Key Points from the Board Report on Management and Disposal of DOE SNF and Board Recommendations Related to the DOE Standardized Canister and on SNF Drying

Presented to:
NWTRB meeting attendees

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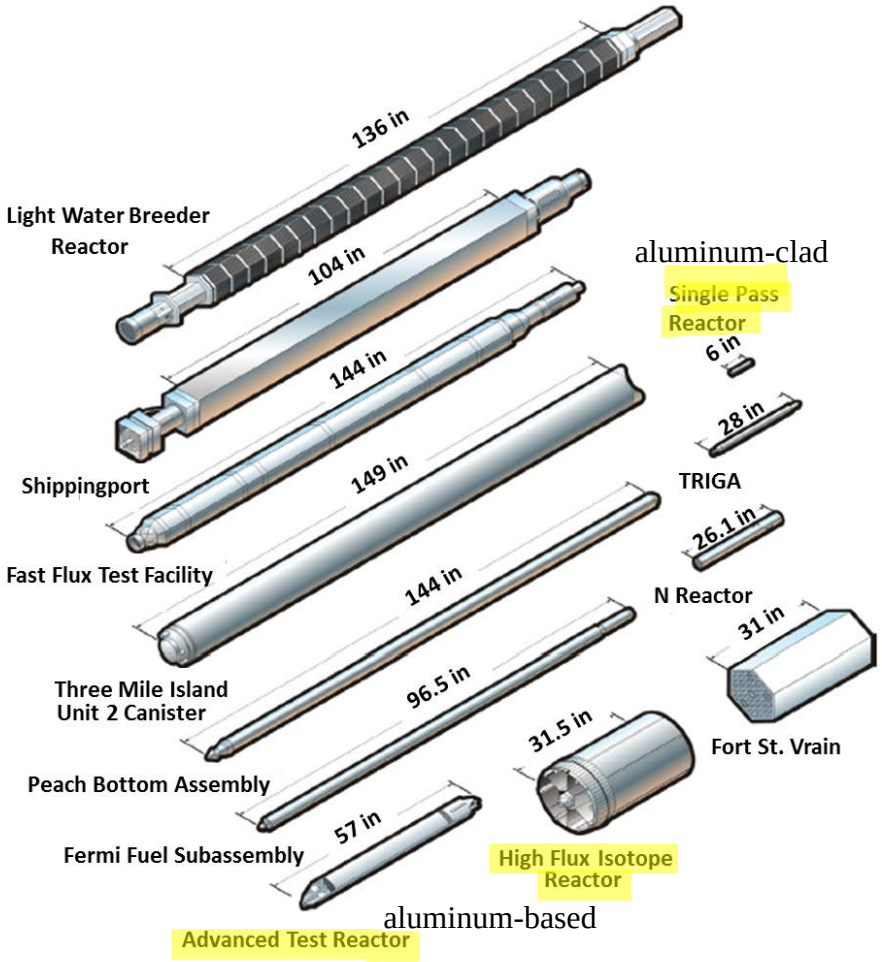
Board Review of DOE Spent Nuclear Fuel

