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

August 31, 2015

Mr. John Kotek
Acting Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

Dear Mr. Kotek:

The Nuclear Waste Technical Review Board (Board) held its 2015 Summer Meeting in Golden, Colorado, on June 24, 2015, to review U.S. Department of Energy (DOE) activities related to the transportation of commercial spent nuclear fuel (SNF). The public meeting included speakers from DOE, the U.S. Nuclear Regulatory Commission (NRC), national laboratories, and the Swiss energy company, Axpo. The meeting also included a panel discussion on the potential for corrosion of canisters used for the storage of SNF. Board observations and recommendations from the meeting are discussed below.

The Board thanks your staff for its work in preparing for the public meeting and for providing several of the informative presentations. The speakers did a good job of addressing the specific questions that the Board provided in advance of the meeting. The questions helped focus the discussions on the technical issues of most interest to the Board and provided a useful context for the public audience. The Board also appreciates the investment of time and effort by DOE and laboratory personnel who developed posters for the poster session that followed the public meeting. The Board notes the good turnout by the public in Golden and via webcast and values the comments made by the public at the meeting. The agenda for the public meeting (including questions posed to DOE), the meeting transcript, and a video recorded during the webcast are all available on the Board's website at www.nwtrb.gov/meetings.

Transportability of Spent Nuclear Fuel from Operating Nuclear Power Plant Sites

Ms. Melissa Bates, of the DOE Office of Nuclear Energy (DOE-NE), presented details of the Nuclear Fuel Storage and Transportation Planning Project. During her presentation, Ms. Bates explained the status of SNF storage at both operating and shutdown nuclear power plant sites and identified those SNF canisters and casks that are licensed for storage only and those that are licensed for both storage and transportation.

Ms. Bates stated that DOE is making good progress on evaluating technical issues associated with transportation of commercial SNF from shutdown sites and has determined that there are no significant technical issues that would prevent the transportation of SNF from those sites in the canisters or casks in which the SNF is currently stored. She noted that it will be necessary to resolve some technical issues before SNF stored at some operating nuclear power plants can be transported. For example, Ms. Bates pointed out that 12 sites with operating commercial reactors are storing SNF in a total of 427 canisters and casks that are currently licensed for storage only, and that collectively, these canisters and casks hold 11,019 SNF assemblies. For the majority of these canisters and casks, however, Ms. Bates said that DOE's evaluation shows no insurmountable technical challenges that would prevent them from being licensed for transportation.

Telephone: 703-235-4473 Fax: 703-235-4495 www.nwtrb.gov

Mr. Meraj Rahimi, of the NRC, discussed differences between the regulatory requirements for storage and for transportation of SNF canisters and casks. He stated that, in a few cases, problems have been encountered in obtaining certificates of compliance for transportation of canisters that are currently licensed for storage of SNF. An example cited by Mr. Rahimi was the failure of certain internal components of the VSC-24 canister to meet structural integrity criteria after a 30-foot drop test. As a result, the canister did not receive a certificate of compliance for transportation. Nuclear utilities using VSC-24 canisters will have to find an alternative for transporting SNF stored in these canisters.

The Board observes also that many nuclear utilities are loading SNF into very large capacity canisters—the largest canister in use today can store as many as 37 pressurized water reactor (PWR) assemblies or 89 boiling water reactor (BWR) assemblies. For example, the Holtec International MPC-37 canister can hold 37 PWR assemblies and, when loaded, weighs 116,400 pounds, excluding the substantial weight of a transportation overpack. The weight of the combined canister and overpack will exceed the capacity of standard transportation methods, and the load will have to be transported by a heavy-haul tractor-trailer or by rail on a specially-designed rail car. The size and weight of these and similar loads may prevent transporting SNF, or limit the road or rail route options for transporting SNF, particularly from operating nuclear power plant sites.

