EPRI) and in other countries: The Board acknowledges DOE's commitment to continue working with EPRI and other countries. The Board commends DOE for working to establish a new Memorandum of Understanding with EPRI in this regard. The Board encourages DOE to expand its collaboration with researchers in other countries where relevant research on HBF continues, e.g., at BGZ [Gesellschaft für Zwischenlagerung mbH] in Germany and at the Paul Scherrer Institute in Switzerland. No additional action is needed, and the Board considers this recommendation closed.

HBF Report Recommendation 1.c., regarding efforts to demonstrate that the work completed to date bounds all existing spent nuclear fuel (SNF) types: The Board notes that the results of the HBF Data Project published to date indicate that, for the HBF types tested, the HBF will not be significantly degraded during storage and transportation, and is expected to meet the relevant requirements promulgated by the Nuclear Regulatory Commission (NRC). However, it is not yet clear that the results of the HBF Data Project testing for irradiated PWR assemblies will bound all existing or new types of SNF, such as boiling water reactor (BWR) HBF, SNF assemblies that include burnable absorbers, or accident tolerant fuel, which will soon join the inventory of SNF. Because the HBF Data Project tested a limited range of fuel and cladding types, fuel operating histories, temperatures, and storage canister designs, DOE will need to show that the HBF Data Project results bound all HBF types. Alternative methods for doing this include accessing commercial fuel vendor data, obtaining and examining the other HBF types, or developing computer models that can accurately predict the characteristics and behavior of the HBF (see HBF Report Recommendation 6 below). The Board reaffirms HBF Report Recommendation 1.c.

SNF Drying.

HBF Report Recommendation 2.a., regarding an evaluation of the amount of chemisorbed water remaining after drying of commercial SNF canisters and the effect of water on SNF and canister internal components: During the fact-finding meeting, the DOE representative noted, and the Board acknowledged, that all commercial SNF canisters are dried using an NRC-accepted drying process (e.g., vacuum drying or forced helium dehydration). SNF canisters must complete the drying process before they are moved to dry storage, and to date, no significant issues have been noted with drying or post-drying storage. The NRC-accepted processes are based on one set of parametric study results and an assumption that drying will eliminate water to a quantity that will generate no more than one (1) mole of oxidizing gases via radiolysis—this equates to 0.1 vol% (0.43 mole) water (PNL-6365).[3]

As described below, there are some documented cases where commercial SNF canisters, subjected to the NRC-accepted drying process, were found to contain more than 0.1 vol% of water after drying. In one case, the HBF Demo Cask, dried and stored at the North Anna Nuclear Generating Station in 2017, was sampled and tested for water content after drying by

[3] Knoll, R.W. and E.R. Gilbert. 1987. *Evaluation of Cover Gas Impurities and Their Effects on the Dry Storage of LWR Spent Fuel*. PNL–6365. Richland, Washington: Pacific Northwest National Laboratory. November.

Dominion Energy (the operator at North Anna). The results, reported by EPRI,[4] confirmed water in the cask after drying at levels greater than 0.1 vol% (results ranged from 0.16 to 0.83 vol%) and were confirmed by measurements at Sandia National Laboratories (SNL). However, at both Dominion Energy and SNL, there were difficulties with handling the samples and measuring water vapor content, and EPRI concluded that "it is difficult to draw any solid conclusions" regarding water content (see the report cited in footnote 4).

In a second example, commercial SNF (including damaged SNF) that had been stored at the West Valley Demonstration Project (WVDP) was loaded into two different storage and transport casks, the TN-REG (holding SNF from the R.E. Ginna nuclear power plant) and the TN-BRP (holding SNF from the Big Rock Point nuclear power plant), in 2001. The casks were drained and dried using the NRC-approved drying process.[5] However, after the drying process was completed, internal cask pressure continued to rise. Conservative estimates of the amount of water remaining in the casks (e.g., water in interstitial spaces in damaged fuel rods as well as physisorbed and chemisorbed water in oxide and crud layers) were 22.3 liters in the TN-BRP cask and 13.3 liters in the TN-REG cask (see the report cited in footnote 5). Additional venting and backfill steps had to be taken to remove more water as well as the gases generated by radiolysis. Eventually, the casks were approved for transportation by the NRC and were shipped by rail from WVDP to Idaho in July 2003. The Board notes that this is an extreme example, due to the large number of damaged SNF rods included in the two casks.

Given these examples, there continues to be uncertainty regarding the amount of water remaining in an SNF canister after drying. The Board believes it is prudent for DOE to better understand the amount of water that may remain in an SNF canister after drying and better understand the effect that water may have on the characteristics and behavior of SNF and canister internals after extended storage and during transportation. Therefore, the Board reaffirms its HBF Report Recommendation 2.a.

HBF Report Recommendation 2.b., regarding measuring water content in a commercial SNF canister: See the discussion above, under HBF Report Recommendation 2.a. The Board reaffirms its HBF Report Recommendation 2.b.

Hydrogen Effect in HBF Cladding.

HBF Report Recommendation 3.a., regarding the use of irradiated SNF cladding in testing: The Board understands that ongoing and proposed DOE-sponsored research on HBF is focused on using only irradiated cladding. No additional action is needed, and the Board considers this recommendation closed.

HBF Report Recommendation 3.b., regarding the development of standard test procedures: The Board acknowledges that DOE has worked to provide consistency in the testing programs across the national laboratories. Furthermore, for some test procedures (e.g., ring compression testing),

[4] EPRI. 2019. *High Burnup Dry Storage Research Project Cask Loading and Initial Results*. Electric Power Research Institute. Palo Alto, California. 3002015076. October.

[5] Winston, P.L. 2018. *Potential Research and Development Opportunities for Light Water Reactor Spent Nuclear Fuel at INL*. INL/EXT-18-45988, Revision 0. Idaho National Laboratory: Idaho Falls, Idaho. August.

national consensus standards have been developed with input from the DOE-sponsored testing program. No additional action is needed, and the Board considers this recommendation closed.

HBF Report Recommendation 3.c., regarding the development of a database for test results related to hydride reorientation in zirconium-based alloy cladding: Based on discussions in the fact-finding meeting, the Board understands that the current research related to hydride reorientation may be concluding within a year or two. The Board notes that the national laboratories have routinely made their testing results publicly available through annual reports posted on the OSTI.gov website. These reports serve as a good source of information regarding hydride reorientation testing. Given the availability of these reports, the Board considers this recommendation closed. However, if additional funding becomes available, the Board encourages DOE to consider creating a unified database of testing results related to hydride reorientation in zirconium-based alloy cladding.

HBF Performance Under Normal Conditions of Dry Storage.

HBF Report Recommendation 4.a., regarding relating HBF testing results to the closure of HBF technical information needs (gaps): The Board notes that DOE's most recent gap analysis report[6] and 5-year storage and transportation R&D test plan[7] lay out the information to be collected during testing and identify what is needed to close each gap. The Board understands, from discussions at the fact-finding meeting, that these two R&D planning documents may soon be revised or superseded by other R&D planning documents. The Board intends to interact with DOE to remain informed of DOE's evolving R&D plan so that timely Board feedback may be provided. The Board commends DOE for identifying what information is needed to close the gaps, and encourages DOE to continue this practice going forward. No additional action is needed, and the Board considers this recommendation closed.

HBF Report Recommendation 4.b., regarding preserving HBF sister rods or rod segments: During the fact-finding meeting, DOE representatives stated that all unused HBF sister rods or rod segments would be preserved for future examinations. No additional action is needed, and the Board considers this recommendation closed.

HBF Report Recommendation 4.c., regarding thermal modeling development: The Board understands that DOE, in cooperation with EPRI, continues to refine thermal models (COBRA-SFS and STAR-CCM+) that can predict temperature profiles in SNF canisters. These efforts are mature and include collaboration with research groups in other countries. For example, EPRI published the results of an international collaboration where many thermal models were benchmarked against temperatures measured in the HBF Demo Cask, and work continues to

[6] Teague, M., S. Saltzstein, B. Hanson, K. Sorenson, and G. Freeze. 2019. *Gap Analysis to Guide DOE R&D in Supporting Extended Storage and Transportation of Spent Nuclear Fuel: An FY2019 Assessment*. SAND2019-15479R. Sandia National Laboratories. Albuquerque, NM. December.