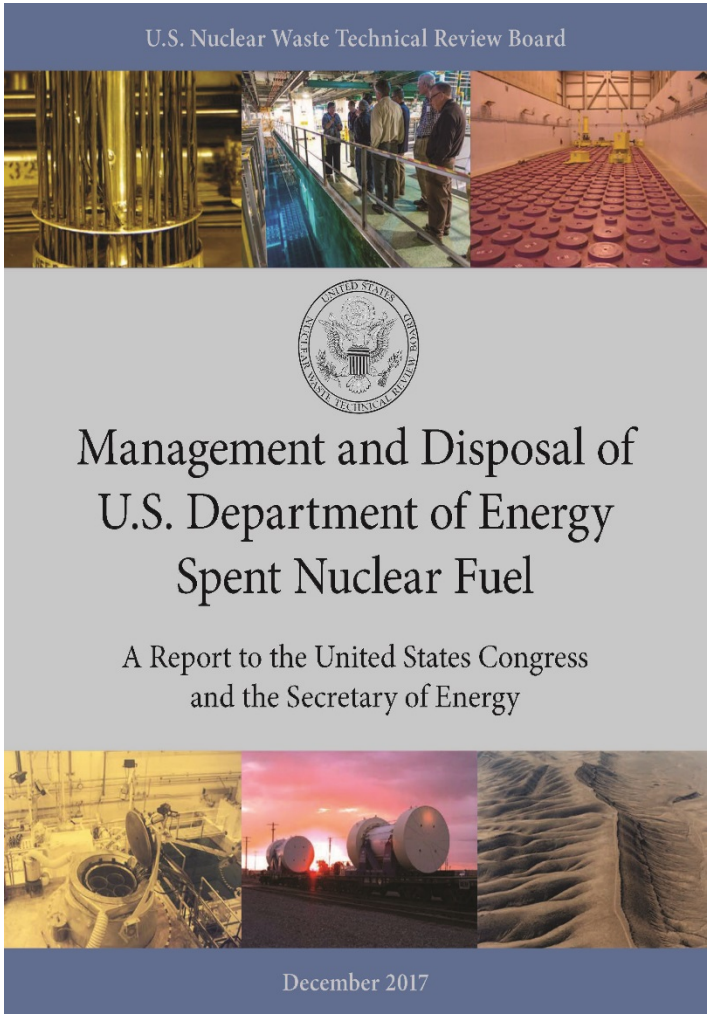
- Multi-year review of DOE's activities to manage and dispose of DOE SNF
  - Focused on storage and packaging of DOE SNF
  - Included site visits and public meetings
- Examined technical issues related to DOE SNF packaging and storage that might affect continued storage, transportation, and disposal



There are approximately 250 types of DOE SNF. Aluminum-clad and aluminum-based fuel types are highlighted (INL 2007)

Board Report

- Recorded quantities and characteristics of DOE SNF
  - Hanford, Idaho National Laboratory (INL), Savannah River Site (SRS), and Fort St. Vrain
- Analyzed DOE's packaging and storage activities and plans for management and disposal
- Identified aging management, packaging, and disposal issues
- Provided recommendations to DOE

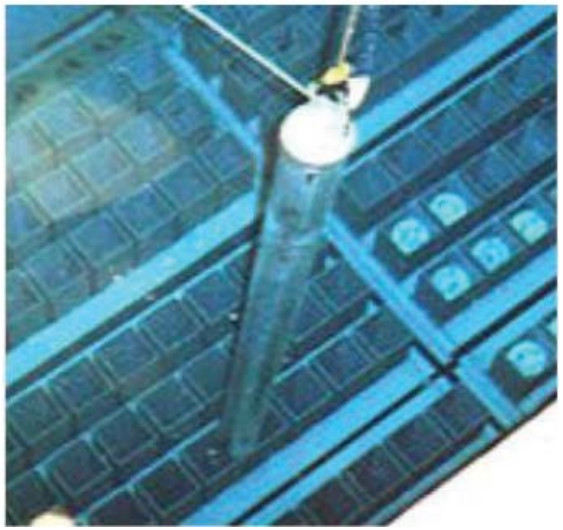


Aging Management and Packaging

- Aging management is the program to manage the aging of DOE SNF and the facilities in which it is stored
  - DOE SNF will be stored decades longer than expected
  - DOE SNF is more degraded than commercial SNF
  - Aging management activities may include prevention, mitigation, condition monitoring, and performance monitoring
- Packaging approach for DOE SNF
  - Some DOE SNF is already in multi-purpose (storage, transport, and disposal) canisters
  - DOE plans to package remaining SNF in multi-purpose canisters

