

Management and Disposal of U.S. Department of Energy Spent Nuclear Fuel – 19133

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ABSTRACT

Congress created the U.S. Nuclear Waste Technical Review Board (NWTRB) 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. In accordance with this mandate, the NWTRB reviewed the U.S. Department of Energy's (DOE) efforts to manage the inventory of spent nuclear fuel (SNF) that is under its control (DOE SNF) at several facilities around the country: the Hanford Site in Washington, the Idaho National Laboratory (INL) in Idaho, the Savannah River Site (SRS) in South Carolina, and the Fort St. Vrain independent spent fuel storage installation (ISFSI) in Colorado. While disposal of SNF and high-level radioactive waste (HLW) in a deep geologic repository remains the ultimate objective of the DOE nuclear waste management program, there is significant uncertainty about when such a repository will be constructed in the United States. Until disposal occurs, it is essential to manage DOE SNF in a way that will facilitate its eventual disposal, and it is also important to improve understanding of processes related to packaging and storage of the SNF that could affect its future transportation and disposal.

The NWTRB's review, which was a multi-year effort, was documented in a report to Congress and the Secretary of Energy and is summarized here. The NWTRB reviewed the quantities and characteristics of DOE SNF at each of the four sites. It also examined DOE packaging and storage activities and plans at each of the sites. The NWTRB highlighted three main issue areas in its review. First, the review identified issues related to managing the aging of DOE SNF and the facilities used to store the DOE SNF. Second, the review addressed issues related to packaging of stored non-naval DOE SNF into a standard canister. Third, the NWTRB assessed issues that could affect disposal of DOE SNF if DOE continues to evaluate a range of repository settings. Based on the information and findings developed as part of its review, the NWTRB made six recommendations to Congress and the Secretary of Energy related to aging management, packaging, and disposal of DOE SNF. DOE has begun to address some of the NWTRB recommendations.

INTRODUCTION

While disposal of SNF and HLW in a deep geologic repository remains the ultimate objective of the DOE nuclear waste management program, there is significant uncertainty about when such a repository will be constructed in the United States. Until a viable disposal solution is found, it is necessary that DOE manage its SNF in a manner that does not impede its eventual transportation and disposal.

Categories of SNF and HLW that require disposal in a geologic repository with radioactivity in exabecquerels (EBq) and mass in megagrams of heavy metal (Mg HM, which is equivalent to metric tons of heavy metal^b) are presented in Figure 1. DOE's SNF inventory comprises a broad range of fuels, resulting primarily from defense-related activities (Figure 1). DOE is responsible for packaging, storing, transporting, and eventually disposing of the SNF that it manages. Properly managing SNF in the near

^a The views expressed in this paper are those of the author and do not necessarily represent the views of the U.S. Nuclear Waste Technical Review Board. The author is a member of the NWTRB's Senior Professional Staff.

^b Metric ton of heavy metal is a commonly used measure of the mass of "heavy metal" initially present in nuclear fuel. Heavy metal refers to elements with an atomic number greater than 89 (*e.g.*, thorium, uranium, and plutonium). The mass of other constituents of the fuel, such as cladding, alloy materials, and structural materials, are not included. A metric ton is 1,000 kilograms.

term is particularly important because, in the absence of a permanent geologic disposal option, SNF will need to be stored for decades longer than originally planned. Furthermore, the waste needs to be managed (*e.g.*, stored and packaged) in a way that will facilitate—not hinder—its eventual transport and disposal in a geologic repository. Because of the importance of the processes that could affect management and disposal of DOE SNF, the NWTRB has undertaken a review of the technical and scientific validity of DOE’s SNF management activities. Over the course of the multi-year review process, the NWTRB held public meetings on DOE SNF management activities [1-4] and visited DOE SNF storage facilities at the Hanford Site in Washington [5], the INL in Idaho [1,2], and the SRS in South Carolina [3]. This paper summarizes the NWTRB’s evaluation, findings, and recommendations on DOE SNF management activities, which were documented in a report to Congress and the Secretary of Energy [6]. It also discusses recent DOE actions to address the NWTRB recommendations.