The Board commends DOE-NE for its efforts to assess and fully understand the transportability of SNF now stored at shutdown nuclear power plant sites. However, the Board notes that technical challenges remain regarding the transportability of SNF now stored in canisters and casks at operating nuclear power plants. In particular, the regulatory requirements for transportation of commercial SNF[1] *and certain commercial SNF canisters*[2,3] *may be difficult to meet. DOE would be well-served to address these technical challenges sooner rather than later. The Board recommends that DOE-NE work closely with nuclear utilities and the NRC to expeditiously define and resolve technical issues that may limit or prevent the transportation of SNF in current canisters and casks from nuclear power plant sites. As a result of such consultation, if repackaging of the SNF is determined to be necessary, it is more likely that the site infrastructure to support repackaging would still be in place.*

System-Level Analyses and Stakeholder Engagement

During her presentation, Ms. Bates summarized five major computer-based tools that DOE is developing to assist in the integration and analyses of the SNF storage and transportation programs:

- Multi-Objective Evaluation Framework (MOEF)
- Next Generation System Analysis Model (NGSAM)
- Execution Strategy Analysis (ESA)
- The Used Nuclear Fuel Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS)
- Stakeholder Tool for Assessing Radioactive Transportation (START)

Ms. Bates provided a high-level overview of these five tools, which appear to be potentially valuable in helping DOE plan for transportation of SNF. However, information regarding the detailed structure and

---

[1] The NRC provides the requirements for the transportation of spent nuclear fuel in Title 10 of the Code of Federal Regulations, Part 71, *Packaging and Transportation of Radioactive Materials* (10 CFR 71) and regulates the application of the requirements; specific requirements for SNF are contained in 10 CFR 71.33, *Package Description*, and 10 CFR 71.55, *General Requirements for Fissile Material Packages*.

[2] For transportation of canisters and casks holding SNF, 10 CFR 71 includes specific requirements for containment of radioactive materials, criticality control, SNF retrieval, thermal loads, and dose rates.

[3] If a canister is relied on to provide moderator (water) exclusion from the canister to prevent criticality during transportation, then the canister must meet additional requirements associated with maintaining its structural integrity to preclude flooding the canister with water, even under accident conditions.

planned use of some of the tools was not readily available. Based on discussion during the meeting, it appears that the UNF-ST&DARDS and, in particular, its unified database, represents a significant resource that will become increasingly valuable in standardizing DOE's planning and analysis, and as a safeguard against the loss of institutional knowledge as experienced personnel retire. In previous letters to DOE, *e.g.*, the letter, Ewing to Lyons, January 29, 2014, the Board has recommended that DOE make data such as the unified database available to the public in an easily accessible format, subject to security restrictions.

The Board would like to learn more about the tools, including the UNF-ST&DARDS. Additionally, the Board suggests that demonstrating the tools to local communities and making the related documentation available would improve stakeholder engagement. In particular, the START program, if provided in a modified form to avoid security issues, could be an excellent tool to help stakeholders understand the basis for selecting different routing options for the transportation of SNF.

Mr. Jim Williams, of the Western Interstate Energy Board, gave a presentation on stakeholder perspectives regarding the transportation of commercial SNF. According to Mr. Williams, DOE has improved its outreach efforts to stakeholders who have an interest in the transportation of SNF. For example, during one of its site assessments, DOE invited members of interested stakeholder groups to visit a shut-down nuclear power plant site, where the only remaining activity is the storage of SNF in dry-storage casks.

However, Mr. Williams maintained that much of DOE's focus continues to be on siting a repository for SNF and high-level radioactive waste, and that less attention has been paid to the issues related to the transportation of nuclear wastes to a repository. He suggested that the views of some stakeholders, such as the communities along the proposed SNF transportation routes, should receive more attention. These "corridor communities" will be subjected to the risk associated with the transportation of SNF through their areas, but they may not receive any benefits. He urged early engagement with stakeholders to clearly explain the purpose, mission, and importance of the SNF transportation plan, including interim steps such as the addition of a consolidated interim storage facility.

