UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
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October 14, 2021

Mr. William (Ike) White
Acting Assistant Secretary for Environmental Management
U.S. Department of Energy
1000 Independence Ave., SW
Washington, D.C. 20585

Dear Mr. White:

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 Summer 2021 public meeting, held virtually on August 24, 2021. The purpose of the meeting was to review information on the U.S. Department of Energy (DOE) technology development activities related to aluminum-clad spent nuclear fuel (ASNF) packaging, drying, and dry storage. This letter presents the Board's findings and conclusions resulting from the meeting. The agenda and presentation materials for the meeting are posted on the Board's website at https://www.nwtrb.gov/meetings/past-meetings/summer-2021-virtual-board-meeting---august-24-2021. The meeting transcript and an archived recording of the webcast also are posted on the same web page.

As you know, the DOE Office of Environmental Management (DOE-EM) manages ASNF primarily at the Idaho National Laboratory (INL) and at the Savannah River Site in South Carolina. Since 2017, DOE has been supporting technology development work to study extended dry storage of ASNF, including corrosion of aluminum cladding, radiolytic gas generation, and drying processes to remove residual water from the cladding corrosion layers (also called oxide layers or oxyhydroxide layers). INL manages the integrated technology development program for DOE. The Board commends DOE for sponsoring this research.

Public Meeting

U.S. DOE Support of Research on ASNF Packaging, Drying and Dry Storage. Mr. Mark Senderling and Dr. John Shultz, DOE-EM, described the DOE support for ASNF research, through the DOE-EM technology development program. In 2017, the DOE Spent Nuclear Fuel Working Group issued a report that identified technical data needs related to ASNF dry storage.[1] DOE-EM provided funding for research to meet the data needs, and progress has been made in achieving a better understanding of ANSF packaging, drying, and extended dry storage. Dr. Shultz stated that DOE has prioritized safety and efficiency in these activities. Dr. Shultz also

[1] DOE Spent Nuclear Fuel Working Group Report, *Aluminum-Clad Spent Nuclear Fuel: Technical Considerations and Challenges for Extended (>50 Years) Dry Storage*, DOE/ID RPT #1575, June 2017.

described the organization of the technology development program and noted that the ASNF work is a congressionally-directed activity, funded at $5M per year.

The Board notes that DOE incorporated recommendations from the Board's 2017 report on DOE-managed SNF, as well as recommendations from DOE's Spent Nuclear Fuel Working Group report, to provide the framework for its research. The Board suggests that DOE continue to provide resources (personnel, facility access, etc.) for follow-on research as the technology development program progresses.

Review of the Research Program on ASNF Packaging, Drying, and Dry Storage. Dr. Josh Jarrell, INL, provided an update on the technology development program and its progress since 2017. In the 2017 Spent Nuclear Fuel Working Group report, DOE identified five main technical data needs for ASNF extended dry storage. In response, INL designed a research program with six main research tasks and an Instrumented Lid Project for sensor development. Among the six research tasks, Dr. Jarrell indicated that Task 1 (behavior and chemistry of hydrated oxide layers on ASNF) and Task 4 (performance of Advanced Test Reactor ASNF in existing dry storage systems) are complete. Tasks 2, 3, 5, and 6 are continuing and are discussed in more detail in later sections of this letter.

Dr. Jarrell offered preliminary conclusions based on the research completed to date. He stated that ASNF, including high dose-rate SNF from the Advanced Test Reactor, in vented dry storage at INL is safe for continued, extended dry storage (> 50 years) without corrosion degradation challenges. He also stated that ASNF from L Basin at the Savannah River Site can be safely placed in sealed canisters for dry storage pending ultimate disposal. To provide more confidence in the research results, INL arranged for Pacific Northwest National Laboratory (PNNL) to conduct an independent review of Tasks 2 and 3 and offer suggestions for improvement.

The Board commends DOE and INL for enabling the independent peer review by PNNL. The Board encourages INL to further evaluate whether Advanced Test Reactor fuel bounds all other ASNF types, especially with regard to the cumulative dose that is expected over a 50-year storage period.

Drying of ASNF Surrogates (part of Task 5) and Scale-up Radiolysis Testing of ANSF in L Basin at the Savannah River Site (part of Task 6). Ms. Rebecca Smith, INL, discussed research to study the drying of ASNF surrogates. This research was a collaborative effort, including INL, Savannah River National Laboratory (SRNL), Holtec International, and the University of South Carolina. The testing utilized an engineering-scale drying vessel, and experiments were developed to dry lab-grown surrogate materials using either forced helium dehydration or vacuum drying. Results from Task 5 indicate significant progress in understanding the removal of residual water from hydrated oxide layers. Forced helium dehydration drying is significantly more effective than vacuum drying at the removal of water that is chemically bound to the oxide layers. Future work will be focused on providing more experimental data that can be used to benchmark predictive process models (see Task 3).