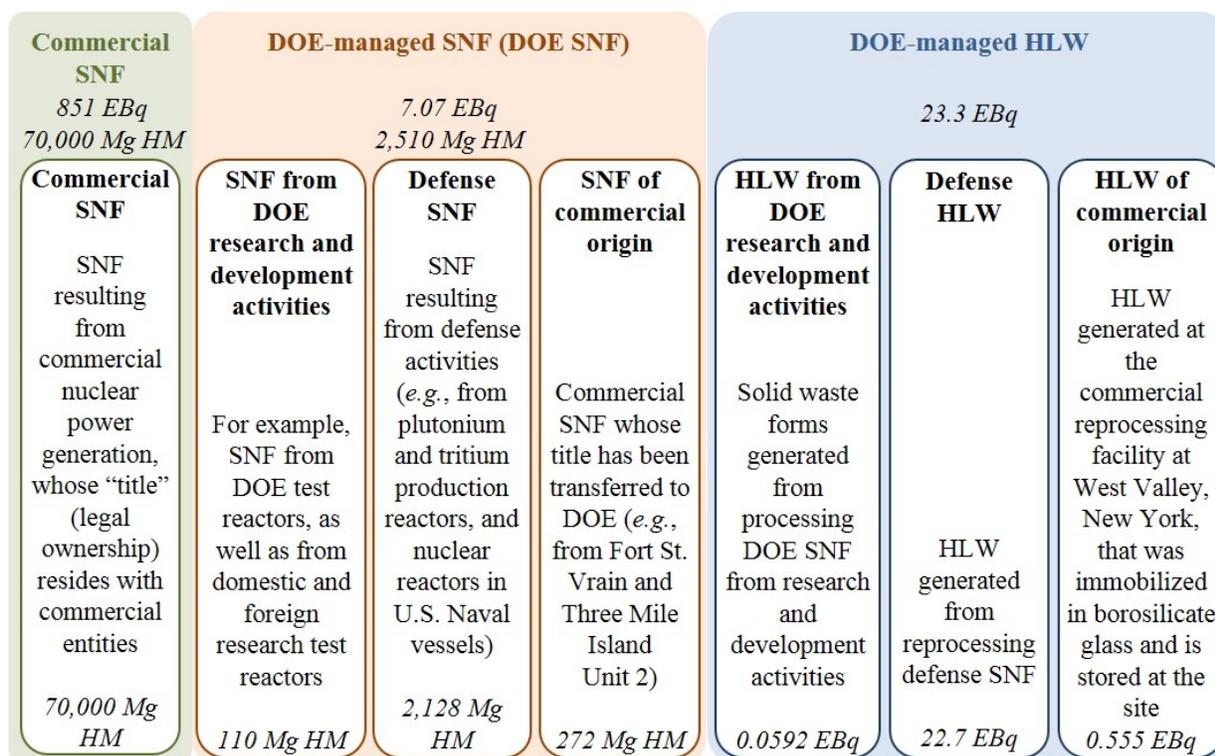


Fig. 1. Wastes that require disposal in a geologic repository [6; see Figure A2-6 for data sources].

DISCUSSION

The NWTRB report [6] recorded the quantities and characteristics of DOE SNF by storage site and the evaluation of DOE’s packaging and storage activities and plans related to DOE SNF. Figure 2 depicts the status of DOE management activities, as of August 2014, leading to disposal of DOE SNF. Figure 2 is a simplified depiction of DOE SNF management activities at the Hanford Site, the INL, the SRS, and the Fort St. Vrain ISFSI from on-site storage of DOE SNF through disposal of SNF in a geologic repository. In the figure, the mass of SNF in storage is depicted in italics. Some stored SNF will be processed into HLW—56 Mg HM of sodium-bonded SNF at INL and 3 Mg HM of aluminum-based SNF at the SRS—and will not be disposed of as SNF. Undamaged SNF of commercial origin would be packaged and transported off site using bare fuel rail transport casks.