DOE Spent Nuclear Fuel

- Wide diversity of fuel types and storage conditions affects spent fuel management efforts
  - Fuel compound (*e.g.*, U metal, U dioxide, Th-U dioxide, Th-U carbide, mixed oxide, and U-aluminum)
  - Cladding composition (*e.g.*, none, stainless steel, zirconium alloy, and aluminum) and condition (good-fair-poor-none)
  - Enrichment of U-235 varies widely (0.2-93%)
  - Storage (wet and a variety dry storage configurations)
  - Storage materials (*e.g.*, aluminum, carbon steel, and stainless steel)



(A) Wet storage at SRS

(B) Storage operations at INL

[(A) Maxted and Eisele 2013 and (B) Cooper 2014]

Management of DOE Spent Nuclear Fuel

- DOE SNF management responsibilities and acceptance criteria for disposal were defined by DOE Office of Civilian Radioactive Waste Management (OCRWM)
- *Memorandum of Agreement for Acceptance of Department of Energy Spent Nuclear Fuel and High-Level Radioactive Waste* (DOE 2007)
- *Waste Acceptance System Requirements Document* (DOE 2008)
- DOE Office of Nuclear Energy (DOE-NE) became responsible for OCRWM's mission and activities (DOE 2010)

Management of DOE SNF(continued)

- DOE Office of Environmental Management (DOE-EM)
  - Management of DOE-SNF during storage at DOE sites
  - Designing containers that are acceptable for transportation and disposal
  - Packaging DOE SNF into containers that are acceptable for transportation and disposal

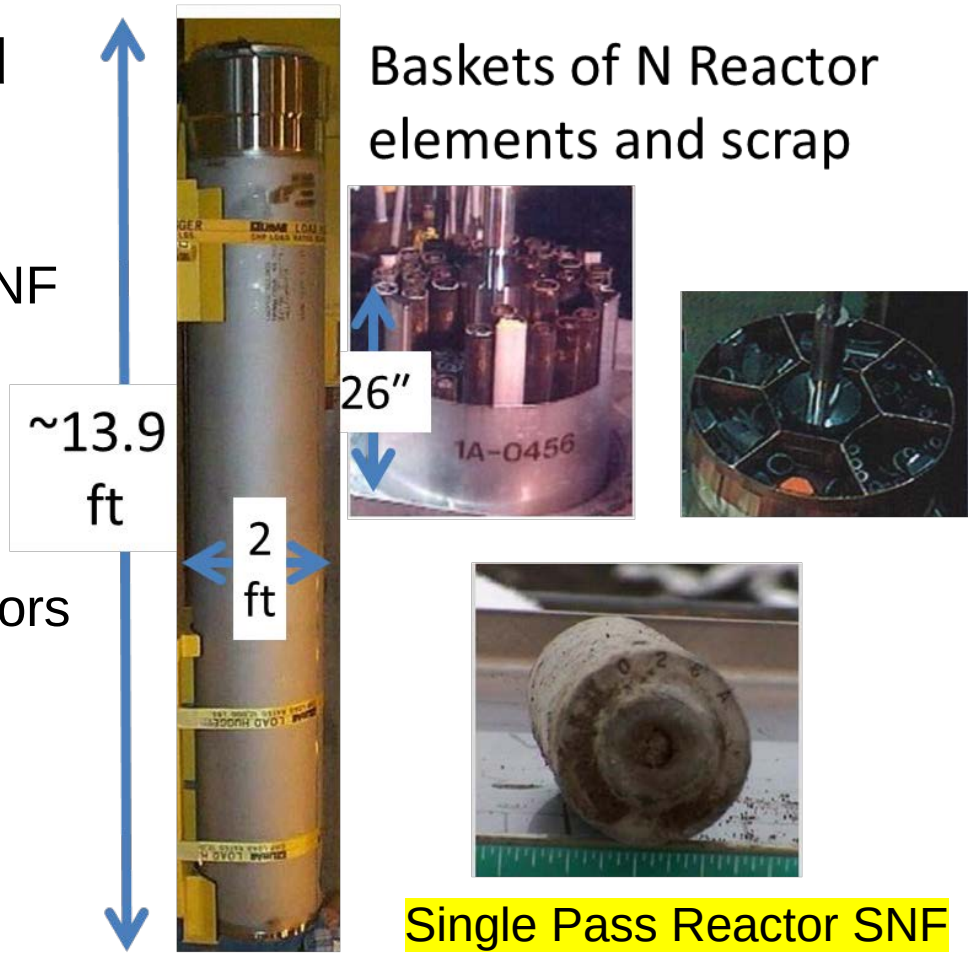
- DOE Office of Nuclear Energy (DOE-NE)
  - Acceptance of SNF from DOE-EM for transport and disposal
  - Transportation of DOE SNF from DOE sites to a geologic repository and disposal of the waste