[7] Saltzstein, S., B. Hanson, G. Freeze, and K. Sorenson. 2020. *Spent Fuel and Waste Science and Technology Storage and Transportation 5-Year R&D Plan*. SAND2020-9310R. Sandia National Laboratories. Albuquerque, NM. August.

quantify model uncertainties.[8] The Board notes that DOE has completed other work to benchmark its thermal models using a variety of dry storage casks (e.g., horizontal and vertical) and SNF configurations (PWR, BWR, single assembly, multiple assemblies). Work at SNL benchmarked the models against a surrogate BWR fuel assembly in a horizontal dry storage cask, including conditions of helium gas mixed with air.[9] PNNL validated the models for a belowground vertical dry cask storage system, considering environmental effects of external wind and solar radiation at the air intake and exhaust vents.[10] PNNL also conducted comprehensive sensitivity and uncertainty analyses of the thermal models, including input uncertainty (manufacturing tolerance and boundary conditions), numerical uncertainty (discretion and convergence), and model uncertainty (correlations, simplifications, and assumptions).[11] A Latin hypercube sampling statistical method was used to run the uncertainty analysis and determine the 95% confidence error bars associated with the temperature predictions. Based on the sensitivity study and uncertainty quantification results, PNNL reached the following conclusions, among others:

- Key sensitivities were identified in the TN-32B [Demo] Cask; these will inform uncertainty analysis and future transient modeling.
- [Latin hypercube sampling uncertainty quantification] was demonstrated as a practical method for UQ even with computationally intensive full cask models.
- Full cask model uncertainty results showed good agreement with data and demonstrated the importance of input parameter distribution selection.
- [A m]ethodology for a streamlined workflow utilizing multiple analysis tools was developed and can be applied to any future spent fuel cask modeling or other relevant systems that can be computationally modeled.[12]

Based on these results, the Board considers this recommendation closed.

HBF Performance Under Normal Conditions of Transport.

HBF Report Recommendation 5., regarding SNF performance under normal conditions of transport: The Board observes that the DOE-sponsored research and analysis of SNF under normal conditions of transport included extensive field testing with instrumented equipment as well as detailed modeling of the mechanical behavior of SNF assemblies. The field testing

[8] EPRI. 2022. *International Thermal Modeling Benchmark Project: Phase I Results*. Electric Power Research Institute. Palo Alto, California. 3002023976. November.

[9] Pulido, R.J.M., R.E. Fasano, E.R. Lindgren, R.W. Williams, G.T. Vice, and S.G. Durbin. 2021. *Investigation of Thermal-Hydraulic Effects of Dry Storage Canister Helium Backfill Loss Using the Horizontal Dry Cask Simulator*. SAND2021-3653R. Sandia National Laboratories. Albuquerque, NM. March.

[10] Jensen, B.J., S.R. Suffield, M.E. Higley, B.M. Hom, and J.A. Fort. 2021. *Modeling Environmental Effects on Ventilated Spent Fuel Storage Systems*. PNNL-32093. Richland, Washington: Pacific Northwest National Laboratory. September.

[11] Richmond, D. J., S. R. Suffield, J. A. Fort, and M. E. Higley. 2022. *Uncertainty in Thermal Modeling of Spent Nuclear Fuel Casks*. PNNL-33409. Richland, Washington: Pacific National Laboratories. September.

[12] Ibid.

results showed that normal conditions of transport impart mechanical loads on the fuel cladding that "are orders of magnitude lower than those needed to challenge cladding integrity,"[13] and more specifically, "the strain range of 1 uE to 100 uE [measured during transportation testing] is far below irradiated zirconium alloy cladding yield strength (about 10,000 uE)."[14] The structural dynamic analysis of SNF conducted by PNNL included parametric studies of key factors, such as cladding stiffness and pellet-cladding bonding. PNNL reported "Both low fuel rod stiffness conditions and high fuel rod stiffness conditions were evaluated. Across all cask motion cases, the models predict the peak cladding strains will remain below the strains recorded during the [transportation testing],"[15] PNNL also concluded "The calculated results are not sensitive to variations in fuel assembly design. The results are slightly influenced by the presence of a fuel rod canister, but the effect is not strong enough to significantly change the calculated strains."[16] Based on these results, the Board considers this recommendation closed.

Fuel Performance Modeling.

HBF Report Recommendation 6., regarding fuel performance modeling (i.e., multiphysics modeling of hydrogen concentration in cladding, hydrogen migration, hydride formation, hydride reorientation, pellet-cladding interaction, fission gas release, and the effects of these phenomena on cladding mechanical properties): The Board reaffirms recommendation 6, in the case that DOE cannot obtain the needed data from SNF post-irradiation examinations to support amendments to NRC Certificates of Compliance for transportation, as discussed below.

The Board notes that SNF characteristics and behavior for low burnup SNF are well understood and factored into NRC-approved Certificates of Compliance for SNF extended storage and transportation. Less is understood about the characteristics and behavior of HBF. The DOE HBF Data Project has obtained testing results that provide confidence that certain types of HBF can meet the requirements for extended storage and transportation. However, this testing has been limited to an incomplete range of fuel and cladding types, fuel operating histories, temperatures, and storage canister designs.

In order to understand the characteristics and behavior of other types of HBF (PWR HBF with more extreme operating histories, BWR HBF, SNF assemblies containing burnable absorbers, etc.), and support the needed amendments to NRC Certificates of Compliance for extended storage and transportation, DOE will need to obtain post-irradiation examination data relevant to these other HBF types. This data may be available from commercial nuclear fuel vendors or sources in other countries who have conducted post-irradiation examinations of relevant HBF, and it may be possible for DOE to gain access to the data. If DOE cannot gain access to this data, DOE would need to obtain samples of these HBF types and complete the necessary post-

[13] Klymyshyn, N.A., P. Ivanusa, K. Kadooka, C. Spitz, J. Fitzpatrick, P.J. Jensen, S..B. Ross, and B. Hanson. 2019. *Structural Dynamic Analysis of Spent Nuclear Fuel*. PNNL-29150. Richland, Washington: Pacific Northwest National Laboratory. September.

[14] Ibid.

[15] Ibid.

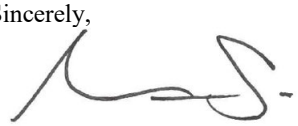
[16] Ibid.

irradiation examinations, or develop fuel performance models that can be used to predict the characteristics and behavior of the full range of HBF types.

Timing is a consideration. Based on the "roadmap" published in DOE's consent-based siting process document,[17] a federal consolidated interim storage facility may not begin operations until 2035-2040, at the earliest. The Board also notes that initial DOE planning[18,19] suggests removing SNF from shutdown nuclear power plant sites first (within the limits of the Standard Contract).[20] In this scenario, initial SNF shipments would comprise only older low burnup SNF and, as discussed above, low burnup SNF is well understood, so no additional information is needed before transportation. DOE also estimates that removing SNF from the oldest shutdown sites would take four years and that SNF shipping rates would start at 500 MTHM [metric tons heavy metal of SNF]/per and ramp up to 3,000 MTHM/year over the course of seven years (see DOE 2013; footnote 18). Given these SNF transportation assumptions, the Board observes that it may be two to three decades before any appreciable quantities of HBF are transported—and before information is needed to support amendments to NRC Certificates of Compliance for transportation of HBF types not included in the HBF Data Project. DOE may use this intervening time to determine which approach to obtaining the necessary HBF data will be most effective and efficient.

Thank you again, on behalf of the Board, for the participation of DOE and laboratory staff at our February 2024 fact-finding meeting. We look forward to continuing our review of DOE's activities related to managing and disposing of SNF and high-level radioactive waste (HLW).

Sincerely,



Nathan Siu
Chair

Attachment

cc: Mr. Paul Murray, DOE-NE
Dr. Erica Bickford, DOE-NE

[17] DOE. 2023. *Consent-based Siting Process for Federal Consolidated Interim Storage of Spent Nuclear Fuel*. Department of Energy. Washington, DC. April.

[18] DOE. 2013. *Strategy for the Management and Disposal of Used Nuclear Fuel and High -Level Radioactive Waste*. Department of Energy. Washington, DC. January.

[19] DOE. 2016. *Nuclear Fuels Storage and Transportation Requirements Document*. FCRD-NFST-2013-000330, Revision 2. Department of Energy. Washington, DC. February.