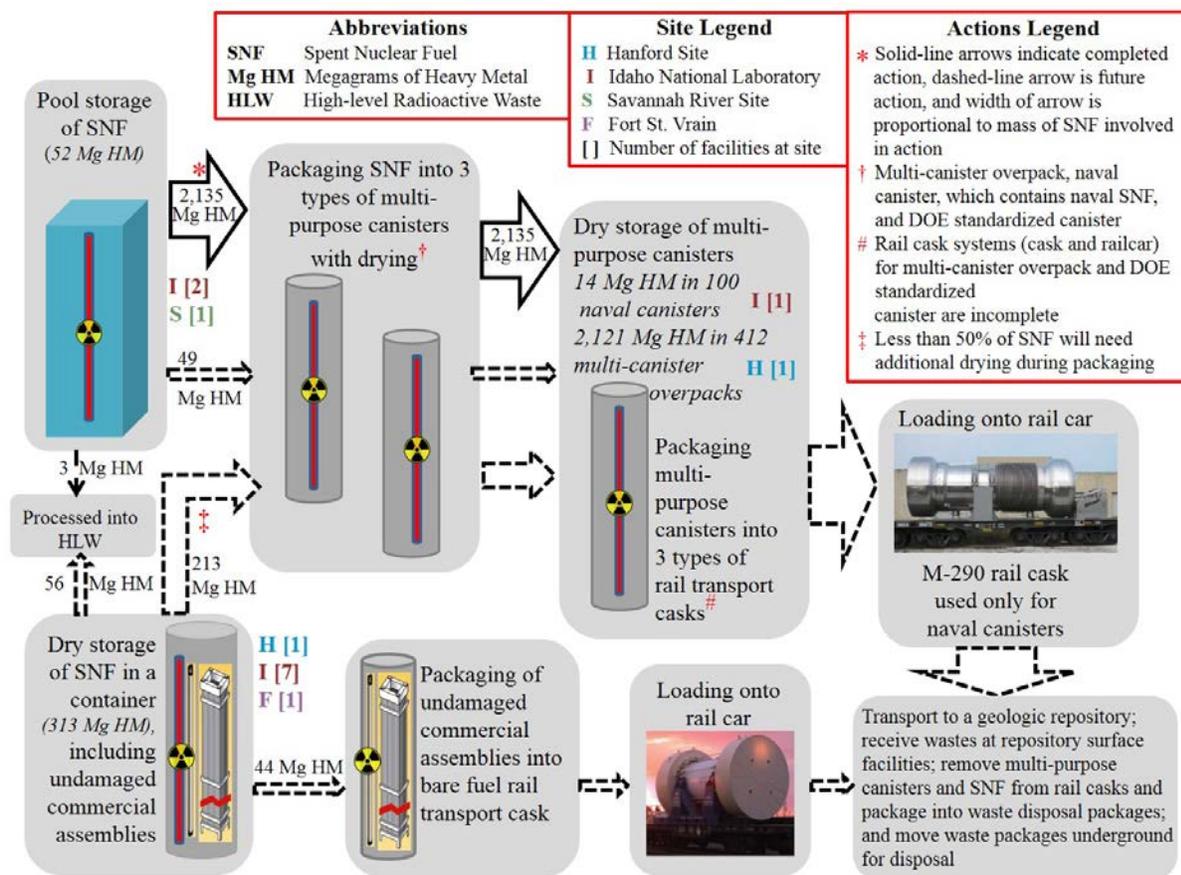


Fig. 2. Status of activities that lead to disposal of DOE SNF.

Damaged fuel of commercial origin will be packaged into the DOE standardized canister,^c a type of multi-purpose (storage, transportation, and disposal) canister. The three main issues addressed in the NWTRB review were aging management, packaging, and disposal of DOE SNF.

Quantities and Characteristics of DOE SNF

DOE currently manages about 2,500 Mg HM of SNF, most of which is stored at four locations (Figure 2; Table I): the Hanford Site in Washington State, INL in Idaho, SRS in South Carolina, and the Fort St. Vrain ISFSI in Colorado. At these sites, DOE stores about 50 Mg HM of SNF in storage pools—two located at INL and one at SRS (Figure 2). The remaining inventory of DOE SNF at the sites is stored dry in containers at 11 different dry storage facilities: two facilities at Hanford, eight facilities at INL, and one at Fort St. Vrain. As of December 2017, DOE had been using six storage facilities, including two pools, beyond their 40-year design lifetimes.

The DOE SNF inventory consists of more than 250 types of SNF. Figure 3 depicts a selection of the many types of DOE SNF and the lists the reactors from which they came. The small N Reactor SNF and Single Pass Reactor SNF, which are composed of uranium metal slugs, are types of defense SNF that were produced in plutonium production reactors at Hanford.

^c The NWTRB adopted DOE’s nomenclature for this canister even though it is not standard by any conventional definition. The DOE standardized canister is a canister system that consists of four cylindrical stainless-steel canisters with two different diameters (18 inches and 24 inches) and two different lengths (10 feet and 15 feet). The different sizes and eight internal basket designs of the multi-purpose canisters accommodate the wide dimensional variability of DOE SNF.

TABLE I. Mass and types of SNF stored at four locations

Storage Site	Mass of Stored Spent Nuclear Fuel (Megagrams of Heavy Metal)	Number of Types of Spent Nuclear Fuel
Hanford	2,130	20
INL	325	250
SRS	30	60
Fort St. Vrain	15	1
Total	2,500	>250 ^a

Footnotes:

^a Some types of spent nuclear fuel are stored at more than one location. In general, the complexity of spent nuclear fuel management activities correlates with the diversity of fuel types at a site.