Dr. Anna d'Entremont, SRNL, described radiolysis testing of ASNF surrogates and reactor-exposed aluminum cladding samples in a mini-canister environment. The test apparatus allows on-line monitoring and data acquisition that can be used to evaluate the impact of drying and help benchmark predictive models. Results indicate that elevated temperature drying removes more water, thereby reducing subsequent radiolytic gas generation. SRNL plans additional drying tests using different irradiated cladding specimens to gather more data on hydrogen gas generation.

The Board commends DOE and INL for collaborating with industry and universities while conducting the ASNF research. The Board also commends DOE and the national laboratories for their progress on developing experiments to perform drying tests to better understand the different drying processes and removal of residual water. The Board encourages DOE to continue these experiments, which can generate useful data to inform predictive models and to validate results obtained from surrogate materials.

Radiolytic Gas Generation due to Aluminum-clad SNF Corrosion Layers (part of Task 2). Dr. Greg Horne, INL, discussed laboratory testing designed to measure radiolytic hydrogen gas generation from the water retained in ASNF corrosion layers. The testing examined hydrogen gas generation as a function of absorbed gamma dose, corrosion layer composition, gaseous environment, relative humidity, and temperature. Results indicated that hydrogen gas generation increases with temperature and relative humidity and is more pronounced in argon or nitrogen atmospheres (compared to helium atmospheres). Future work includes investigations of how corrosion layer surface compositions change with absorbed dose upon reaching steady state and what effect alloy composition has on hydrogen gas production.

The Board suggests that DOE explore more fully the maximum expected dose for ASNF in the DOE inventory to ensure the testing is bounding. The Board also suggests that DOE conduct a more detailed evaluation of the fate of oxygen that is produced during radiolysis of water in sealed SNF canisters to provide support for assumptions in modeling and simulations. The Board encourages DOE to support additional surface characterization of surrogate sample materials prior to future drying tests.

Modeling and Simulation Results for ASNF in DOE Standard Canisters (part of Task 3). Dr. Alex Abboud, INL, described computer modeling efforts focused on predicting the behavior of ASNF in sealed dry storage canisters for up to 50 years. Key parameters to be predicted are hydrogen and oxygen gas concentrations and internal canister pressure. Several different scenarios have been modeled, including canisters loaded with different types of ASNF, different oxide layers on the cladding, and different quantities of air in-leakage. The INL model includes a 3D computational fluid dynamics code one-way coupled with a chemistry code that predicts chemical species evolution, including gas generation due to radiolysis. Early model predictions for hydrogen concentrations were compared to the experimental results of Tasks 1 and 2 and shown to be in reasonable agreement. In most scenarios modeled, hydrogen was predicted to accumulate to concentrations above 4%, but oxygen is assumed to be irreversibly scavenged, so no flammable gas mixture is predicted. The maximum predicted pressure inside a canister was 2.6 atmospheres (compared to a canister limit of 34 atmospheres).

The Board encourages INL to implement a well-documented verification and validation process for its modeling software. The Board also suggests that INL work to include formal uncertainty quantification in its modeling efforts to improve confidence in model predictions, since decisions related to safely storing ASNF for an extended time period will be based mainly upon these model predictions.

Development of Wireless Sensors for Dry-Storage of ASNF (Instrumented Lid Project). Dr. Evans Kitcher, INL, presented details of the Instrumented Lid Project to develop wireless sensors for use in vented ASNF canisters that are stored in the INL CPP-603 facility. These vented canisters, holding primarily Advanced Test Reactor SNF, are different than the proposed, sealed DOE Standard Canister. Wireless sensors would provide real-time monitoring of temperature, relative humidity, and hydrogen concentration inside the canister. Dr. Kitcher noted that INL is partnering with Idaho State University and Westinghouse to develop the sensors and fabricate the needed components.

The Board notes that this development work has many parallels with work sponsored by the DOE Office of Nuclear Energy (DOE-NE) to develop remote sensor technology applicable to canisters holding commercial SNF. The Board suggests that DOE-EM coordinate with DOE-NE and the Electric Power Research Institute on the development of wireless sensors for SNF canisters.

Future activities related to ASNF. As an extension of the work leading to dry storage of ASNF, the Board encourages DOE to consider the following:

- Ensure that the Nuclear Regulatory Commission transportation requirements are considered when planning follow-on research on ASNF and in advancing the design of the DOE Standard Canister for DOE-managed SNF.
- Evaluate the amount of residual water that may remain in an ASNF canister after drying and evaluate the potential consequences of that water (e.g., corrosion, creation of flammable gas mixtures, and pressure buildup).
- Continue to develop the wireless sensor technology and to look for other applications (e.g., use in waste disposal environments), while also paying close attention to cybersecurity precautions.

The Board thanks you and your staff members for assisting with the organization of the Summer 2021 Board Meeting. The Board also thanks researchers from the national laboratories for preparing and giving detailed technical presentations. The Board staff will be contacting representatives of DOE-EM and the laboratories with follow-up questions. The Board looks forward to continuing its ongoing review of DOE's technical activities related to managing and disposing of SNF and high-level radioactive waste.

Sincerely,

{Signed by}

Jean M. Bahr
Chair