[20] Title 10, Code of Federal Regulations, Part 961, "Standard Contract for Disposal of Spent Nuclear Fuel and and/or High-Level Radioactive Waste." Government Printing Office. Washington, DC.

Attachment 1

Findings and Recommendations from the Board Report:
Evaluation of the Department of Energy's Research Program to Examine the Performance of Commercial High Burnup Spent Nuclear Fuel During Extended Storage and Transportation
(July 2021)

1. General Recommendations

   a. Summary Finding: The Board finds that the results of DOE-sponsored research on HBF have been reported by a variety of organizations and in a variety of formats but there is no compendium that contains the results of all DOE research related to extended storage and transportation of HBF. (general finding; report section not applicable)

      Recommendation: The Board recommends that, following the completion of HDRP sister rod examinations and drop testing of surrogate SNF assemblies, DOE prepare a document that compiles the results of DOE research on extended storage and transportation of HBF, with the purpose of providing the technical bases for conclusions reached regarding HBF performance during extended storage and transportation.

   b. Summary Finding: The Board finds that important research relevant to extended storage and transportation of HBF is being sponsored by organizations outside of DOE, both in the U.S. and in other countries. (See section 2.3 and Appendices A, F, and G)

      Recommendation: The Board recommends that DOE continue to review the results of the Electric Power Research Institute's Extended Storage Collaboration Program and research in other countries to determine if the results of ongoing HBF studies either change the priorities for DOE's planned research or add technical information needs requiring new research.

   c. Summary Finding: The Board finds that many of the tests and models used to determine the performance of HBF have been completed for a relatively narrow range of fuel and cladding types, burnup levels, temperatures, storage and transportation system designs, etc. The limitations of the tests and models are not always clear with respect to their applicability to a wider range of HBF types, storage and transportation system designs, and storage and transportation conditions. (See sections 3.1–3.5)

      Recommendation: The Board recommends that DOE indicate how its tests and models do or do not apply to the broad range of HBF types and storage and transportation system designs for which information is still needed and take steps to meet those remaining technical information needs.

2. Spent Nuclear Fuel Drying

   a. Summary Finding: The Board finds that water remaining inside SNF dry cask storage systems may cause corrosion of SNF cladding or the internal components of the system and significant uncertainty remains regarding the quantities of hydrogen and oxygen gases that can be generated due to radiolysis of the remaining water. While the SNF drying process used by industry removes most of the water, including water physically adsorbed on metal surfaces, some of the more tightly bound chemisorbed water is likely to remain. (See section 3.1 and Appendix E)

      Recommendation: The Board recommends that DOE evaluate the extent to which chemisorbed water remains after the drying process is completed and whether this water could affect the ability of SNF cask or canister systems and their contents to continue to meet storage and transportation requirements.

   b. Summary Finding: The Board finds that few gas samples have been obtained from inside dry cask storage systems containing commercial SNF. (See section 3.1 and Appendix E)

      Recommendation: The Board recommends that DOE further explore the possibility of monitoring the moisture content and gas composition of dry cask storage systems loaded by nuclear utilities with HBF for an extended period. DOE should improve and validate gas sampling methods, with a particular focus on water vapor sampling and measurement, before the next samples are obtained.

3. Hydrogen Effects in High Burnup Fuel Cladding

   a. Summary Finding: The Board finds that data obtained from testing of unirradiated cladding does not replicate data obtained from testing of irradiated cladding. (See section 3.2. and Appendix F)

      Recommendation: The Board recommends that, as the need for new testing of HBF cladding is identified, DOE's research efforts make use of irradiated samples rather than unirradiated samples to avoid the large uncertainties and difficulties in interpreting test results that arise from using unirradiated samples.

   b. Summary Finding: The Board finds that there are a variety of tests methods for examining hydride reorientation in HBF cladding and that the results of the testing are reported with significant format variations that make comparison of results difficult. (See section 3.2 and Appendix F)

      Recommendation: The Board recommends that DOE define a standard set of test parameters (e.g., fuel burnup, test temperatures, rod internal pressures) and results, where possible, that must be recorded for all DOE-funded research related to hydride reorientation. This will allow DOE managers, computer model developers, and nuclear industry practitioners to better use the data to make scientifically meaningful

comparisons of experimental results from various research sources, even when the data were not collected for that purpose.

c. Summary Finding: The Board finds that data on the characteristics of HBF (e.g., HBF rod internal pressures) and results of research on hydride formation and hydride reorientation in zirconium-based alloys are reported by a variety of organizations and saved in a variety of information archives. (See section 3.2 and Appendix F)

   Recommendation: The Board recommends that DOE gather into one database all relevant information available on hydride-related testing of zirconium-based alloys to provide the basis for (1) evaluating the effects of variables that influence hydride reorientation; (2) supporting the ongoing development of new standards for inducing hydride reorientation in test samples and quantifying hydride reorientation and its effects; (3) explaining the differences in hydride reorientation and its effects among cladding types; and (4) developing computer models to predict hydride formation and reorientation in all zirconium-based cladding types, including those that have not been tested.

4. High Burnup Fuel Performance under Normal Conditions of Dry Storage

   High Burnup Dry Storage Research Project

   a. Summary Finding: The Board finds that DOE has not clearly indicated how the data obtained from the HDRP and related sister rod testing will be used to meet the DOE-identified technical information needs or support modeling of HBF performance during dry storage and transportation. (See section 3.3 and Appendix G)

      Recommendation: The Board recommends that the test plan for the HDRP sister rods should (a) link each proposed test to one or more of the technical information needs identified in the most recent DOE report on technical information needs and (b) explain how the results of each proposed test will be used to meet the technical information needs or support modeling of HBF performance during dry storage.

   b. Summary Finding: The Board finds that obtaining and characterizing the sister rods has been a worthwhile undertaking but has required the expenditure of extensive time and resources. These rods constitute a valuable asset for future research and development. (See section 3.3 and Appendix G)

      Recommendation: The Board recommends that DOE preserve selected sister rods (or rod segments and components) for future use in follow-up studies to the HDRP, if needed, or in support of other programs.

      Thermal Modeling

   c. Summary Finding: The Board finds that DOE-sponsored thermal models will be valuable tools for calculating realistic SNF cladding temperatures during drying and storage in dry cask storage systems if realistic input data are used and if the predicted

temperature uncertainty due to all sources of uncertainty can be quantified and defensibly bounded. (See section 3.3 and Appendix G)

Recommendation: The Board recommends that DOE continue its activities to ensure its thermal models are rigorously validated, including industry-standard uncertainty quantification, for use on SNF storage or transport systems. Important factors to consider during validation are the various designs of cask and canister systems, inclusion of new fuel designs like accident tolerant fuel, and inclusion of SNF assemblies with other components, such as control rod assemblies or discrete burnable absorber rods.

5. High Burnup Fuel Performance under Normal Conditions of Transport

   a. Summary Finding: The Board notes that DOE continues to develop a structural model that can be used to predict the structural response of SNF, SNF cask or canister systems, and SNF transport vehicles under normal conditions of transport. The Board finds that the DOE structural model development and validation efforts include a number of uncertainties stemming from the use of dummy or surrogate fuel assemblies and unirradiated fuel material properties. (See section 3.4 and Appendix H)

   Recommendation: The Board recommends that DOE quantify the uncertainties introduced by the use of unirradiated assembly components and surrogate components, such as concrete mock-SNF assemblies, in experiments being used to benchmark the DOE structural model. The structural model should also be exercised to evaluate HBF cladding strains for different cask and canister types, fuel types, and degree of pellet-cladding bonding.

6. Fuel Performance Modeling

   a. Summary Finding: The Board finds that the limited testing of irradiated HBF provides a potentially insufficient database of mechanical properties and other HBF characteristics required to develop accurate fuel performance models. (See section 3.5 and Appendix I)

   Recommendation: The Board recommends that DOE continue to develop fuel performance models (e.g., BISON) that are validated utilizing experimental data. In so doing, DOE-sponsored fuel performance model developers should clearly identify the data they need to develop and validate models to DOE-sponsored experimentalists, and experimentalists should clearly explain the capabilities and limitations of their experimental equipment and facilities to model developers. This close collaboration is needed to ensure optimal experimental setup and collection of the data needed to improve the models and achieve a better understanding of HBF characteristics and performance.

