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

January 10, 2020

The Honorable Rita Baranwal
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Mr. William White
Senior Advisor for Environmental Management
to the Under Secretary for Science
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Dr. Baranwal and Mr. White:

On behalf of the U.S. Nuclear Waste Technical Review Board (Board), I want to thank you and your staff for supporting the Fall 2019 Board Meeting, which was held on November 19, 2019, in Alexandria, Virginia. The purpose of the meeting was to review research and development activities being sponsored by the Department of Energy (DOE) related to the dry-storage of commercial spent nuclear fuel (SNF) and DOE-managed SNF. The agenda and presentation materials for the meeting, as well as the meeting transcript and an archived version of the meeting webcast, are posted on the Board's website at: https://www.nwtrb.gov/meetings/past-meetings/fall-2019-board-meeting---november-19-2019.

Congress created the Board in the 1987 Nuclear Waste Policy Amendments Act (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 and to advise Congress and the Secretary on technical issues related to nuclear waste management. DOE activities to manage SNF, including packaging, drying, storing, and planning for transportation and disposal, have long been topics of Board review.

In recent years, relevant Board activities have included a 2014 public meeting on DOE plans for the packaging, transportation, and disposal of DOE-managed SNF and high-level radioactive waste (HLW). That public meeting provided information that formed a basis for the Board's 2017 report, *Management and Disposal of U.S. Department of Energy Spent Nuclear Fuel*. In the summer of 2018, the Board visited the Idaho National Laboratory (INL) and received briefings on a new research effort to study corrosion mechanisms affecting aluminum-clad SNF during drying and long-term dry storage. This research effort is one of the topics discussed at the Fall 2019 Board Meeting.

At its Fall 2019 meeting, the Board received opening presentations from senior managers in the DOE Office of Nuclear Energy (DOE-NE). The Board then heard from Pacific Northwest National Laboratory and Sandia National Laboratories researchers who are conducting thermal analyses of SNF dry cask storage systems, INL representatives who are working on programs related to the management of DOE SNF (with a focus on aluminum-clad SNF), and a representative of Sellafield, Ltd., in the United Kingdom (UK), where research is being conducted on the drying of UK SNF. More information about these presentations and the Board's observations and recommendations are noted in the enclosure to this letter.

A number of specific recommendations are made in the enclosure. Summaries of those specific recommendations are provided below.

> *Recommendation 1. The Board recommends that DOE give higher priority to evaluating how advanced nuclear fuels and accident tolerant fuels may impact later operations, including SNF packaging, transportation, and disposal in a geologic repository.*
>
> *Recommendation 2. The Board recommends that DOE-NE pursue an increased understanding of the effect of moisture on SNF in dry storage, and continue its efforts to identify alternative methods of obtaining moisture measurements from inside SNF dry cask storage systems used by the nuclear industry and undertake similar efforts for the DOE Standard Canister.*
>
> *Recommendation 3. The Board recommends that greater emphasis be placed on validating computer models before applying them to particular dry cask storage systems.*
>
> *Recommendation 4. As DOE continues to develop and use computer models to predict SNF dry cask storage system parameters, the Board recommends that DOE ensure all assumptions and uncertainties be properly identified and accounted for, computer models be validated against data from real-world systems, fuel performance models be integrated within the multiphysics models, and enhanced coordination be achieved between model developers and experimentalists.*
>
> *Recommendation 5. Regarding the DOE Standard Canister, the Board recommends that DOE engage early with the Nuclear Regulatory Commission (NRC) to ensure that the DOE Standard Canister project team is aware of all applicable regulatory requirements, including requirements for criticality safety and limiting hydrogen concentrations, and develop a firm path forward and schedule for completing development of the DOE Standard Canister and obtaining the necessary NRC approvals.*

In addition to these recommendations, the Board makes the following observations.