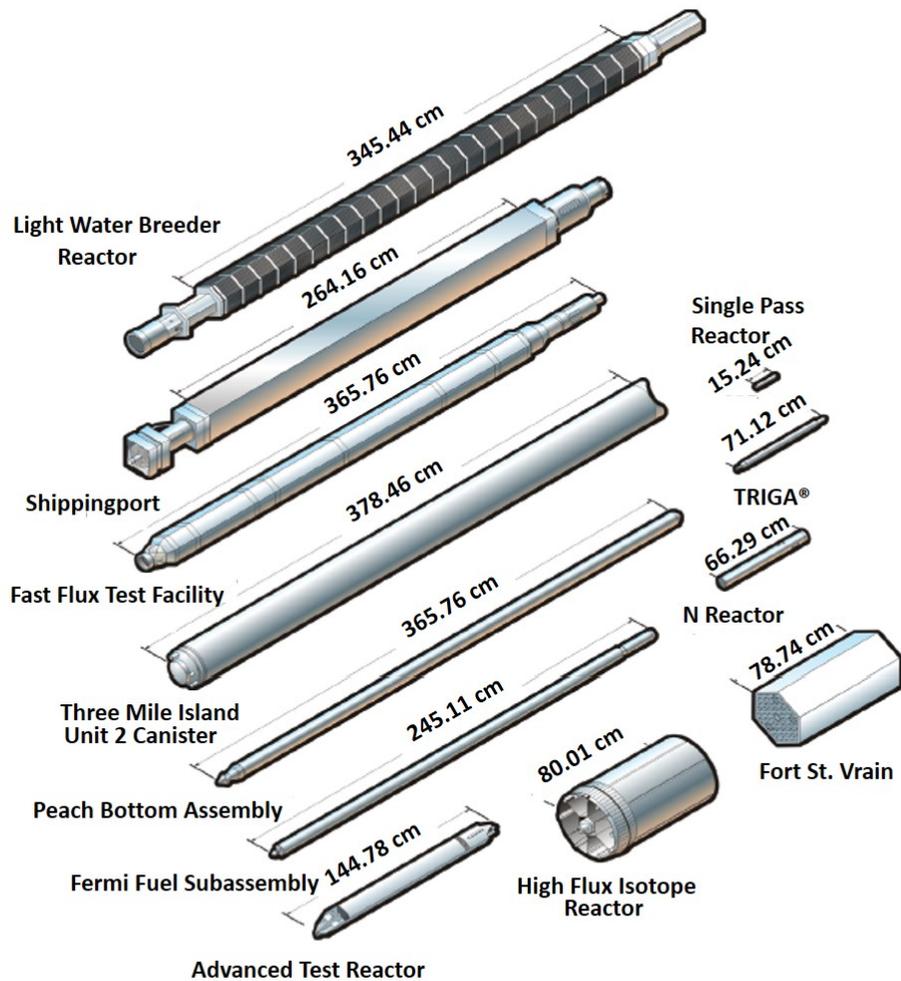


Fig. 3. Some of the more than 250 SNF types and their sources [7].^d

^d TRIGA is a registered trademark of General Atomics in the United States and/or other countries.

Examples of commercial-origin SNF that DOE manages include Fort St. Vrain fuel, which is thorium-uranium carbide particles dispersed in graphite; Three Mile Island Unit 2 Canisters, which contain SNF debris; Light Water Breeder Reactor fuel, composed of thorium-uranium oxide pellets; and Shippingport SNF. High Flux Isotope Reactor and Advanced Test Reactor fuels, which have high fissile isotope concentrations and are aluminum-based, are examples of research reactor SNFs that are still being produced. The majority of DOE SNF—about 85% of the mass, in terms of Mg HM—is from atomic energy defense activities. The defense-related inventory mostly comprises SNF from plutonium production reactors and nuclear reactors on U.S. Naval vessels. About 11% of the mass of DOE SNF is of commercial origin (Figure 1).

The DOE SNF inventory other than that of defense or commercial origin (the remaining 4% by mass) includes SNF from DOE research and development activities, as well as from domestic and foreign research and test reactors. Both INL and SRS receive small amounts of SNF from foreign and domestic research reactors. However, the pool facility at SRS has limited space available to accommodate more fuel so DOE is removing some aluminum-based SNF from the pool and processing it to create HLW (Figure 2).

INL continues to receive and store SNF from naval vessels. The existing building and equipment for handling naval SNF are over 50 years old and are too small to handle the largest fuel-containing components. In response, DOE decided to build a new naval SNF handling facility at INL. With that new facility, DOE will be able to load all naval SNF into multi-purpose (storage, transport, and disposal) naval SNF canisters, transfer the canisters into or out of temporary dry storage, and load waste shipping containers for transport to a repository. The acceptability of such containers for disposal depends on the repository design and is presently unknown.

Unlike commercial SNF, of which there are two types, the characteristics of DOE SNF vary widely. The inventory includes more than 10 different fuel compounds including uranium metal, thorium-uranium carbide, and thorium-uranium oxide. The range of different cladding compositions for DOE SNF is greater than for commercial SNF, including some compositions that can degrade during storage. Other characteristics of DOE SNF also vary. For example, DOE SNF has a wide-range of fissile material concentrations that, at the higher end of the range, increases the potential for nuclear criticality. DOE SNF is more damaged than commercial SNF. Compared with commercial SNF, there is less knowledge about the present physical state of the DOE SNF, including the extent of its degradation and the potential for further degradation. The total mass-averaged radioactivity of DOE SNF—mainly from fission products—is about eight times less than that of commercial SNF.

The diverse physical and chemical properties of DOE SNF, and the degraded condition of some of it, drive the technical challenges associated with DOE's SNF management activities. In general, these challenges increase with time because of deleterious aging effects on both the cladding and fuel. Requirements stipulated in legal agreements and regulations add to the challenges. For example, a 2035 deadline for DOE to remove SNF from the state of Idaho, affects SNF management at INL. Also, U.S. Nuclear Regulatory Commission (NRC) regulations related to storage, transport, and disposal to varying degrees limit DOE's use of multi-purpose canisters (*i.e.*, canisters used for storage, transportation, and disposal). This creates a challenge because most DOE SNF, by mass, is either packaged in or planned for packaging in such canisters (Figure 2). After disposal, degradation of individual DOE SNF types will vary depending on the disposal environment.

In its review [6], the NWTRB examined technical issues concerning DOE SNF packaging and storage resulting from both technical and external constraints that might affect continued storage, transport, and final disposal of the fuel.

In its analysis, the NWTRB assumed that DOE will use the three types of multi-purpose canisters that it has proposed [the multi-canister overpack (MCO) and the naval canister—both of which are in use—and a DOE standardized canister which has yet to be deployed] to package and store DOE SNF. For evaluating the conditions under which the three-canister approach might work, the NWTRB's analysis also assumed that DOE will not remove SNF from the multi-purpose canisters and repackage it prior to disposal.

Aging Management Issues

As materials age, they can degrade. An aging management program manages degradation effects to ensure continued safe operations for extended periods. Different fuel materials—and the cladding that surrounds the fuel—have different rates of degradation in storage (Figure 4), and the stability of an individual fuel compound or cladding material depends on the storage environment. For example, DOE's storage practices, particularly those of storing some aluminum-clad SNF in water pools, could adversely affect DOE's ability—decades in the future—to retrieve and package stored SNF into a canister for disposal. Figure 4A [8] depicts pit-corrosion damage on fuel plate cladding over fuel material region in an aluminum-based Materials Testing Reactor type-assembly.