Department of Energy
Washington, DC 20585

SEP 19

September 9, 2024

Dr. Nathan Siu
Chair
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Suite 1300
Arlington, VA 22201-3367

Dear Dr. Siu,

The U.S. Department of Energy's (DOE) Office of Nuclear Energy appreciates your letter of August 24, 2023, which summarized the Nuclear Waste Technical Review Board's 2023 Spring Public Meeting. During the meeting, held March 28, 2023, in Orlando, Florida, information was presented by DOE and national laboratory participants on DOE's activities related to transportation plans for and evaluations of commercial spent nuclear fuel (SNF) and high-level radioactive waste (HLW). Additionally, activities related to the consent-based siting process for siting one or more federal interim storage facilities were discussed.

The Board's letter provided findings and recommendations on these DOE activities.

DOE thanks the Board for their input and looks forward to its future insights on DOE's activities related to the management and disposal of SNF and HWL.

The enclosure provides the DOE's responses to the Board's specific findings and recommendations. If you have any questions on the responses, please contact Erica Bickford at erica.bickford@nuclear.energy.gov.

Sincerely,

K. Michael Goff
Acting Assistant Secretary
Office of Nuclear Energy

Enclosure

DOE Responses to NWTRB Board's Comments, Observations, Findings, and Recommendations in their letter to Assistant Secretary for Nuclear Energy, Dr. Huff, dated August 24, 2023

NWTRB Board Comment 1a:
The Board finds that DOE is making progress in its IWM program, particularly in three major cross-cutting areas: (i) transportation preparations, (ii) storage design and regulatory considerations, and (iii) systems analysis tools and integration. The Board recognizes that DOE activities related to CBS of a federal interim storage facility are in the early stages of a multi-year effort.

DOE Response:

The U.S. Department of Energy (DOE) appreciates the Board's finding regarding the progress of the Office of Integrated Waste Management, which as of an April 2024 office reorganization is now divided into two separate offices, the Office of Storage and Transportation (S&T) and the Office of Consent-Based Siting. In the past few years IWM has hired over 10 new employees to support execution of the program mission to site one or more federal consolidated interim storage facilities, using a consent-based siting process, ready to receive spent nuclear fuel (SNF) as soon as practicable. While still in the first stage of DOE's *Consent-Based Siting Process for Federal Consolidated Interim Storage of Spent Nuclear Fuel* (2023), the program looks forward to building capacity and engaging in broader conversations with the public, interested stakeholders, State and Tribal government partners, and others through our 12 Consent-Based Siting Consortia awardees along with other new and ongoing Departmental activities.

NWTRB Board Comment 1b:
The Board finds that incorporating public feedback in the early development of a Package Performance Study is important; the Board previously encouraged DOE to engage early with stakeholders in developing a plan. To date, DOE has obtained limited feedback from a few groups, but has not yet received broad public feedback on its early plans for a Package Performance Study.

If DOE pursues a Package Performance Study, the Board recommends that DOE first determine what the public's major safety concerns are, how public participants would like to be involved, and how meeting this goal can be integrated with regulatory testing goals. This will better enable DOE to identify the key issues to be addressed and to set clear outcomes for any demonstration. Further, planning for the demonstration should include a strategy for effective communication of test goals, expectations, and results to the public, and for a post-demonstration assessment of how well the test met its goals.

DOE response:
IWM's (now S&T's) primary motivation for pursuing a package performance study (PPS-now being called a package performance demonstration, or PPD) is to build public trust and confidence in the safety of transporting SNF to federal storage and disposal facilities in general,

and specifically transportation by rail. For a PPD to be successful, incorporating perspectives of key partners, such as State and Tribal governments who have primary responsibility for public safety within their jurisdictions, communities who may consider hosting a federal storage or disposal facility, members of the public, and other stakeholders is critically important.

However, a PPD is currently estimated to cost between $50 - $100 million dollars over up to 5 years, depending on the scope and scale of the demonstration(s) and any potential cost-sharing with project partners. Previous attempts have been made over the last 25 years by the Nuclear Regulatory Commission (NRC) and S&T predecessor programs at DOE to conduct a PPS, yet none moved beyond the planning stages. Until S&T has confidence that appropriations will be available to execute a PPD, outreach and engagement on such a demonstration is being carefully managed to limit the risk of building up expectations that will ultimately go unfulfilled and undermine the objective of building public trust and confidence. In May 2024, DOE approved Critical Decision-0 (CD-0), Approve Mission Need for the Federal Consolidated Interim Storage Facility (CISF) Project. Obtaining CD-0 is the first step (of a 5-step process) under the DOE rules for project acquisition. The PPD was included as a component of that project for the purposes of mitigating risk for large-scale transportation of spent nuclear fuel. The CISF Project, including the PPD, are expected to be submitted in future budget requests as a project line-item, which provides a measure of confidence for S&T to continue the PPD engagement process that it has already begun.

Subsequent to the March 2023 NWTRB public meeting, S&T, developed a draft stakeholder engagement plan (the Plan) for a PPD that is being reviewed and discussed internally. It is a flexible plan for evaluating and engaging a broad spectrum of stakeholders including Federal agencies, States, Tribes, emergency responders, emergency planners, industry, and interest groups, and to the extent practicable, members of the public.

The Plan is a concept for determining what kind of input stakeholders can reasonably provide for consideration regarding the design and implementation of a PPD; methods for interacting with and eliciting feedback from stakeholders (such as public comment periods, requests for information (RFI), virtual meetings, etc.); how outcomes from a package performance demonstration could best be used for respective stakeholder groups to increase stakeholder confidence in DOE's transportation plans; and what research needs may be able to be met through a PPD. Some of the aspects of the Plan have evolved as the project has evolved and as initial feedback has been received, but the team continues to operate under an engagement strategy framework consistent with the Plan that will allow effective external engagement over the planned 5-year process. An updated draft Plan was developed in June 2024. S&T has recently published the RFI July 2024 seeking input from the general public, cask vendors, testing facilities, and marketing/PR firms on approaches to conducting the PPD. The 60-day open input period closes on September 30, 2024. Depending on the interest and requests, DOE may opt to extend the input period for 25 to 30 days.

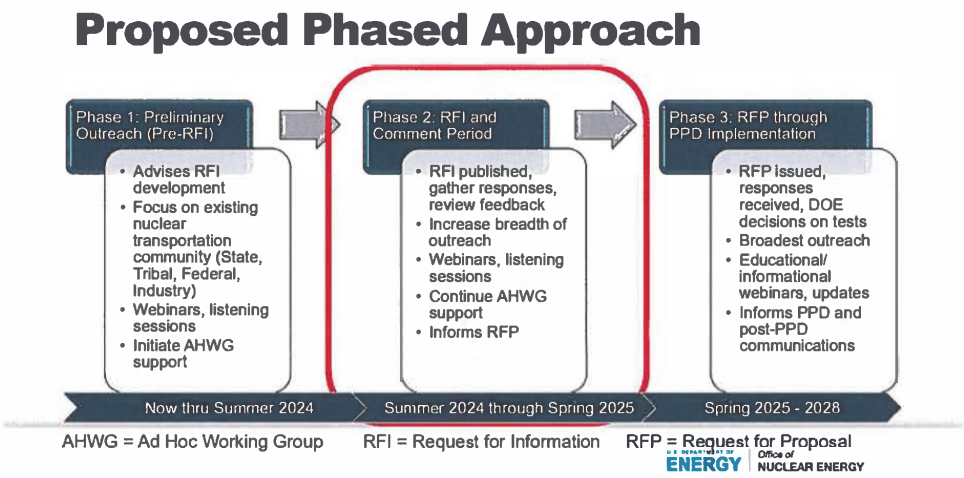
To date, DOE has already collected significant feedback that contributed to development of the RFI and updating the Plan. Working within the framework described in the Plan, S&T began conducting focused external engagement on a PPD in October 2023. At the time, the DOE team began seeking informal feedback from various stakeholder groups by giving presentations to

introduce the topic and ending in a Q&A session posing 6 initial questions for discussion. A limited list of engagements thus far includes:

- Nuclear Waste Strategy Coalition Meeting (October 2023)
- Western Interstate Energy Board's (WIEB) High-Level Radioactive Waste Committee Fall Meeting (November 2023)
- National Transportation Stakeholders Forum (NTSF) Communications Ad-Hoc Working Group webinar (December 2023)
- Southern States Energy Board (SSEB) Radioactive Materials Transportation Committee Meeting (December 2023)
- NRC-hosted "Nuclear Communicators" Meeting (January 2024)
- The 37th INMM Spent Fuel Seminar presentation (January 2024)
- Tribal Radioactive Materials Transportation Committee (TRMTC) Mid-year Meeting (January 2024)
- Federal Railroad Administration (FRA) and Pipeline and Hazardous Materials Safety Administration (PHMSA) introduction meeting (February 2024)
- Council of State Governments- Midwest Radiological Materials Transportation Committee webinar and listening session (March 2024)
- WM Symposia conference panel presentation and technical presentation (March 2024)
- NRC Internal Staff Seminar (March 2024)
- DOE-NE's Transportation Core Group presentation (March 2024)
- NEI Used Fuel Working Group presentation and listening session (March 2024)
- TRMTC listening session (April 2024)
- NEI Used Fuel Conference presentation and Q&A panel session (May 2024)
- National Transportation Stakeholder Forum multiple presentations (June 2024)

The presentations generated wide-ranging and generally positive feedback that provided invaluable input to the draft RFI and the updated Plan.. For a visual description of the Plan and its different phases, please see the graphic below.