1. *The Board observes that by continuing the High Burnup Demonstration Project (HDRP), even in light of less than ideal circumstances, and by exploring new solutions to project*

challenges, DOE-NE and the project team have obtained valuable results. For example, data collected on SNF temperatures have been used to improve SNF cask thermal-hydraulic modeling. The Board understands that the HDRP research team received the Secretary of Energy's Achievement Award for their work on this project and the Board congratulates the team for earning this award.

2. *The Board consistently observes that there are lessons to be learned from other countries that are not obvious unless one engages in some meaningful manner with researchers in these countries. At the Fall 2019 meeting, an example from the UK of a lesson to be learned was setting up an organizational structure with which to respond to challenges, as Sellafield Ltd. did in establishing an Innovation Team. This team is working on the concept of a Smart Package—an instrumented radioactive waste storage package that would include real-time monitoring of the conditions inside the package.*

The Board notes that the information on aluminum-clad DOE SNF presented at the Fall 2019 meeting was limited and provided insufficient opportunity for the Board to pursue areas of technical inquiry it wanted to pursue. Since the work is important and relevant to future DOE activities to package, dry, store, transport, and dispose of DOE-managed aluminum-clad SNF, the Board would like to have the opportunity to interact more directly with representatives of the DOE Office of Environmental Management (DOE-EM) and the research team being coordinated by Dr. Connolly. The Board will contact DOE-EM through separate correspondence to request additional interactions.

The Board would like to thank you again for the support of staff members within DOE-NE and DOE-EM during the planning and preparation of the Fall 2019 Board Meeting. The presentations and interactions during these meetings provide valuable information for the Board as it carries out its mission to review and evaluate DOE activities related to the management of SNF and HLW. We look forward to future productive interactions with you and your staff.

Sincerely,

{Signed by}

Jean M. Bahr
Chair

Enclosure

cc: Dr. William Boyle, DOE Office of Nuclear Energy
Ms. Betsy Connell, DOE Office of Environmental Management

Enclosure

Fall 2019 Board Meeting Summary, Observations, and Recommendations

This enclosure summarizes the contents of the presentations made at the Fall 2019 Board Meeting. Also presented are the Board's observations and recommendations that arise from the Fall 2019 meeting presentations and discussions, and from previously-reviewed written materials.

Department of Energy Office of Nuclear Energy (DOE-NE) Research and Development (R&D) Related to Advanced Fuels and Accident Tolerant Fuels. Dr. William Boyle, Acting Deputy Assistant Secretary for Spent Fuel and Waste Disposition in DOE-NE, provided opening remarks about the R&D efforts of his office, potential funding levels for the R&D work, and focus areas for future research. The Board is encouraged by the continued focus of Dr. Boyle and his office on the management of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) and their continuing support of important research that will allow the Department to better understand these waste streams.

Following his presentation, the Board asked Dr. Boyle about what planning is being done now to assess the potential impacts of new nuclear fuel designs, including accident tolerant fuels, on the back end of the fuel cycle, especially disposal in a geologic repository. Dr. Boyle expressed a position that new fuel designs being tested now in commercial power reactors are not substantially different from existing fuel designs, so there are no expected impacts on the back end of the fuel cycle. He also stated that the development and implementation of new fuel designs are initiatives of the private nuclear industry and are largely outside the scope of the activities of his office. Nonetheless, the Board pointed out that some of the newly proposed fuels include materials that are considerably different from those used in contemporary U.S. nuclear fuels. Examples of these materials are chromium coatings on zircaloy, uranium-silicide fuel material, and silicon-carbide cladding. The number and variety of these new materials raise questions about possible unintended consequences of their use, including their behavior after disposal in a geologic repository.

Recommendation 1. The Board recommends that DOE give higher priority to evaluating how advanced nuclear fuels and accident tolerant fuels may impact later operations, including SNF packaging, transportation, and disposal in a geologic repository.