The Board recommends that DOE expedite its efforts to finalize and publish documentation supporting its integration and planning tools associated with the transportation of SNF. The Board also recommends that DOE consider producing a version of START that is not restricted in its release, so that it can be demonstrated and provided to members of the general public in order to increase their understanding of the constraints on routing options for the transportation of SNF. Such an effort should be initiated early in DOE's route selection process and be used to clearly explain all aspects of DOE's plans.

Chloride-Induced Stress Corrosion Cracking Under Dry-Storage Conditions

Dr. Robert Einziger, of the Board's senior professional staff, moderated a panel discussion on the potential for chloride-induced stress corrosion cracking (CISCC) of dry-storage canisters. The panel members included of Dr. David Enos, Sandia National Laboratories; Mr. Joe Carter, Savannah River National Laboratory; Dr. Steve Marschman, Idaho National Laboratory; Dr. Shannon Chu, Electric Power Research Institute (EPRI); and Mr. Meraj Rahimi, NRC. Dr. Einziger explained that CISCC requires three conditions for crack initiation and growth: a susceptible material such as austenitic stainless steel, high tensile stresses in the material, and the presence of wet chlorides in contact with the material. These three conditions can be found at some of the dry-storage locations for commercial SNF.

Most dry-storage canisters are fabricated from austenitic stainless steel (304, 304L, 316, or 316LN stainless steel) and closed by welding on a stainless steel lid. Welding can create a heat-affected zone in the steel that is susceptible to various forms of corrosion including CISCC if the residual tensile stresses are sufficiently high and the local environment is sufficiently aggressive. The locations of many dry storage sites at reactors are especially vulnerable to chloride aerosol deposition and high humidity, which could combine to create conditions conducive to CISCC on the canister surfaces. Dr. Chu indicated that, whereas CISCC has not yet been found on any dry-storage canisters, it has been found in steel structures in similar atmospheric conditions. Given the possibility of high crack propagation rates from CISCC and extended dry-storage times, this issue requires attention. For example, a crack growing at 0.5 millimeter per year, which is possible under aggressive conditions, would penetrate the wall of a susceptible stainless steel canister in 25–50 years.

Cracking of sensitized stainless steel under immersion conditions has been studied in detail, but this cracking phenomenon is much more complicated under atmospheric conditions where the susceptibility of the canisters to cracking will depend on several complex factors. The local environment on the canister surface is critical, but is variable and not well understood under atmospheric conditions. For example, magnesium chloride, a component of sea salt that can become airborne in droplets, will deliquesce (transform to a concentrated liquid by absorbing moisture from the air) at 35% relative humidity to create a very aggressive aqueous environment even under relatively dry conditions. However, Dr. Enos described chemical analyses performed on samples taken from the surfaces of canisters at three sites located in brackish or marine atmospheric environments, and the chloride concentrations were either very low or much lower than expected. Dr. Enos suggested that the apparent absence of cracking of the dry-storage canisters might be associated with the low chloride concentration. The chloride ions deposited from aerosols on the surface of a canister may be depleted while dry (*e.g.*, decomposition of ammonium chloride into ammonia and hydrogen chloride gas) or they may be depleted after they have deliquesced in the presence of humidity to form hot brine. Dr. Enos suggested a mechanism by which chloride ions in the hot brine are converted to volatile hydrogen chloride, which could then degas from the surface to leave a much less aggressive environment. However, this mechanism has not been proven and even very small concentrations—parts per billion—of dissolved hydrogen chloride (hydrochloric acid) can be very corrosive. Thus, the local environment on canisters, including chloride concentration, temperature, and local humidity, must be understood in order to develop meaningful models. Dr. Chu indicated that models have been developed, but they were based on limited data, such as those from a Japanese study (conducted by the Central Research Institute of Electric Power Industry[4]), which used salt solution dropped onto steel samples under tensile stress. Such accelerated tests using conditions that are more aggressive than realistic environments must be carefully assessed to ensure that the failure mechanism has not been changed.