As developing the Plan moves forward, S&T would be happy to brief the Board on the progress of the PPD and stakeholder engagement efforts.



NWTRB Board Comment 3:
The Board commends DOE for continuing to work closely with Tribes and finds that the Office of IWM emphasis on making Tribal government engagement a priority is a positive step for CBS efforts. The Board also commends DOE for working to identify practical steps to enhance full participation, including efforts to engage with Tribes through its NTSF section 180(c) ad hoc working group, and with Tribal governments through NETWG and TRMTC.

The Board commends DOE for looking into developing metrics (i.e., ways to measure and evaluate Tribal engagement and progress) to assess or track the extent to which such efforts have been successful, as each Tribal government is independent and will be facing a variety of situations that are unique to its Tribe. The Board looks forward to seeing more detailed information about such metrics at future Board meetings.

The Board observes that some Tribes may lack adequate resources for emergency preparedness and response programs, which could hamper the Tribes' ability to support DOE activities to plan for future SNF transportation. However, as noted above, the Board recognizes DOE for its ongoing preparedness work with the Tribes, primarily through its renewed efforts relative to section 180(c) of the Nuclear Waste Policy Act. The Board believes that, through Tribal engagement, DOE can help Tribes plan for the necessary emergency preparedness and response, technical expertise, and capabilities.

DOE Response:

DOE thanks the Board for its observations on IWM's Tribal engagement activities to date.

Consistent with DOE Order 144.1, *Department of Energy American Indian Tribal Government Interactions and Policy*, this work now under S&T and the Office of Consent-Based Siting, both of which are committed to fulfilling its trust responsibility to federally recognized Tribes and engaging with Tribes on a government-to-government basis as preparations for implementing a federal consolidated interim storage facility (CISF) and associated transportation capability develop.

The Offices appreciate the willingness of many Tribes to engage in discussions with DOE on long-lead time activities and provide their perspectives and insights on historical and planned future DOE projects. Through these engagements, both Offices have been made aware of the unique circumstances, needs, and concerns of different Tribes that has informed IWM programs and planning over the past decade. The work the Board referenced through the National Transportation Stakeholders Forum (NTSF) Section 180(c) ad hoc working group, including the Section 180(c) Proposed Policy Implementation Exercise conducted by State and Tribal ad hoc working group members from 2015-2017, was instrumental in bringing to light significant differences in preparedness and capabilities among States, among Tribes, and between Tribes and States. For example, Tribes and States that had prior experience with radioactive materials shipments from DOE Waste Isolation Pilot Plant (WIPP) or Foreign Research Reactor programs had a basis from which to adapt and build training programs for DOE SNF shipments. Tribes and States that did not have that experience will likely need additional support in developing approaches to training and public outreach in their jurisdictions.

Additionally, the NTSF Rail/Routing ad hoc working group is co-chaired by a representative from the Parie Island Indian Community. An outstanding example of Tribal coordination and support is evident in a first-of-a-kind collaboration, IWM and the Prairie Island Indian Community jointly planned and conducted in July 2022 a transportation dose assessment to estimate the site-specific incident-free radiation doses from SNF that is expected to be transported by rail in the future from the Prairie Island Nuclear Generating Plant (PINGP) through the Prairie Island Indian Community Reservation and Trust Land.

The new Office of Storage and Transportation and Office of Consent-Based Siting continue to adapt and update its approach to Tribal engagement around program activities as well. While IWM has invited Tribal (and State) government representatives to join its nuclear power plant infrastructure assessments since 2013, invitations were handled informally to Tribal representatives IWM staff had existing contact information for. Recent infrastructure assessments have intersected with federally recognized Tribes that IWM did not have prior engagement or contact information for. S&T has since developed a formal invitation process for Tribes within the areas of future nuclear power plant infrastructure assessments to communicate on a government-to-government basis, provide connection to resources such as the TRMTC, and contextual information on the offices' work and why a Tribe may be interested to engage with DOE.

For consent-based siting work, now in the Office of Consent-Based Siting, engagement with Tribes was built into the requirements for consent-based siting consortia awardee projects, and Tribes were directly informed by postal mail of the funding opportunity. Consequently, some consortia awardees are partnering or engaging with Tribal Nations or Tribal organizations to

understand their perspectives and needs, engage in mutual learning, and provide resources. Additionally, DOE national laboratories have invited Tribes to participate in their pilot work to understand the perspectives of communities that currently host spent nuclear fuel at operating and shutdown nuclear reactor sites, and work to develop recommendations for Tribal engagement and consultation. Internal to DOE, analysis is being conducted to incorporate Tribal-specific outreach and engagement strategies into overall consent-based siting engagement approaches. A new task order has been initiated to develop a Tribal engagement strategy developed directly by Tribal nations and Tribal representatives. This work is still in early stages and will be rolled out as it matures. The now distinct Office of Consent-Based Siting looks forward to continuing and growing engagement with Tribes in all areas of IWM's program and working with them to understand their perspectives and needs, so that this feedback can continue to be incorporated in programmatic future activities and operations. DOE would be happy to share information with the Board on progress engaging with Tribes going forward.

NWTRB Board Comment 4:
The Board finds that the DOE-sponsored site evaluations provide a good opportunity for DOE to meet with onsite staff and discuss technical details, including SNF condition, anomalies, and canister loading maps.

During future site infrastructure evaluation visits, the Board recommends that DOE engage with site personnel and cask vendors regarding the NRC-approved transportation CoCs that apply to SNF in dry storage and assess whether the stored SNF will meet the requirements in the NRC-approved transportation CoCs. Site personnel and cask vendors who know the specific SNF contents for each storage canister and the approved contents for the transportation cask could potentially identify whether amendments or exemptions to the transportation CoCs will be needed prior to transportation.

DOE Response:

The Department agrees that IWM's, now under S&T, nuclear power plant infrastructure assessments have provided valuable information to support transportation planning for commercial SNF and understanding whether as-loaded SNF is likely to be transportable through straight forward updates to NRC certificates of compliance (CoCs) to canisters and/or casks, or whether there may be challenges with transporting as-loaded SNF. In conducting infrastructure assessments, the S&T team sends a list of questions to the site in advance, which includes questions on the condition and configuration of the as-loaded SNF and casks and/or canisters in use at the site or planned to be used moving forward, where questions about amendments or exemptions to CoCs can be added. To date, only two sites of 22 visited had SNF loaded into canister or cask systems that may have significant challenges to certify for transport.

Additionally, NRC staff have been present at or invited to join some of S&T's more recent infrastructure evaluations and have added value to the discussions and information obtained. Continuing this work, S&T is considering extending the offer of NRC participation to all future infrastructure evaluations, subject to NRC staff availability and travel resources. S&T staff also continue to meet quarterly with NRC staff to exchange information on program activities and identify challenges and opportunities in topics of mutual interest, including any significant gaps

to close prior to commencing operation of a federal CISF and associated transportation of SNF. S&T is considering suggesting as a topic for a future quarterly meeting with NRC is whether and/or how changes made to SNF in a storage configuration under 10 CFR 72.48 propagate into transportation cask CoCs under 10 CFR Part 71.