High Burnup Demonstration Project (HDRP).[1] Mr. Ned Larson, DOE-NE, presented an overview of the R&D work sponsored by DOE-NE to understand the characteristics of, and the forces impacting the behavior of, high burnup[2] SNF during extended storage and transportation.

[1] The HDRP is also known by the names "High Burnup Dry Storage Cask Research and Development Project" and "High Burnup Data Project."

[2] Fuel burnup is a measure of the thermal energy generated in a nuclear reactor per unit of initial mass of nuclear fuel and is typically expressed in units of gigawatt-days per metric ton of uranium (GWd/MTU). In the United

One of the largest projects in this effort is the HDRP, in which 32 high burnup SNF assemblies were loaded into a Transnuclear (TN; now part of Orano) TN-32 cask, dried, and stored on the SNF dry-storage pad at the North Anna Nuclear Generation Station. The HDRP test plan calls for the cask to be transported, after storage for a period up to 10 years or possibly longer, to a facility that can open the cask and remove selected fuel rods. These rods would then undergo non-destructive and destructive examinations to compare their characteristics and performance to those of the HDRP sister rods[3] to determine the combined effects of drying, aging, and transportation. An important component of the project is the use of computer models to predict temperatures inside the HDRP cask, followed by a comparison of those predictions against temperatures measured inside the cask. Being able to predict the temperature of SNF is important since it influences the subsequent properties of the cladding relevant to storage, transportation, and disposal. Thermal modeling efforts are discussed in more detail in the next section. Mr. Larson summarized work completed to date on the HDRP and described two project challenges as noted below.

Mr. Larson stated that, during the course of the project, the HDRP research team encountered a number of unexpected events but made adjustments, as needed. In one example, the team found, through thermal model predictions, that the temperatures inside the HDRP cask would not be high enough to induce the kind of changes in the fuel cladding properties they wished to study (i.e., hydride reorientation in the fuel cladding). The team adjusted by heating some HDRP sister rods to 400°C using a furnace in a hot cell to try to induce hydride reorientation in the cladding so that the effects of hydride reorientation on cladding properties could be studied further. The results of this effort are not yet available but will be made known when the sister rod metallographic examinations are completed.

A second project challenge involved sampling the HDRP cask for moisture content. The research team had hoped to obtain gas samples from the HDRP cask after drying, in order to gain valuable information about cladding integrity and moisture levels remaining in the cask after drying. However, equipment and analysis problems prevented the team from obtaining reliable measurements of moisture concentrations. Mr. Larson stated that the research team is considering the options available for obtaining additional moisture samples from SNF storage casks. One option would be to move the HDRP cask to the CPP-603 facility at the Idaho National Laboratory (INL) before the end of the planned 10-year dry-storage period, in order to allow taking additional periodic gas samples.[4] Mr. Larson stated that a second option would be to work with the commercial nuclear industry to identify a to-be-loaded SNF cask from which gas samples could be obtained while the cask is still inside a radiologically-controlled facility. A decision about the preferred option had not been made at the time of the Board meeting.

States, nuclear fuel utilized beyond 45 GWd/MTU is defined by the Nuclear Regulatory Commission as high burnup SNF.

[3] Sister rods are high burnup SNF rods removed from SNF assemblies that are included in the HDRP cask or removed from SNF assemblies of the same type and operating history as SNF assemblies in the HDRP cask. The sister rods are being examined to determine their condition before drying, aging, and transportation.

[4] The Board recognizes that the terms of the Idaho Settlement Agreement may impact DOE's ability to transport SNF to the state of Idaho.

Obtaining moisture measurements from inside an SNF storage cask was a goal of the HDRP. The resulting data would help fill a knowledge gap related to the amount of moisture remaining in an SNF cask after drying and how that moisture may affect the condition of the SNF over time. In its November 2018 letter to DOE-NE,[5] the Board encouraged DOE to pursue alternatives for obtaining moisture measurements.