Much of the analysis to date in submerged environments has focused on the crack growth rate of CISCC in austenitic stainless steel, with the assumption that surface flaws and cracks will exist and that the initiation stage will not be rate-determining. Therefore, it is important to understand the dependence of crack growth rate on the environmental factors during atmospheric exposure. However, the crack initiation stage, including pit formation and pit-to-crack transition, is much harder to study. This early stage may be the rate-limiting step in the overall failure process.

The state of stress at the welds and the resultant stress intensity at defects or corrosion pits are also critical for assessing the susceptibility to CISCC. It is not uncommon for residual stress to vary through the thickness of a component such that a tensile stress at the surface becomes a compressive stress at the interior, thus stifling crack growth and preventing penetration of the wall. Dr. Enos described ongoing experiments on a mock-up canister to assess the three-dimensional stress state. He indicated that some models predict the formation of short cracks perpendicular to the welds, which might impede further crack growth and not pose integrity concerns. The mock-up experiments will be very useful for validating such models.

The final important aspect of this issue is inspection. Dr. Marschman stated that dry-storage systems in use were not designed to allow for inspection. The size and position of vents in the overpacks as well as the high radiation field and temperature make inspection extremely difficult. Fully-automated inspection systems are not yet available; thus, inspection equipment is manipulated through the vents by hand. Based

[4] K. Shirai and J. Tani, 2011, "Study on Interim Storage of Spent Nuclear Fuel by Concrete Cask for Practical Use, Feasibility Study on Prevention of Chloride Induced Stress Corrosion Cracking for Type304L Stainless Steel Canister", CRIEPI Report N10035 (in Japanese).

on the panel discussion, DOE appears to be applying resources through the Nuclear Energy University Program (NEUP) and the Integrated Research Program (IRP) at Pennsylvania State University and other schools to develop new systems for the inspection of the surfaces of canisters.

In the future, there are good opportunities for canister vendors to apply stress-relieving treatments to welded canisters or fabricate new canisters from materials that are not susceptible to CISCC. In addition, dry-storage systems could be designed to facilitate inspection of the SNF canisters.

The time allocated at the meeting to the discussion of CISCC of dry-storage canisters was insufficient for the Board to gain a full appreciation of the topic and the activities of DOE in this important area. The Board plans to gather additional information from DOE, EPRI, and other sources in order to more fully understand the phenomenon of CISCC under atmospheric conditions.

In the meantime, the Board recommends that DOE-NE continue to work with EPRI and NRC, but assume a greater leadership role in integrating research and development being performed by multiple organizations on CISCC of dry-storage canisters, particularly in 1) determining the environments on canister surfaces, 2) assessing the state of residual stress in the welded canisters, 3) determining the time interval until crack initiation under current storage conditions, 4) confirming crack growth rates, and 5) developing robust inspection tools and methods appropriate for the conditions and requirements of dry-storage systems.

Regarding other research needs associated with commercial SNF, the Board recommends that DOE-NE expand its leadership in the identification and communication of technical gaps, technical information needed to fill the gaps, and research being done related to commercial SNF wet storage, drying, dry storage (onsite or centralized), transportation, and repackaging (if needed).

Standardized Transportation, Aging, and Disposal Canisters

Dr. Josh Jarrell, of the Oak Ridge National Laboratory, presented information about DOE's evaluation of the feasibility and potential benefits of using a standardized transportation, aging, and disposal (STAD) canister for commercial SNF. The use of such a canister can offer the benefits of common handling equipment, common transportation equipment, and common procedures and training programs—features that can potentially improve operational efficiency and reduce overall program cost. However, the potential benefit would be significantly less if STAD canisters are introduced after much of the SNF has been moved into large dry-storage canisters.

Dr. Jarrell described recent activities, including collaboration with nuclear utilities and vendors, to assess the time and cost of using STAD canisters for dry storage of commercial SNF when the fuel is removed from wet pool storage. He noted that, by September 2015, his team expects to report their recent findings on the impacts of using STAD canisters, and, in fiscal year 2016, to issue a final report on all STAD canister impacts.