Board Comment 5:
The Board commends DOE for sponsoring the as-loaded analyses needed to understand which commercial SNF canisters can meet the requirements of the corresponding transportation CoCs and which cannot, without an NRC-approved amendment or exemption to the CoC.
The Board observes that access to UNF-ST&DARDS would be valuable to the nuclear industry for analyses of SNF canisters for loading, storage, and transportation scenarios.
The Board finds that DOE can enhance its IWM system planning by engaging early with the NRC regarding the need for amendments or exemptions to the transportation CoCs for SNF canisters that do not currently meet the CoC requirements.
The Board recommends that DOE work with the NRC to identify the number and scope (including potential technical challenges) of amendments or exemptions to transportation CoCs that will be needed to allow the transportation of the affected SNF canisters.

DOE Response:

DOE agrees that it would be beneficial to identify any need for transportation package CoC amendments or exemptions well in advance of transport of SNF from a site. The Department is also mindful of its planned future role as a license applicant to the NRC, and the need for appropriate separation of technical analysis tools and personnel to ensure independent technical reviews are appropriately independent. S&T plans to coordinate with nuclear power plant sites and vendors to identify status of CoCs, data needs, and timelines for amending them. S&T currently plans for nuclear power plant sites to have at least five years advance notice before DOE arrives to accept SNF, during which time it is currently understood from discussions with NRC staff and recent DOE experience through the High-Burnup Demo Project CoC review process, that most transportation cask CoCs could be amended, as needed. In the interim, S&T will continue to assess the status of CoCs and anticipated amendment needs as new nuclear power plant site infrastructure evaluations occur, making use of the STANDARDS spent fuel analysis tool, formerly known as UNF-ST&DARDS, which is being further enhanced for potential commercial use by the US nuclear industry.

Board Comment 6:

The Board finds that there may be some technical difficulties with meeting the 10 CFR Part 72 requirements for SNF storage following the transportation of SNF, governed by 10 CFR Part 71. For example, 10 CFR Part 72 requires the licensee to demonstrate that the SNF cladding can meet its intended confinement function before placing the SNF into dry storage; but it is unclear how the licensee will demonstrate adherence to this requirement for SNF inside a welded canister.

The Board recommends that DOE expand its engagement with the NRC to understand the

technical difficulties with respect to meeting the 10 CFR Part 72 requirements for storage following the transport of commercial SNF, subject to 10 CFR Part 71 requirements. Recognizing that the issues could be different and unique for each specific SNF cask loading and for each cask or canister design, this action should commence well in advance of starting a large-scale transportation campaign, such as one that DOE may start in support of a new federal interim storage facility.

DOE Response:

DOE recognizes there are different requirements between 10 CFR Part 72 and 10 CFR Part 71 regarding fuel condition and protection. DOE is also aware of NRC questions regarding the situation where as-loaded SNF in a storage configuration under 10 CFR Part 72 will be placed into a transportation cask under 10 CFR Part 71 and then placed back into a storage configuration at a CISF under 10 CFR Part 72. The SNF and canisters that have been in storage at an Independent Spent Fuel Storage Installation (ISFSI) for 20 years or longer are subject to an NRC-approved aging management program, whether at the originating site or at a federal CISF.

DOE has been working to monitor and examine approaches to address questions on this topic known as the "72 - 71 –72" issue. For example, some activities such as SNF loading which are performed by utilities can be demonstrated by a review and transfer of appropriate records packages prior to receipt of a canister at a federal CISF. This approach is similar to that utilized in the licensing processes for private CISFs.

S&T currently has quarterly senior level meetings with NRC staff that provide a means to exchange information on technical research activities that are crosscutting for both transporting and storing SNF. For example, prior technical exchanges have included discussion of the need for canister testing to ensure the canister confinement boundary integrity following shipment. The now S&T program has developed a test program to investigate the testing methodology and is currently procuring the necessary equipment in FY24 with testing scheduled for FY25. Additional exchanges with the NRC are expected in this topical area as work proceeds.

S&T currently expects that NRC licensing requirements can be met, including aging management, for commercial SNF placed back into storage at a federal CISF.

Department of Energy
Washington, DC 20585

September 18, 2024

Dr. Nathan Siu
Chair
Nuclear Waste Technical Review Board
2300 Clarendon Boulevard
Suite 1300
Arlington, VA 22201-3367

Dear Dr. Siu,

The U.S. Department of Energy's (DOE) Office of Nuclear Energy appreciates your letter of April 24th, 2024, which summarized the Nuclear Waste Technical Review Board's 2023 International Workshop on Siting of Radioactive Waste Facilities and Summer Board Meeting. In that meeting, held on August 29-30, 2023, in Idaho Falls, Idaho, information was presented by DOE and national laboratory participants to help update the Board's understanding of the lessons learned from the siting of radioactive waste management facilities domestically and in other countries and to hear how DOE has addressed, or plans to address, the Board's recommendation to incorporate lessons learned into its consent-based siting efforts.

The Board's letter provided findings and recommendations on these DOE's activities. DOE appreciates the Board's input to our program and looks forward to its future insights on DOE's activities related to the management and disposal of SNF and HLW.

The enclosure provides DOE's responses to the Board's specific recommendations. If you have any questions on the responses, please contact Marla Morales at marla.morales@nuclear.energy.gov.

Sincerely,

K. Michael Goff
Acting Assistant Secretary
Office of Nuclear Energy

Enclosure

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201-3367

May 22, 2025

Dr. Michael Goff
Acting Assistant Secretary for Nuclear Energy
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1000 Independence Ave., SW
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Dear Dr. Goff:

On behalf of the U.S. Nuclear Waste Technical Review Board (Board), I want to thank you and your staff, as well as the staff from the national laboratories, for supporting the Board's Spring 2024 Meeting, which was held on May 21–22, 2024, in Knoxville, TN. The purpose of the meeting was to review information on U.S. Department of Energy, Office of Nuclear Energy (DOE-NE) research and development (R&D) activities related to the geologic disposal of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) in crystalline host rocks[1] and on corrosion of commercial spent nuclear fuel[2] (CSNF) after disposal. This letter[3] presents the Board's review resulting from the Spring 2024 Meeting and information obtained during a tour of Oak Ridge National Laboratory (ORNL) facilities on May 20, 2024. The agenda, presentation materials, meeting transcript, and an archived recording of the webcast for the meeting are posted on the Board's website.[4]

The Board also thanks the staff from DOE and the national laboratories for supporting technical fact-finding meetings on April 23 and 25, 2024. These fact-finding meetings enabled the Board to prepare for the Spring 2024 Meeting.

In 2024, DOE-NE had been continuing non-site-specific R&D on the potential disposal of SNF and HLW in several host rocks including crystalline rock formations. Crystalline rocks offer advantages such as low bulk permeability and high thermal conductivity, making them potentially suitable for waste disposal. However, they also require a robust engineered barrier system to reduce the potential for radionuclide release through fractures which can serve as fast pathways for the transport of radionuclides. DOE had been assessing the performance of a repository in crystalline host rock using the Geologic Disposal Safety Assessment (GDSA) Framework. Additionally, DOE was developing a Fuel Matrix Degradation Model (FMDM) to model the corrosion of CSNF under various repository conditions. The Board's review focused on these R&D activities.

[1] Crystalline host rock is a term for igneous rocks and metamorphic rocks (e.g., granite and gneiss) in which a repository could be developed.

[2] The focus of the Board's review in this letter is limited to CSNF and does not include R&D activities related to corrosion of DOE-managed SNF and advanced reactor fuels.

[3] Current and past Members of the Board who have contributed to this letter include P. Swift (Chair), R. Ballinger, S. Becker, A. Croff, T. Illangasekare, K. L. Peddicord, N. Siu, S. Tyler, and B. Woods.

[4] https://www.nwtrb.gov/meetings/past-meetings/spring-2024-board-meeting---may-2024

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At the meeting, the Board heard presentations from DOE staff and national laboratory researchers about their work for DOE. These presentations covered the recent reorganization forming the Office of Disposal R&D within DOE-NE and its research activities, as well as topics related to disposal in crystalline host rocks, including site characterization, physical and chemical processes, buffer behavior, conditions in the engineered barrier system, and the integration of process models into the GDSA Framework.