Waste Acceptance Criteria

- Waste acceptance criteria (DOE 2008) include
  - DOE SNF will be packaged in a DOE standardized canister prior to acceptance for disposal
  - Waste form limits for pyrophoricity, explosivity, combustibility, chemical reactivity, and organic content
  - Canister contents limits with respect to gas generation, thermal effects, particulate concentrations, and internal corrosion of the canister
  - Requirements for limiting the potential for criticality during operations at a repository and after the repository is closed

DOE Packaging Approach

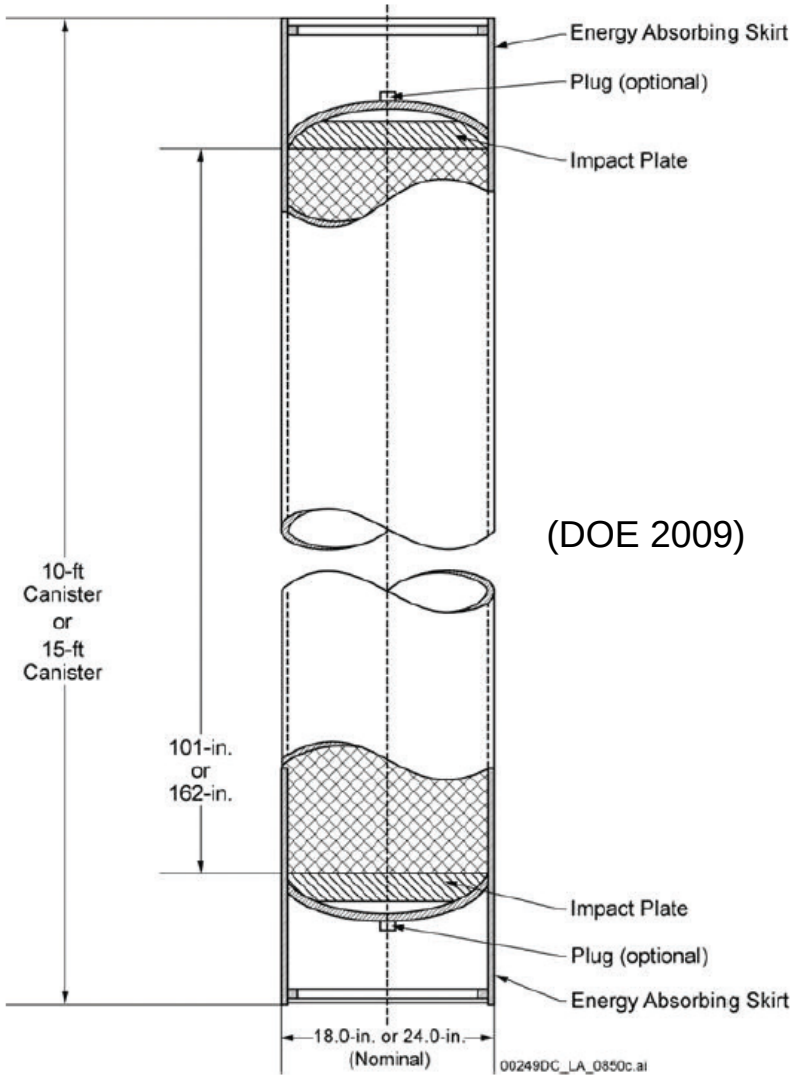
- Multi-purpose canisters (storage, transportation, and disposal)
  - 2 different systems developed for different non-naval DOE SNF
- Multi-canister overpack (MCO)
  - Used only at Hanford
  - SNF from Pu-production reactors stored wet for decades
  - Packaging completed
  - 15 of 394 were monitored for pressure, temperature, and gaseous constituents