Recommendation 2. Consistent with its previous communication, the Board recommends that DOE-NE continue its efforts to identify alternative methods of obtaining moisture measurements from inside SNF dry cask storage systems, to include early shipment of the HDRP cask to the INL CPP-603 facility for gas sampling, and to work with the nuclear industry to identify one or more additional SNF dry cask storage systems that can be sampled for moisture content.

The Board commends DOE-NE and the HDRP research team for continuing the HDRP, even in light of less than ideal circumstances, described above, and for exploring new solutions to the challenges the project has faced. The Board notes that, in the same November 2018 letter mentioned above, the Board expressed a belief that continuing the HDRP was desirable, even though the maximum temperatures in the HDRP test cask did not reach the high levels desired. The Board also encourages the continued use of "blind" model predictions, which can then be compared against data collected during field or laboratory experiments, as a means for completing rigorous validation of the computer models.

Mr. Larson then discussed the results from the early phases of the sister rod destructive examinations. These examinations, which include cyclic bending tests, provide data regarding fuel and cladding characteristics and help analysts to understand how the fuel may perform during storage and normal conditions of transport. Of note, Mr. Larson stated that the destructive examinations being conducted at Oak Ridge National Laboratory (ORNL) are using segments of SNF rods that include the fuel inside the cladding (i.e., fueled cladding). In contrast, destructive examinations at PNNL and Argonne National Laboratory are being conducted on unfueled cladding segments. Comparing the results from the two laboratories will provide information on how much the fuel pellets contribute to the strength, or structural rigidity, of the fuel rod, as a result of the bond between the fuel pellets and the cladding. Understanding this is important since many destructive examinations have been completed using defueled samples of cladding, so the conclusions drawn from that work may not be directly applicable to SNF rods that contain fuel pellets.

During the question and answer period, Mr. Larson noted that the research completed to date includes testing consistent with normal conditions of transport but not accident conditions. He stated that DOE is considering adding new tests, such as drop tests of surrogate fuel assemblies, that can provide information about how the SNF may perform in hypothetical accident conditions. Mr. Larson invited the Board to meet with DOE personnel and laboratory analysts to review new data from the HDRP sister rods, once destructive examination tests are completed in 2020.

[5] See the Board letter, Bahr to McGinnis, dated November 27, 2018, following the Fall 2018 Board meeting held in Albuquerque, New Mexico.

The Board endorses the DOE plan to continue pursuing additional testing that will provide information about the fuel-clad bonding and how the SNF will perform in accident conditions. The Board will continue to follow this work, and also appreciates the invitation to participate in a fact-finding meeting.

Mr. Larson's presentation concluded with a discussion of future plans for the HDRP, including transporting the HDRP cask to a hot-cell facility, removing SNF rods from the cask, and performing examinations of the SNF. He stated that the original plans for transporting the cask included a step of cutting the thermocouple cables and sealing the corresponding cask lid penetrations. However, DOE is now considering the possibility of leaving the thermocouple cables intact so that temperatures can be recorded while the cask is in a horizontal configuration, as it is being prepared for transport. Regarding a facility in which to open the HDRP cask, Mr. Larson explained that considerable work has been done to modify the CPP-603 facility at INL such that the facility can accept the HDRP cask, move the cask into the shielded portion of the facility, and remove selected SNF rods from the cask for transfer to a fuel examination facility. He noted that the modifications to CPP-603 make it suitable as a receipt facility for other SNF casks that are as large as (but no larger than) the TN-32 cask that is being utilized for the HDRP. Mr. Larson noted that DOE continues to consider options for HDRP SNF rod examinations, after the SNF rods are removed from the TN-32 cask. One option is to move the SNF rods to the Hot Fuel Examination Facility at INL.