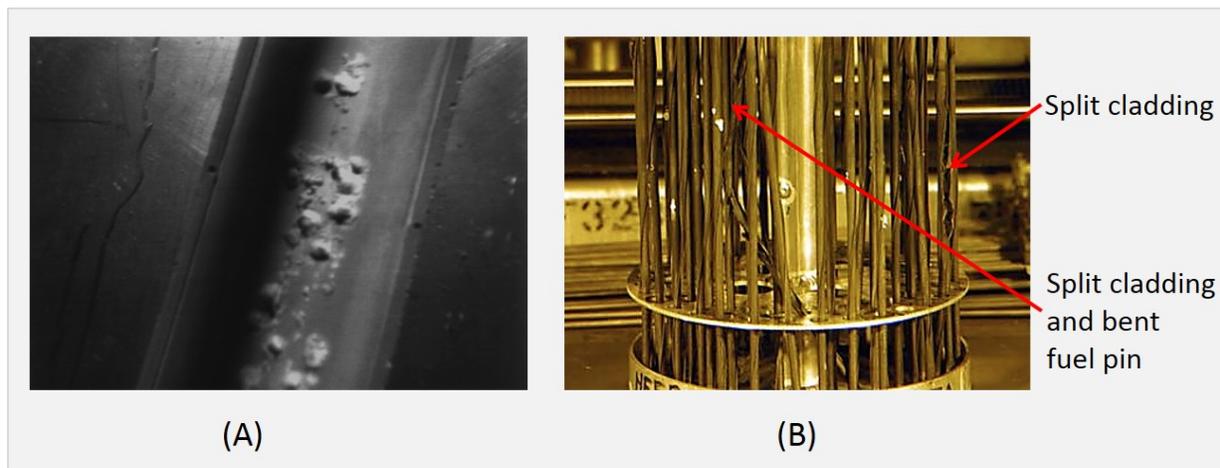


Fig. 4. Examples of degradation that has occurred during extended storage of DOE SNF [8,9].

Different materials used in SNF storage systems (*e.g.*, aluminum containers that hold aluminum-based fuel, stainless steel and carbon steel containers that hold a variety of SNF types, and concrete used for pools and dry storage facilities) also have different rates of degradation during storage that depend on the storage environment.

Some sodium-bonded SNF, which contains metallic sodium between the cladding and the fuel, has been stored in containers in a pool and in dry storage at INL. Under both wet and dry storage conditions, the SNF degraded when moisture entered either the storage container or the cladding of the fuel (Figure 4B [9]). Moisture in dry storage containers penetrated small pinhole-sized holes in the stainless-steel cladding surrounding the SNF from a reactor that used sodium for heat transfer (cooling) and reacted vigorously with metallic sodium inside the cladding. This reaction created hydrogen and sodium hydroxide, which split the cladding. Hydrogen was created due to the reaction of water with sodium and accumulated in the storage canisters. Because metallic sodium reacts with water to produce corrosive sodium hydroxide and hydrogen gas, DOE considers and treats sodium-bonded SNF as a hazardous waste. The DOE Office of Nuclear Energy (DOE-NE) is treating some sodium-bonded SNF in an electrochemical process that creates two new (other-than-glass) types of HLW. These new waste forms need to be acceptable for disposal in a geologic repository.

Damaged metallic uranium SNF stored in pools at Hanford corroded, which made DOE's retrieval and packaging process more complex. DOE cleaned corrosion products (*e.g.*, loose corroded pieces of fuel and hydrated uranium and aluminum minerals) off the metallic SNF before packaging it into MCOs and drying it to minimize the amount of water that might be contained in the canister and to limit degradation of the SNF and canister during storage. The MCO design allows for monitoring of temperature, pressure, and gaseous constituents like hydrogen and oxygen—generated from interactions of radiation from the fuel with water remaining after drying and packaging—inside the MCOs during storage. DOE monitored representative MCOs, which include a range of contents from undamaged fuel to baskets containing loose corroded pieces of SNF, to ensure MCO design limits (*e.g.*, gas pressurization) are not exceeded during storage.

Packaging Issues

Outstanding packaging issues primarily are related to the DOE standardized canister. DOE has yet to finish research and development activities for the DOE standardized canister that will be needed to design and operate any packaging facility it develops. DOE needs to develop both the remote welding techniques required to seal the canisters and the advanced neutron absorbers—metal sheets used to create baskets for the SNF—required to reduce the potential for criticality to occur in canisters containing SNF with high fissile isotope concentrations. Finally, DOE also plans to add water-bearing pelletized supplemental neutron absorbers [8] to hundreds of DOE standardized canisters, but DOE has not decided the final composition of material that will surround the absorbers.

