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

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.

<u>HBF Report Recommendation 1.a.</u>, 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.

<u>HBF Report Recommendation 1.b.</u>, 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.

<u>HBF Report Recommendation 1.c.</u>, 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.

<u>HBF Report Recommendation 2.a.</u>, 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.

<u>HBF Report Recommendation 2.b.</u>, 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.

<u>HBF Report Recommendation 3.a.</u>, 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.

<u>HBF Report Recommendation 3.b.</u>, 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.

<u>HBF Report Recommendation 5.</u>, 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.

<u>HBF Report Recommendation 6</u>., 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.

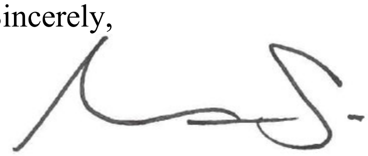
[16] Ibid.

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.