The Board endorses DOE-NE's consideration of leaving the HDRP cask thermocouples intact to allow further temperature monitoring and commends DOE-NE for the proactive efforts to prepare the CPP-603 facility to accept the HDRP cask. The Board also commends DOE-NE for considering other useful missions for the facility now that it has been upgraded to allow handling of the HDRP cask.

Mr. Larson noted that the ORNL hot cells will be cleared out to make way for new activities when the HDRP sister rod examinations are complete. During the question and answer period, Mr. Larson clarified that sister rod segments that have not been examined will be saved for later testing, if needed. As noted in previous correspondence with DOE, the Board encourages DOE to retain the untested sister rod segments because they are valuable assets, and similar samples of high burnup SNF will be difficult and costly to obtain.

The Board observes that the HDRP has provided valuable information regarding the characteristics and behavior of high burnup SNF and this productive testing continues. Furthermore, DOE has sponsored significant work to adapt computer models, validated against the HDRP test data, that can be used to predict thermal-hydraulic conditions in the HDRP cask. However, the Board notes that the HDRP, including the TN-32 cask, is not representative of the typical SNF loaded in dry cask storage systems currently stored at nuclear power plant sites or the new SNF types that will likely be stored at nuclear power plant sites in the next few years. Some of the key differences are the following:

- The TN-32 cask is a bolted-lid cask, while approximately 90 percent of all dry cask storage systems loaded to date are welded canister-based systems.

- The TN-32 cask is a vertically oriented system, while approximately one-third of the dry cask storage systems loaded to date are horizontally oriented.

- The HDRP includes several types of pressurized water reactor SNF assemblies, but no boiling water reactor (BWR) SNF assemblies nor SNF assemblies with the types of materials used in accident tolerant fuels that are already being tested in commercial power reactors.

Given these specific features of the HDRP, it cannot be assumed that the computer modeling applicable to the HDRP will be applicable to other dry cask storage systems.

Recommendation 3. Consequently, the Board recommends that, before the computer models adapted for the HDRP cask are validated for application to other dry cask storage systems, additional testing be done to support model validation for these systems.

<u>Thermal Analyses of SNF Dry Cask Storage Systems</u>. Mr. David Richmond, PNNL, and Dr. Sam Durbin, SNL, presented information about DOE-sponsored research activities, including the HDRP, the Dry Cask Simulator at SNL, and computer model development focused on the prediction of temperatures in SNF dry cask storage systems. Extensive work was done in support of the HDRP effort, leading to substantial progress in validating the models against temperatures measured in the HDRP cask. Additionally, thermal-hydraulic models are being used to predict temperatures and gas flows in the Sandia Dry Cask Simulator, which includes a single surrogate BWR fuel assembly inside a mock storage cask. Testing and modeling have been completed using the Dry Cask Simulator in a vertical configuration. Testing has begun using the Dry Cask Simulator in a horizontal configuration and the results will be compared to predictions from existing thermal-hydraulic models.

Mr. Richmond displayed some of the modeling results for the HDRP cask, including mismatches between measured and predicted temperatures, and noted that the models typically over-predicted system temperatures. The research team attributed this over-prediction of temperatures to the use, in the models, of a design-specified uniform air gap between the SNF basket and the interior cask wall. In contrast, the actual loaded cask system had, in some places, direct contact between the SNF basket and the interior cask wall, causing greater conductive heat transfer and lower system temperatures.

Mr. Richmond also discussed an effort being coordinated by the Electric Power Research Institute (EPRI), through its Extended Storage Collaboration Program, to examine thermal modeling efforts for SNF dry cask storage systems. This effort, utilizing a Phenomena Identification and Ranking Table (PIRT) process, includes participation from EPRI, DOE, NRC, and the nuclear industry. This PIRT effort will consider the implications of the margins between the predicted cask system temperatures and the Nuclear Regulatory Commission (NRC) limit of 400°C for peak cladding temperature or the higher design basis temperature limits that are less than the NRC limit and which vary among storage systems. One key step in this process is identifying all parameters and phenomena that can affect SNF dry cask storage system temperatures and to assess the state of knowledge and importance of each parameter. Mr. Richmond described the process and displayed the set of parameters that the thermal PIRT team identified. The Board observes that the thermal PIRT process appears to include a thorough identification of the parameters and phenomena that affect SNF dry cask storage system temperature, and the Board looks forward to reviewing the results of this effort, which are expected in 2020.