Defining and proving what is “suitable” drying of the SNF and any water-bearing materials added during packaging of the DOE standardized canister is critical. Water remaining in the standardized canister after drying affects degradation within the canister and can create conditions (*e.g.*, generation of hydrogen) that impact the suitability of the canister for later transport. DOE needs NRC's approval before transporting the SNF from storage sites to either a centralized interim storage facility or a geologic repository. DOE model predictions for hydrogen concentrations inside the DOE standardized canister that it believes to be conservative show that hydrogen concentrations could exceed limits that NRC applies during transport package reviews. Similar models predict high hydrogen concentrations in stored MCOs. However, monitoring results for MCOs show that less hydrogen accumulates during storage than predicted.

Disposal Issues

As discussed earlier, the types of DOE SNF vary widely, are mostly different from commercial SNF, and will behave differently during disposal depending on the repository environment. Since 2010, DOE's disposal research and development activities have focused on a range of geologic disposal options, including repositories in granite, clay/shale, salt, and deep boreholes. Earlier, the focus had been on unsaturated volcanic tuff. The variability in physical and chemical characteristics of the SNF affects processes that can occur in geologic repositories. If damaged, both uranium metal DOE SNF and thorium-uranium carbide DOE SNF can react with water and create gas. Understanding gas generation and migration is a key issue in the assessment of repository performance, especially for granite and clay/shale repositories. Some DOE SNF, such as uranium metal and aluminum-based SNF, will corrode after disposal and can create small particles (colloids) that affect the release of radionuclides from the waste package into the disposal environment.

The total radioactivity of DOE SNF is much less than commercial SNF (Figure 1). Therefore, for a repository that accommodates both commercial and DOE SNF, the contribution of DOE SNF radioactivity to post-closure repository performance is generally unimportant.

However, the total radioactivity from commercial and DOE SNF for some radionuclides that can be important contributors to the post-closure repository performance is dominated by a small mass (50 Mg HM) of DOE thorium-uranium oxide SNF (roughly 2% of the total mass of DOE SNF). If DOE SNF is disposed of separately from commercial SNF (*e.g.*, a defense-only waste repository that contains HLW) the contribution of DOE SNF radioactivity to post-closure repository performance will be significant (Figure 1).

NWTRB Findings and Recommendations

Based on the information developed in its multi-year review, the NWTRB developed six principal findings and recommendations on managing and disposing of DOE SNF [6].

Aging Management

Finding: DOE's aging management programs are not fully implemented. Some DOE SNF storage facilities lack aging management programs to facilitate retrieving stored SNF and packaging it into multi-purpose canisters needed to transport the DOE SNF to either a centralized interim storage facility or a permanent repository. Aging management programs also provide assurance that the SNF can continue to be safely stored, transported when required, and retrieved if necessary. For most of its SNF storage facilities, DOE has not completed an aging management assessment identifying the actions it should take now, and in the future, to facilitate retrieving stored SNF many decades from now. DOE does have an aging management assessment for the Savannah River Site pool facility, but it has yet to implement all the activities identified in the assessment. Furthermore, DOE has not completed aging management assessments that could facilitate continued use of the multi-purpose canisters at its existing storage facilities beyond 40 years and during subsequent transportation and geologic repository operations.

The NWTRB recommended [6] that DOE develop and fully implement programs to manage degradation of SNF, the materials that contain SNF, and SNF facilities for additional multiple decades of storage operations at all storage facilities. Managing degradation includes assessing its potential of occurring, and—when it is predicted to occur at unacceptable rates—monitoring storage conditions of the SNF and the materials in which it is stored to prevent degradation or to mitigate degradation effects. These programs should take into account the following important considerations:

- a. the diversity of degraded DOE SNF, storage facility construction materials, and storage systems that differ from those used commercially;
- b. the potential for additional multiple decades of storage operations;
- c. the requirements that may have to be met to manage degradation of multi-purpose canisters—and any other canisters that may be used—after multiple decades of storage until final disposal occurs;
- d. the impact of potential future missions for existing storage facilities when assessing what aging management activities may be needed at each facility; and
- e. lessons learned from similar programs developed for commercial nuclear reactors and commercial SNF dry storage facilities.

Measuring and Monitoring Conditions During Storage

Finding: measuring and monitoring conditions of the SNF during dry storage is important. The ability to measure and monitor conditions of the SNF in the storage facility during future dry storage (*e.g.*, monitoring gas composition in a multi-purpose canister as was done for the MCOs) is important to the design, development, and deployment of new DOE storage systems. Although DOE has considered including monitoring capability for new storage systems, it has not done so in its baseline design for the DOE standardized canister.

The NWTRB recommended [6] that DOE include the capability for measuring and monitoring the conditions of the SNF in new DOE storage systems, such as the DOE standardized canister, and in new packaging and storage facilities to aid in establishing the condition of the SNF during subsequent operations and its acceptability for those operations.

Drying Procedures

Finding: an improved technical basis is needed for proposed drying procedures for DOE SNF before packaging it in multi-purpose canisters. A better understanding of how much water remains in sealed multi-purpose canisters and the cumulative conditions inside the canisters adds confidence that proposed drying procedures for DOE SNF will be adequate. DOE assessed physical and chemical processes that could occur inside sealed DOE standardized canisters over a 50-year storage period. DOE proposed drying procedures for aluminum-based SNF but did not consider all the sources of water that could be in the canisters. It also did not account for how long the sealed multi-purpose canisters may serve as a radionuclide containment barrier. Using the expected amount of residual water, including chemisorbed water associated with supplemental neutron absorbers and hydrated SNF corrosion products, can improve DOE's understanding and technical basis for drying SNF. An understanding of gas composition and pressure in multi-purpose canisters can inform the technical and regulatory considerations for storage, transport, and disposal operations. Predicting and monitoring gas composition and pressure of sealed multi-purpose canisters can confirm DOE's understanding of, and the basis for its conclusion that, proposed SNF drying procedures are adequate.