(McCormack 2010, 2014)

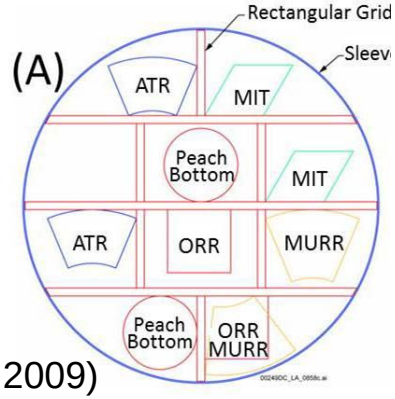
DOE Packaging (continued)

- DOE standardized canister
  - Development stopped before deployment
  - For all remaining non-naval DOE SNF (~3,500 packages)
  - 2 heights (10 and 15 feet)
  - 2 diameters (18 and 24 inches)
  - 8 basket arrangements
  - Advanced neutron absorbers



(DOE 2009)

(A) Aluminum fuels basket where all aluminum fuel can fit in any part of the basket (ATR—Advanced Test Reactor, MIT—Massachusetts Institute of Technology, MURR—University of Missouri Research Reactor, and ORR—Oak Ridge Research Reactor)



(DOE 2009)

Criticality Safety After Disposal

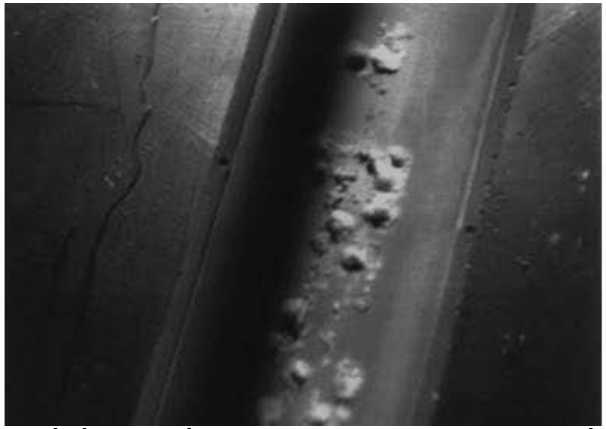
- DOE's approach to criticality safety in the repository during the post-closure period
  - Evaluated in-package intact and degraded configurations
  - Excluded criticality from the performance assessment on the basis of low probability ($<1.0 \times 10^{-4}$ over 10,000 years)

- DOE standardized canister neutron absorbers
  - Nickel-gadolinium alloy basket material (~1080 canisters; including for the aluminum-based fuels) or
  - Nickel-gadolinium alloy basket plus gadolinium phosphate pellets (~214 canisters)
  - Research and development not completed for nickel-gadolinium alloy basket material and for gadolinium phosphate pellets
  - For remaining canisters stainless steel baskets with no neutron absorbers