Dr. Durbin described the Sandia Dry Cask Simulator used for studying temperature distributions and gas flows associated with a mock SNF dry cask storage system. The test system includes instrumentation to measure system temperatures and air flow rates. The simulator will be operated at four power levels (500, 1,000, 2,500, and 5,000 watts), with an internal pressure of 100 or 800 kilopascals, and a fill gas of helium or air.

Dr. Durbin also described thermal-hydraulic models (for predicting temperatures and gas flow rates) that were adapted for the simulator in a vertical configuration. He stated that the same models are being modified in order to predict temperatures and gas flow rates with the simulator in a horizontal configuration. As part of the overall test and modeling plan, Dr. Durbin stated that the computer modelers would be provided data sets including measured temperatures and air flow rates for two test runs conducted at 2500 watts. The modelers can use the data to calibrate their models and, then, they will be asked to predict the temperatures and gas flow rates for all other sets of test parameters. While using Dry Cask Simulator test data for computer model calibration may allow more accurate prediction of temperatures and gas flow rates in subsequent simulator tests, this approach does not ensure the models will be sufficiently flexible, or adaptable, for application to real-world dry cask storage systems, where such calibration data are not available.

The Board recognizes and commends DOE’s work to develop modeling tools that can be used to predict SNF dry cask storage system performance. However, the Board believes DOE can do more to support and advance computer model development. The Board encourages DOE to identify which models perform well or poorly and also to develop a deeper understanding of the importance of various modeling aspects (e.g., numerical approximations and discretization, values assigned to material properties, boundary conditions, processes that are represented by the physics incorporated in the models) to good or poor model performance. Also, if several distinct models provide comparable matches to observations, the modelers and experimentalists should attempt to determine conditions for which the models might not yield comparable predictions. Then, they can design experiments to reproduce those conditions and determine which of the models better represents the system.

Recommendation 4. The Board recommends that DOE

a. ensure current and new model development activities properly identify all assumptions and uncertainties and account for them to the extent possible,

b. ensure thermal models and multiphysics models (like the thermal-hydraulic models) are formally validated by collecting data from real-world systems and comparing the data with blind model predictions, wherever possible,

c. ensure computer models are used only for conducting analyses of systems for which model applicability is clearly shown,

d. *promote the development and validation of broader multiphysics models that have the capability to predict fuel performance, such as cladding fracture behavior in accident conditions, and*

e. *promote greater coordination between model developers and experimentalists so that computer models and experiments are properly aligned.*

DOE Standard Canister[6] for SNF. Dr. Josh Jarrell, INL, presented information on the design, analysis, testing, and intended use of the DOE Standard Canister. Dr. Jarrell pointed out that the work he is conducting is funded by DOE-NE, but there is other work on the DOE Standard Canister being funded by the DOE Office of Environmental Management (DOE-EM). The DOE-EM work was not presented.

Dr. Jarrell noted that the DOE Standard Canister was originally designed by DOE in support of the Yucca Mountain license application as a multipurpose (storage, transport, and disposal) canister for DOE-managed SNF.[7] Because of the large variety and range of sizes of DOE-managed SNF, the DOE Standard Canister was designed to be available in two diameters (0.46 and 0.61 meters [18 and 24 inches]) and two lengths (3.05 and 4.57 meters [10 and 15 feet]). Although DOE completed some R&D on the Standard Canister in support of the Yucca Mountain license application, that work was not finished and no application was submitted to the NRC for approval to use the canister to transport SNF.