The NWTRB recommended [6] that DOE conduct research and development activities to confirm that reactions between DOE SNF and any water remaining in any multi-purpose canister do not cause cumulative conditions inside the canister (*e.g.*, combustibility, pressurization, or corrosion) to exceed either the design specifications or applicable regulatory operational requirements. The period of interest extends over the duration of canister use, including the time spent in storage, transportation, and at a repository until it is closed. These research and development efforts should include the following activities:

- a. collecting and analyzing data applicable to drying DOE SNF—particularly aluminum-based fuels—that focus on the quantity of chemisorbed water;
- b. determining whether the results and associated models from a DOE-NE study of a vacuum drying chamber can be used to inform efforts to understand and implement DOE SNF drying;
- c. collecting data on potential hydrogen generated from SNF corrosion products that are focused on characterizing the mass and chemical composition of water-bearing aluminum minerals present after drying;
- d. collecting data on the rates of hydrogen produced from dissociation of water molecules by materials composing and within storage canisters (*e.g.*, supplemental neutron absorbers or fuel corrosion products) by ionizing radiation;
- e. using validated models for physical and chemical processes that could occur inside sealed canisters to predict internal gas composition and pressure over the expected length of time the canisters will be in use and comparing model predictions to monitoring data collected during storage; and
- f. re-evaluating the adequacy of proposed drying protocols that reflect all the sources of water to assess the extent of potential corrosion damage and gas pressurization of the canister during its use.

Packaging Facilities

Finding: technical and regulatory uncertainties complicate planning for packaging facilities. A key step in DOE's SNF management plans is developing packaging facilities at INL, Hanford, and SRS for DOE SNF that still needs to be placed into approximately 3,500 DOE standardized canisters. DOE has not completed all the research and development activities for the standardized canister that will define the full capabilities required for a packaging facility. DOE does not know whether the packaging facility would be licensed by NRC, or which NRC licensing regulation(s) would apply if NRC regulated the facility. NRC will also need to approve the canister for transport years hence, and any conditions associated with NRC's approval could affect the design for the canister and packaging facility. These technical and regulatory uncertainties complicate planning for these packaging facilities, the first of which is planned for INL.

The NWTRB recommended [6] that to minimize complications in developing and operating a packaging facility for DOE SNF at INL, DOE should complete research-, development-, and licensing-related activities for the DOE standardized canister—and any other canisters that may be used—prior to completing the facility's preliminary design. In particular, DOE should complete the following tasks related to the DOE standardized canister:

- a. conduct remote welding and real-time, non-destructive, weld-testing research and development activities;
- b. research and develop materials that will be packaged with the SNF (*e.g.*, structural inserts using an advanced neutron absorber);
- c. decide on and develop SNF treatment processes needed for specific SNF types (*e.g.*, epoxied fuel may need to have organic components removed, and Fermi blanket fuel may be electrochemically processed or may have sodium removed and be placed in high integrity cans that are made with advanced corrosion-resistant metals, such as Alloy 22);
- d. confirm through research and development that reactions between SNF and any water remaining in a canister do not cause conditions inside the canister to exceed either the design specifications or any applicable regulatory requirements during dry storage, transportation, and repository pre-closure operations;
- e. obtain NRC approval that the DOE standardized canister meets the transportation moderator exclusion requirements or receive an exemption from these requirements;
- f. analyze an existing NRC-certified rail transport cask, or develop a new one, and obtain NRC approval to transport DOE standardized canisters to ensure that any canister packaging design features needed inside the rail cask (*e.g.*, a supplemental impact limiter) to meet regulatory requirements are considered in the design of the packaging facility; and
- g. define the technical requirements for the packaging facility, including the regulatory standards (*e.g.*, NRC regulations) that it will need to meet.

Waste Acceptance System Requirements

Finding: Waste acceptance system requirements affect the disposition of DOE SNF and DOE-NE is not subject to the requirements. Both the DOE Office of Environmental Management (DOE-EM) and the naval nuclear propulsion program are waste custodians and have signed agreements with the DOE Office of Civilian Radioactive Waste Management (OCRWM)[°] to accept their SNF for disposal.

[°] Until 2010 when DOE closed it, the OCRWM was responsible for the transportation and disposal of DOE SNF and the disposal of naval SNF.

These agreements require waste custodians to use waste acceptance system requirements, which apply to all SNF and HLW that will be disposed of in a repository, in order for the DOE organization responsible for waste disposal (at the time the agreements were signed that organization was OCRWM) to accept the waste for disposal. Both DOE-EM and the naval nuclear propulsion program continue to manage their waste according to the waste acceptance system requirements [10]. DOE-NE manages some SNF and is treating sodium-bonded SNF to yield two HLW forms, both of which will need to be shown to be acceptable for geologic disposal. Previously, DOE-NE transferred some of its SNF from the Advanced Test Reactor to DOE-EM. DOE-NE is not a “waste custodian” and does not have a waste acceptance agreement with OCRWM.