Presentations on the corrosion of CSNF after disposal included an overview that addressed models for the degradation rate of CSNF, process model coupling and implementation within the GDSA Framework, international collaborations, and a strategic approach to fill identified knowledge gaps for waste form degradation. Additional presentations addressed the FMDM, surrogate models, and electrochemical testing used to obtain data needed for model implementation.

The Board also heard presentations by Dr. Laura Pyrak-Nolte, from Purdue University; Mr. Andrew Parmenter from Nuclear Waste Management Organization, Canada; Dr. Erika Holt from the Finnish Technical Research Centre; and Dr. Barbara Pastina from Posiva Oy, Finland.

Based on the information presented at this Spring 2024 Meeting, in fact-finding meetings, and in related technical reports, the Board has developed observations regarding DOE's non-site-specific disposal R&D program, R&D activities related to disposal in crystalline host rock, and corrosion of CNSF after disposal. The Board commends the presenters for their informative and comprehensive presentations, which effectively addressed a number of key questions presented in the meeting agenda.

DOE R&D activities related to nuclear waste disposal

As the Board has noted earlier, DOE can gain valuable insights from international experience in nuclear waste disposal and leverage global expertise in program integration, siting, research strategy, and public engagement.[5, 6] International efforts highlight the importance of early public involvement and the decades-long nature of repository characterization and modeling. Regardless of the chosen disposal strategy, DOE's program can benefit significantly from these international experiences.

The Board commends DOE for its leadership and participation in international collaborative research projects on geological disposal of nuclear waste such as DECOVALEX[7] and modeling

[5] NWTRB. 2020. Filling the Gaps: The Critical Role of Underground Research Laboratories in the U.S. Department of Energy Geologic Disposal Research and Development Program. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. January. https://www.nwtrb.gov/docs/default-source/reports/nwtrb-url-report.pdf?sfvrsn=9.

[6] NWTRB. 2021. Six Overarching Recommendations for How to Move the Nation's Nuclear Waste Management Program Forward. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. April. https://www.nwtrb.gov/docs/default-source/reports/nwtrb-six-recommendations-report.pdf?sfvrsn=20.

[7] DEvelopment of COupled models and their VALidation against EXperiments - https://decovalex.org/

of experiments being conducted at underground research laboratories in different host rocks such as argillites (e.g., Mont Terri), granites (Grimsel Test Site) and salt (WIPP[8]). Furthermore, the Board commends DOE for participating in several international projects related to SNF degradation. These include EURAD[9] projects on the fraction of relatively mobile radionuclides that may be released from high burn-up SNF immediately following failure of waste packaging and cladding relevant to all host rock types,[10] and SNF dissolution and chemistry under failed container conditions;[11] as well as the International Atomic Energy Agency project focusing on spent fuel performance assessment and research.[12]

The Board notes that DOE is using state-of-the-art modeling approaches and methods of analysis for evaluating and predicting long-term repository performance in crystalline host rock. DOE efforts also include activities related to understanding the crystalline host rock and engineered barrier behavior at high temperatures and evaluating alternative buffer materials. The Board recognizes the technical challenges DOE faces related to field and laboratory studies needed to support and validate numerical models but is encouraged by ongoing DOE efforts to collaborate with and leverage experience from disposal programs in other countries.

The Board observes that DOE's focus on international collaborations has been effective in advancing DOE's state of knowledge related to nuclear waste disposal. The Board also notes that DOE has a technically valid approach to developing its modeling capability, the GDSA Framework, which will enable DOE to evaluate the post-closure performance of a potential repository in crystalline host rock. The Board encourages DOE to continue international collaborations and its engagement with countries who have made considerable progress in repository design, construction, and operation.

Leveraging advances in geophysical characterization tools and techniques from other industries

There is a rapidly growing knowledge base in geophysical techniques for fracture characterization, especially in deep formations used in geothermal, geologic carbon storage, and hydraulic fracturing industries. The DOE has supported collaborative programs like SubTER[13] in the past. These advances can be used for site characterization of host rock and excavation damaged zone in geologic repositories.[14]

[8] Waste Isolation Pilot Plant

[9] European Joint Programme on Radioactive Waste Management

[10] http://www.firstnuclides.eu/Default.aspx

[11] Modern Spent Fuel Dissolution and Chemistry in Failed Container Conditions- https://www.disco-h2020.eu/

[12] Spent Fuel Performance Assessment and Research - Phase IV - https://www.iaea.org/projects/crp/t13016

[13] Subsurface Science, Technology, Engineering, and R&D Crosscut (SubTER). https://www.energy.gov/subsurface-science-technology-engineering-and-rd-crosscut-subter

[14] Dobson, P. "Geophysical Techniques for Site and Excavation Damage Zone Characterization," NWTRB Public meeting, May 21-22, 2024. https://www.nwtrb.gov/docs/default-source/meetings/2024/may/day1_dobson-geophysical_site-edz_char.pdf?sfvrsn=a658f005_8

The Board encourages DOE to build on past collaborations to leverage advances in geophysical characterization techniques and tools from petroleum engineering, carbon storage and geothermal energy industries. These efforts can add significantly to DOE's programs in representation of fluid flow, transport, and geomechanical responses in crystalline host rock repository modeling and characterization.

CSNF corrosion after disposal

DOE's FMDM comprehensively addresses electrochemical processes that may affect fuel matrix dissolution behavior in a deep geologic repository. Incorporating the FMDM into a numerical model, such as GDSA, faces multiple challenges and uncertainties, including developing data sufficient to support model implementation, verification, and validation. The DOE has acknowledged and documented these uncertainties in the FMDM as knowledge gaps, and it has been working to prioritize R&D to address these gaps.[15] The Board continues to follow the DOE's efforts with interest. Given the overall uncertainties in the system characteristics and performance, and in particular in the FMDM, it is essential that the program define "good enough" for the models in the FMDM to avoid unnecessary effort for limited benefit.[16] If the DOE continues pursuing the FMDM as a preferred degradation model, the Board looks forward to receiving more information about the FMDM gaps and the DOE's priorities for addressing these gaps.

Site tour at Oak Ridge National Laboratory

The day prior to the Spring 2024 Meeting, the Board toured the Molten Salt Reactor Experiment (MSRE) and High Flux Isotope Reactor facilities at ORNL. The Board expresses its gratitude to DOE and ORNL staff for facilitating this tour. This visit provided crucial insights supporting the Board's ongoing evaluation of DOE's activities related to the management and disposal of SNF and HLW. While acknowledging that MSRE was an experimental reactor, the Board notes that the MSRE experience highlights the importance of clearly and fully understanding the details of proposed reactor operations, and their implications for waste management in the design-build-operation-decommissioning phases, for first-of-a-kind advanced commercial nuclear reactors such as molten salt-fueled or salt-cooled reactors.

Sincerely,

Peter Swift
Chair

[15] Meszaros, J. et al. 2021. Draft Experimental Plan for Commercial SNF Degradation in Repository Environments with a Focus on Fuel Matrix Degradation. M3SF-21OR010309072. Oak Ridge, TN: Oak Ridge National Laboratory. May.

[16] For example, DOE could consider an approach that defines the functions of each barrier in the context of overall system performance and the degree to which each barrier must perform its functions and determine whether a simple model is sufficient to reflect the required performance before developing a more sophisticated or realistic model that would require additional R&D be conducted.

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June 9, 2025

Dr. Michael Goff
Principal Deputy Assistant Secretary for Nuclear Energy
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1000 Independence Ave., SW
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Dear Dr. Goff:

On behalf of the U.S. Nuclear Waste Technical Review Board (Board), I want to thank you and your staff for supporting the Board's Summer 2024 Meeting in North Augusta, SC, on August 29, 2024. One purpose of the meeting was to receive a program update on U.S. Department of Energy, Office of Nuclear Energy (DOE-NE), Office of Spent Fuel and High-Level Waste Disposition activities.[1] This letter[2] presents the Board's review of DOE-NE's presentations during the Summer 2024 Meeting and information obtained from a December 16, 2024, fact-finding meeting with DOE-NE staff on a consent-based siting process for a federal consolidated interim storage facility for commercial spent nuclear fuel.