Dr. Jarrell stated that DOE continues to pursue development of the DOE Standard Canister and has identified the canister as an option for dry-storage of Advanced Test Reactor SNF at INL. Ongoing work includes evaluations of operations to load, dry, seal, and inspect DOE Standard Canisters in the CPP-603 facility at INL. Dr. Jarrell also noted that DOE continues to evaluate neutron absorber materials that can be used in the fabrication of canister components for criticality safety purposes. Dr. Jarrell stated that this work has shown that the use of new variations of borated stainless steels will allow the DOE Standard Canister to meet all criticality safety requirements.

The Board is encouraged by DOE's continuing work to develop the DOE Standard Canister but notes that there is currently a relatively low level of effort and funding devoted to this activity and there is no schedule for completing it. Several important design features of the DOE Standard Canister are yet to be finalized and operations such as drying and inspection need to be more fully developed. Regarding these latter points, the Board notes that it transmitted a report to DOE in 2017,[8] which recommended 1) development of an improved technical basis for the proposed procedures for drying DOE SNF before it is packaged in multi-purpose canisters; and 2) development of the capability for measuring and monitoring the conditions of the SNF in new DOE storage systems, such as the DOE standardized canister.

[6] In previous work, including DOE's License Application for the Yucca Mountain Project, the name of this canister was the DOE SNF Standardized Canister.

[7] The DOE Standard Canister is distinct from the TAD [transportation, aging, and disposal] Canister that was designed by DOE to hold commercial SNF and was included in the Yucca Mountain license application.

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

Recommendation 5. Consistent with the Board's previous recommendations and based on the current state of the DOE Standard Canister, the Board recommends that DOE

a. determine the amount of moisture that can remain in a loaded DOE Standard Canister after drying without adversely affecting the SNF in the canister,

b. develop methods to monitor the conditions inside the DOE Standard Canister after it is loaded and sealed shut,

c. work with EPRI and others in the nuclear industry to apply newly developed remotely-operated techniques for inspecting the exterior surface of loaded DOE Standard Canisters,

d. engage early with the NRC to ensure that the DOE Standard Canister project team is aware of all applicable regulatory requirements, including requirements for criticality safety and hydrogen gas concentrations, and

e. develop a firm path forward and schedule for completing development of the DOE Standard Canister and obtaining the necessary NRC approvals.

<u>DOE-EM Research on Aluminum-clad SNF</u>. Dr. Mike Connolly, INL, presented an overview of DOE-EM-sponsored research on the long-term dry storage of aluminum-clad SNF. Dr. Connolly is coordinating a team of researchers, comprising six sub-teams working on distinct research tasks, all of which are of interest to the Board. However, the Board was informed by DOE-EM management that Dr. Connolly would only provide one presentation at the meeting, giving an overview of the program.

Dr. Connolly described the types and sources of aluminum-clad SNF in the DOE inventory and discussed corrosion mechanisms that can lead to the formation of aluminum-oxide, -hydroxide, and -oxyhydroxide layers on the surface of the fuel. These corrosion layers can retain water, even after drying operations, and this water can then be a source of radiolytically-generated gases, such as hydrogen and oxygen. The DOE-EM research project is examining all stages of these corrosion and gas generation processes. The research includes characterization of aluminum-clad SNF, laboratory experiments on corrosion and gas generation, and computer model development with an aim of predicting the behavior of aluminum-clad SNF during drying and dry storage. All six research tasks within the program are ongoing and early results have just been published within the past year.

Dr. Connolly noted that one particularly challenging aspect of this research is the scope of the corrosion and the reactions resulting in the generation of gases. A full description of gas generation following the corrosion of aluminum is characterized by 115 chemical reactions involving 40 chemical species. In order to make the laboratory research and modeling manageable and timely, the research team conducted sensitivity studies to eliminate the less-significant reactions and species, and reduced the problem to 22 reactions, involving eight chemical species.