The NWTRB recommended [6] that DOE-NE implement the existing OCRWM waste acceptance system requirements to increase the likelihood that SNF managed by DOE-NE and that waste forms resulting from electrochemical processing of sodium-bonded SNF will be acceptable for geologic disposal in a repository.

Disposal Research Efforts

Finding: The diversity of DOE SNF combined with differences in physical and chemical characteristics of potential repository environments complicates the potential disposal of DOE SNF. Since 2010, DOE has explored alternative geologic disposal options, including generic repository environments other than tuff and deep borehole disposal instead of a mined geologic repository for some types of wastes. The diversity of DOE SNF in terms of chemical composition and radionuclide content, combined with the diverse physical and chemical environments that can occur in repositories located in generic environments such as granite, clay/shale, and salt, complicates the evaluation of disposal sites and potentially the disposal of DOE SNF. Understanding processes that may adversely affect the isolation properties of the repository, such as gas generation, is a key issue in the assessment of repository performance. Evaluations of repository post-closure performance depend on the mass and radionuclides content of SNF in a specific package and the number of packages. The diversity of chemical and physical characteristics of DOE SNF leads to widely variable masses of SNF and radionuclides in each package, depending of the specific fuel type and the design of engineered barrier systems. DOE identified and prioritized its research on different disposal environments based on disposing of commercial SNF without thoroughly considering the need to dispose of DOE SNF that has a wide variety of compositions and conditions.

The NWTRB stated in its report [6] that if DOE continues to conduct generic investigations of a range of potential repository environments, that DOE should identify and prioritize its research efforts concerning DOE SNF degradation related to disposing of DOE SNF in each of the potential host-rock environments. As part of this effort DOE should complete the following tasks:

- a. Improve its current understanding of post-closure DOE SNF degradation processes for DOE SNF types that constitute a large portion of the mass or radionuclide content or that could be in a large fraction of the disposal packages in a repository.
 - i. For each disposal environment, identify the processes that will occur, their rates, and their impact on repository performance, including assessing the potential generation of corrosion products that could affect the release of radionuclides from a waste package and the potential generation of hydrogen and other gases.
- b. Prioritize its research based on analyzing the features, events, and processes associated with those aspects of DOE SNF that differ significantly from commercial SNF and on types of DOE SNF that could constitute a significant fraction of the estimated post-closure risk to the public.

DOE SNF Management Activities

During the time that the NWTRB was conducting its review [1-4], DOE recognized its DOE SNF management challenges and established the SNF Corporate Board to promote complex-wide coordination to address such challenges [11]. This group has subsequently been referred to as the DOE SNF Working Group [12]. In June 2016, the DOE SNF Working Group concluded that a study was needed to understand if technical and engineering issues existed that need to be addressed to ensure safe extended (greater than 50 years) storage of aluminum-clad SNF [13]. The DOE study on this topic [13] identified knowledge gaps and technical data needs related to aging management issues and drying SNF, many of which were very similar to those previously identified by the NWTRB [1-3]. DOE developed an action plan to address the knowledge gaps and technical data needs [14] and, in 2018, began six laboratory-based studies to develop the preliminary technical basis for drying and dry storage of aluminum-clad SNF [15]. This multi-year DOE-EM Office of Technology Development-funded study [15] addresses some of the NWTRB findings and recommendations for management and disposal of DOE SNF [6].

In its appropriations for Energy and Water Development for fiscal year 2019 [16], Congress adopted language in the House Appropriations Committee Report [17] directing that the National Spent Nuclear Fuel Program at INL, as part of DOE's Technology and Development program, address some activities recommended by the NWTRB. Specifically, the House report recommended that 5 million dollars be provided for the National Spent Nuclear Fuel Program to address issues related to storing, transporting, processing, and disposing of DOE-owned and managed SNF. The House report stated that "within these amounts, DOE-EM shall utilize funding to address the need for additional assessments into material degradation that may occur as a result of multiple decades of DOE-EM SNF storage facilities [sic], nuclear material measuring and monitoring in DOE storage systems, and other activities recommendation [sic] by the NWTRB in its 2017 report on the Management and Disposal of U.S. Department of Energy Spent Nuclear Fuel" [6].

CONCLUSIONS

The NWTRB has reviewed the technical and scientific validity of DOE activities related to the management and disposal of DOE SNF and documented its review in a report to the Secretary of Energy and Congress [6]. The diversity of DOE SNF, and the degraded condition of some of it, drive the technical challenges associated with DOE's SNF management activities. These challenges are increasing with time because of deleterious aging effects on both the cladding and fuel. Until a viable disposal solution is found, it is necessary and important that DOE manage its SNF in a manner that does not impede its eventual disposal. Based on its review, the NWTB made findings and recommendations on six main areas related to managing and disposing of DOE SNF: (i) aging management, (ii) measuring and monitoring conditions during storage, (iii) SNF drying procedures, (iv) development of packaging facilities, (v) waste acceptance system requirements, and (vi) SNF disposal research efforts. DOE has begun to address NWTRB recommendations related to aging management and SNF drying procedures. Congressional language in the fiscal year 2019 House Appropriations Report, directed DOE-EM to address some NWTRB recommendations.

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