The program update summarized DOE-NE's research and development activities to enable the storage, transportation, and eventual disposal of spent nuclear fuel and high-level radioactive waste from existing and potential future nuclear reactors and emphasized that DOE's program will change in response to the ADVANCE Act of 2024. Mr. Paul Murray, Deputy Assistant Secretary for Spent Fuel and High-Level Waste Disposition, provided information on DOE's responsibility, under the ADVANCE Act, to report to Congress by January 1, 2026, on the cumulative amount spent by DOE to manage spent nuclear fuel and high-level radioactive waste, the activities DOE has taken since 2008 to reduce the liabilities, and the projected lifecycle costs to store, manage, transport, and dispose of those wastes. DOE's program update described a planned package performance demonstration (now known as the Package Performance Project), planned transport of a high burnup spent nuclear fuel[3] demonstration cask (now known as the high burnup research cask), consent-based siting consortia activities, and plans for a federal consolidated interim storage facility that DOE assumes will receive spent nuclear fuel beginning in 2038.[4] Mr. Murray stated that DOE will be prioritizing research and development and

[1] The meeting agenda, presentation materials, transcript, and an archived recording of the webcast are available online at https://www.nwtrb.gov/meetings/past-meetings/summer-2024-board-meeting---august-29--2024.

[2] Current and past Members of the Board who have contributed to this letter include P. Swift (Chair), R. Ballinger, S. Becker, A. Croff, T. Illangasekare, K.L. Peddicord, N. Siu, S. Tuler, S. Tyler, and B. Woods.

[3] Fuel burnup is a measure of the thermal energy generated in a nuclear reactor per unit mass of nuclear fuel as initially loaded in the reactor. Burnup is typically measured in units of gigawatt-days per metric ton of uranium (GWd/MTU). In the U.S., the U.S. Nuclear Regulatory Commission defines nuclear fuel utilized beyond 45 GWd/MTU as high burnup fuel.

[4] DOE also assumes a repository will be operating in the mid-2060s https://www.nwtrb.gov/docs/default-source/meetings/2024/august/nwtrb-summer-2024-meeting_8-29-24.pdf?sfvrsn=7244c305_3.

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refocusing its program to reduce liabilities. As he explained, resource constraints could adversely affect DOE's programs moving forward and its communication efforts will be integral to engendering public trust that is vital for program success.

Based on the information presented at the Summer 2024 Meeting, in the fact-finding meeting, and in related technical reports, the Board has developed observations on Office of Spent Fuel and High-Level Waste Disposition activities. The Board commends Mr. Murray for his informative presentation at the Summer 2024 Meeting, which effectively addressed the Board's questions, as well as the DOE staff for their candid discussions in the fact-finding meeting.

DOE's Activities Supporting Its ADVANCE Act Report

DOE is developing an integrated waste management system program plan that will serve as the basis for DOE's ADVANCE Act report on its liabilities and projected lifecycle costs. Key to accurate estimates of liabilities and lifecycle costs is the number of facilities for storage and disposal,[5] their assumed start dates for operations, and the technical bases underlying the analyses and assumptions. Another key cost consideration is the potential need to repackage commercial spent nuclear fuel in dual-purpose (storage and transportation) canisters to facilitate disposal of the spent nuclear fuel.[6,7]

Although the Board has concluded elsewhere that as of December 2024 the DOE does not have an effective program that could lead to permanent disposal of spent nuclear fuel and high level waste, [8] it commends DOE for its commitment to developing an integrated waste management system program plan that could initiate a workable pathway to site, license, construct, and operate a geologic repository. The Board looks forward to hearing about DOE's integrated waste management system program plan, its assumptions, analyses, and technical bases, and how DOE has addressed relevant Board recommendations (see cited Board reports and letters) in developing the program plan, which will support DOE's ADVANCE Act report.

Activities Focused on Developing Public Trust

[5] NWTRB. 2015. *Evaluation of Technical Issues Associated with the Development of a Separate Repository for U.S. Department of Energy-Managed High-Level Radioactive Waste and Spent Nuclear Fuel*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. June. https://www.nwtrb.gov/docs/default-source/reports/disposal_options.pdf?sfvrsn=4f6f605_7.

[6] Bahr, J.M. 2021. Board letter to DOE following the Board's July 2020 meeting. January 11. https://www.nwtrb.gov/docs/default-source/correspondence/jmb026.pdf?sfvrsn=cab5f105_8. As described in the Summer 2024 meeting, DOE's federal consolidated interim storage facility does not include capabilities for repackaging spent nuclear fuel contained in dual-purpose canisters.

[7] NWTRB. 2024. *Evaluation of the U.S. Department of Energy Research and Development Activities on the Disposition of Commercial Spent Nuclear Fuel in Dual-Purpose Canisters*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. February. https://www.nwtrb.gov/docs/default-source/reports/nwtrb_feb2024_report_evaluation_csnf_dpcs.pdf?sfvrsn=626af005_5.

[8] Swift, P. 2025. Board letter to U.S. Congress and the Secretary of Energy on DOE's program for managing the nation's spent nuclear fuel and high-level radioactive waste. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. March 18. https://www.nwtrb.gov/docs/default-source/correspondence/pns001vf-nwtrb-mar2025-letter-report.pdf?sfvrsn=1c82c205_10.

DOE stated that the Package Performance Project, the planned transport of the high burnup research cask, and the work of the consent-based siting consortia are all important activities for developing public trust in DOE's program to manage, store, transport, and dispose of spent nuclear fuel and high-level radioactive waste. The Board commends DOE for addressing the Board's recommendation to engage the public early in developing the Package Performance Project. DOE's phased approach and extensive efforts[9] both prior to, and post publication, of the July 2024 request for information are noteworthy. DOE's efforts to coordinate among the three projects, including integrated engagement and communication plans, are especially noteworthy. For example, DOE held a virtual event with the consortia to explain the Package Performance Project and invited consortia support on the request for information. The consortia worked with minority serving institutions to improve student engagement in civic processes and these groups subsequently provided input in response to the request for information. Now that DOE has announced the destination for transport of the high burnup spent nuclear fuel demonstration cask as the Idaho National Laboratory,[10] the Board looks forward to hearing an update from DOE on this important project.

Next Steps in the Siting Process and Implementing a Refocused Program

In the December 2024 fact-finding meeting, DOE staff discussed an initial draft report on site screening criteria for a federal consolidated interim storage facility for commercial spent nuclear fuel. At that time, DOE planned to release the final report and a Federal Register notice of expression of interest in Spring to Summer 2025.[11] The Board participants found the draft document criteria logical, clear, simple, and defendable. The Board members noted that improvements to terminology describing the criteria (e.g., initial criteria) and re-organizing portions of the report could make the information clearer and more accessible to the intended audience. The Board looks forward to hearing an update on DOE's siting process prior to DOE's release of the final report and a Federal Register notice of expression of interest.

In the Summer 2024 Meeting, Mr. Murray described that in 2025, DOE would be refocusing its program using a risk-informed approach and that future research and development would have to have a clear programmatic need that reduces risk and liability. DOE staff described that it would develop a risk register[12] to assist in prioritization of activities. The Board looks forward to hearing about DOE's risk register and its prioritization efforts this summer.

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[9] Goff, K.M. 2025. DOE response to the Board's letter to DOE on the Board's March 2023 meeting. September 9. https://www.nwtrb.gov/docs/default-source/correspondence/goff-letter-to-siu_9-sep-2024.pdf?sfvrsn=fe75c305_3.

[10] Idaho National Laboratory. 2025. Idaho and Trump Administration sign agreement to support US nuclear energy future. April 29. https://inl.gov/news-release/idaho-and-trump-administration-sign-agreement-to-support-us-nuclear-energy-future/.

[11] While the schedule has slipped, DOE (2023) described its next steps as starting with "DOE issuing a list of site-screening and preliminary assessment criteria. Then, DOE will issue a national call for volunteer host communities followed by interested communities responding with an expression of interest." DOE. 2023. *Consent-Based Siting Process for Federal Consolidated Interim Storage of Spent Nuclear Fuel*. April. https://www.energy.gov/sites/default/files/2023-05/Consent-Based%20Siting%20Process%20Report-0424%203.pdf.

[12] A risk register is a document used in risk management to identify, analyze, and track potential programmatic risks within a project or organization.

Thank you again, on behalf of the Board, for the participation of DOE staff at our Summer Meeting in August 2024, and the December 2024, fact-finding meeting. We look forward to continuing our ongoing evaluation of the technical and scientific validity of DOE's activities related to managing and disposing of spent nuclear fuel and high-level radioactive waste.

Sincerely,

Peter Swift
Chair

United States Nuclear Waste Technical Review Board

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