The Board considers research on aluminum-clad SNF to be important and encourages DOE's continued support of the program being managed by Dr. Connolly. However, the Board urges that the research teams should review and confirm the results of their efforts carefully, prior to eliminating any chemical reactions and chemical species from further research, recognizing that elimination of many reactions and species may collectively impact predictions. The Board asked Dr. Connolly about the progress in developing a model to predict the behavior of aluminum-clad SNF during drying and dry storage, including progress in validating the models against experimental data. Although Dr. Connolly's presentation did not include comparisons of model predictions against experimental results, he stated that those comparisons are included in the research reports he listed in the reference section of his presentation.

The Board notes that the information presented by Dr. Connolly was limited and provided insufficient opportunity for the Board to pursue areas of technical inquiry it wanted to pursue, particularly the technical basis for drying aluminum-clad DOE SNF, as noted above and in the Board's 2017 report.[9] Since the work is important and relevant to future DOE activities to package, dry, store, transport, and dispose of DOE-managed aluminum-clad SNF, the Board would like to have the opportunity to interact more directly with representatives of DOE-EM and the research team being coordinated by Dr. Connolly. The Board will contact DOE-EM through separate correspondence to request additional interactions.

<u>Research on the Drying and Storage of SNF in the United Kingdom</u>. Dr. Paul Standring, Sellafield Ltd. (UK), provided an overview of SNF managed in the UK, the condition and status of aluminum-clad SNF, and SNF dry storage experience in the UK. He then discussed, in more detail, the research related to Magnox SNF [nuclear reactor fuel with <u>MAG</u>nesium, <u>N</u>on-<u>OX</u>idizing cladding; a cladding composed of magnesium and a small amount of aluminum and other metals] and aluminum-clad SNF.

Dr. Standring pointed out that Magnox SNF is currently reprocessed in a facility at the Sellafield site, but the facility is more than 50 years old, operating beyond its design lifetime, and could be taken out of service at any time. As a back-up plan, Sellafield has sponsored work to develop the "Magnox contingency," which is a plan to package Magnox fuel into a new design of canister, dry it, and place it into dry storage. Dr. Standring described the research being undertaken to support the plan, including the need to address the generation of hydrogen gas, both from corrosion and from the radiolytic dissociation of water, and the formation of uranium hydride, which is pyrophoric in air. The research team found that, after drying the Magnox SNF, hydrogen gas pressures will not reach levels that challenge the design specification of the canister. However, if damaged fuel is present, uranium hydride formation may eventually exceed the limits for handling the SNF in an air atmosphere. Therefore, the current plan is to package, dry, and store undamaged fuel only. For the storage of damaged Magnox SNF, Dr. Standring stated that one possible solution is a newly-designed Self Shielded Box, that is vented (through a filtered vent) to mitigate the hazards associated with the formation of uranium hydride.

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

Dr. Standring stated that the UK manages only a small quantity of aluminum-clad SNF, but said that this SNF will need to be transferred from pool storage to dry storage. Based on an evaluation of alternatives, the best option for managing this fuel would be to include it in the Magnox contingency campaign, if it proceeds. If that option is not implemented for Magnox SNF, then another option, such as the Self Shielded Box, will have to be considered. In a panel discussion at the end of the meeting, Dr. Standring noted that Sellafield has established an "Innovation Team" to look for solutions to waste management challenges such as these. One example of the results of the work of this team is the concept of a "Smart Package" for waste storage that would be instrumented to provide real-time information about the conditions inside the package.

The Board was pleased to hear the insights provided by Dr. Standring and to learn about the SNF management program in the UK. The Board suggests that DOE should take note of the lessons learned in other countries related to the management of aluminum-clad SNF and consider adopting new initiatives such as establishing an Innovation Team and developing an instrumented package like the Smart Package concept being considered in the UK for storage of radioactive wastes.