During the question and answer sessions at the public meeting, DOE representatives clarified that, if implemented, the STAD canister would be used to package commercial SNF taken directly from the spent fuel pools of commercial nuclear power plants. The STAD canisters would not be used for SNF that is currently stored in large dry-storage canisters since this would involve a significant effort to open the welded canisters, transfer the SNF, and dispose of the old canisters (more than 89,000 SNF assemblies are now loaded in 2200 dry-storage canisters and casks[5]). Instead, the SNF now in dry storage would remain stored until transported in its current storage canisters and casks (if licensed for transportation) to an interim storage facility or a geologic repository. Depending on the repository design, the condition of the dry-storage canisters and their contents, and the expected form of a disposal package for SNF, it may be necessary to

[5] Values reported in *UxC Store Fuel*, Volume 16, No. 204, UxC, August 4, 2015.

repackage the SNF from existing dry-storage canisters into disposal containers (possibly incorporating the STAD canister) at an interim storage facility or the repository site.

Dr. Tony Williams, from the Swiss energy company, Axpo, presented a description of SNF management efforts in Switzerland. In particular, he provided detailed information about the use of thick-walled dual-purpose storage and transportation casks for commercial SNF in Switzerland [unlike thin-walled SNF storage canisters inside thick-walled storage overpacks or vaults that are commonly used in the U.S.]. Originally, the Swiss program used only one type of storage and transportation cask for all of its SNF—essentially, a standardized cask. However, this cask and its successors (*e.g.*, the Areva TN®97L and TN®24BH casks) are expensive because of their robust design, including thick shielding and steel walls, and because they need to be maintained to remain qualified for transport. Dr. Williams pointed out that it is not cost-effective to use these casks primarily for storage. He also noted that international regulations for transportation of SNF are updated approximately every five years and that some casks originally licensed for transportation may not meet the new requirements. For this reason, and to allow for greater flexibility in the SNF management program, the Swiss utilities are now looking at procuring a less-expensive dry-storage system that includes a welded, thin-walled SNF canister that can be stored in a storage overpack, and then transferred into a transportation overpack for shipment.

It has not yet been decided whether to use a STAD canister for the nation's commercial SNF, nor has DOE fully defined the purpose, scope, costs, benefits, and timing of the use of such a canister. Without this information, conducting a system-level evaluation of the impacts of implementing STAD canisters is challenging and could have large uncertainties. Therefore, the Board recommends that DOE continue working closely with nuclear utilities to examine the implications of using a STAD canister, including the impacts of implementing a STAD canister at different times and at different repackaging locations (if repackaging is needed).

Tour of the Transportation Technology Center

In conjunction with, but not directly related to the public meeting, several Board members and staff members joined John Herczeg, Deputy Assistant Secretary of Fuel Cycle Technologies in the DOE Office of Nuclear Energy, and other DOE staff and contractors on a tour of the Transportation Technology Center, near Pueblo, Colorado, on June 23, 2015. The tour was planned and coordinated by the Office of Nuclear Energy. In particular, Ms. Erica Bickford (DOE-NE staff member) did an excellent job organizing the tour and coordinating the associated logistics for both DOE personnel and Board members and staff.

The Board members and staff who joined the tour found it informative. The facility personnel provided detailed explanations of the facilities and systems used to test rail transport equipment. They demonstrated a good understanding of DOE's interest in the transportation of SNF and focused the presentations and facility tour on this aspect of rail transport. The information gathered during the tour provided important insights into the planning needed to support the transportation of SNF by rail.

Thank you again, on behalf of the Board, for the participation of DOE-NE staff and technical experts from the national laboratories at our June meeting. We look forward to continuing our ongoing review of DOE's technical activities related to management and disposal of SNF and high-level radioactive waste.

Sincerely,

Rodney C. Ewing
Chairman