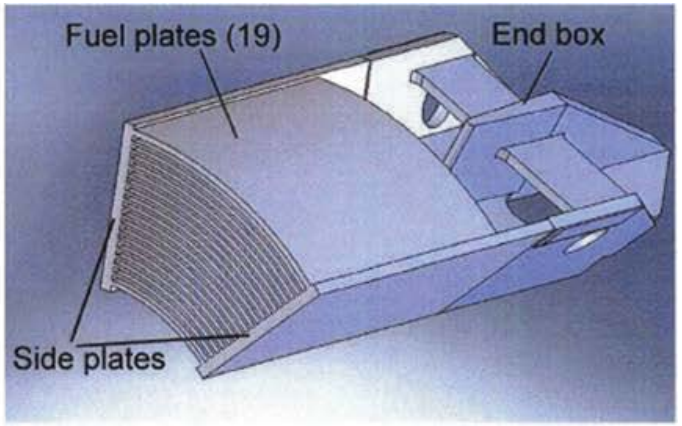
Board's Focus on Aluminum-Based Fuels

- DOE aluminum-based SNF will be in about 29% of all DOE standardized canisters
- Aluminum-based SNF can have a high surface area, a thick corrosion layer on the cladding, a hydrous chemical composition of the corrosion layer, and potentially high water content, the Board review focused on drying procedures for aluminum-based SNF

(A)



(B)



A. Corrosion of Materials Testing Reactor–type assembly (aluminum-based) with pit corrosion damage on fuel plate cladding over fuel material region. (Source: Carlsen et al. 2005). B. Section view of the large surface area of an Advanced Test Reactor fuel element with 19 plates per element. (Source: AREVA Federal Services 2012).

Aging Management

- Board observations:
  - It is essential to manage SNF in a manner that will not impede its eventual disposal
  - It is important to improve understanding of processes related to packaging and storing DOE SNF that could affect future transportation and disposal activities

Aging Management Recommendation

- **Board Finding:** DOE's aging management programs are not fully implemented.
  - Assessments missing for some facilities and incomplete implementation at other facilities

- **Recommendation:** The Board recommends 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.

(Backup slides have Board considerations for implementing this recommendation)

Measuring and Monitoring Recommendation

- **Board 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 like that being done for the MCOs) is important to the design, development, and deployment of new DOE storage systems.

- **Recommendation:** The Board recommends 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 Recommendation

- **Board Finding:** An improved technical basis is needed for proposed drying procedures for DOE SNF before packaging it in multi-purpose canisters.
- **Recommendation:** The Board recommends 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, in transportation, and at a repository, until DOE closes the repository.

(Backup slides have Board recommended research and development efforts)

Packaging Recommendation

- **Board Finding:** Technical and regulatory uncertainties complicate planning for packaging facilities.

- **Recommendation:** To minimize complications in developing and operating a packaging facility for DOE SNF at Idaho National Laboratory, the Board recommends that DOE 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.

(Backup slides have Board recommended tasks)

Activities Since Board Completed Its Review

- DOE (2017) aluminum-clad SNF technical considerations report
  - Knowledge gaps and technical data needs for aging management and drying SNF are similar to those previously identified by Board
- DOE action plan and experiments (Connolly et al. 2019)
- Congress took action on the Board's recommendations
  - House Appropriations Committee Report directed the National Spent Nuclear Fuel Program at INL to address some NWTRB-recommended activities ($5 million)
- DOE developed plans for a DOE standardized canister demonstration project
- DOE activities will be described by Drs. Josh Jarrell and Mike Connolly

BACKUP SLIDES

Aging Management Recommendation (continued)

- These programs should take into account the following important considerations:
  - the diversity of degraded DOE SNF, storage facility construction materials, and storage systems that differ from those used commercially;
  - the potential for additional multiple decades of storage operations;
  - 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;
  - the impact of potential future missions in existing storage facilities when assessing what aging management activities may be needed at each facility; and
  - lessons learned from similar programs developed for commercial nuclear reactors and commercial SNF dry storage facilities.

Drying Recommendation (continued)

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 Office of Nuclear Energy (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 is focused on characterizing the mass and chemical composition of water-bearing aluminum minerals present after drying;

Drying Recommendation (continued)

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 Recommendation (continued)

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 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);

Packaging Recommendation (continued)

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 to these requirements;

Packaging Recommendation (continued)

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.

References

AREVA Federal Services. 2012. *Advanced Test Reactor Fresh Fuel Shipping Container (ATR FFSC) Safety Analysis Report*. Rev. 9. December.

Carlsen, B., D. Fillmore, R. McCormack, R. Sindelar, T. Spieker, and E. Woolstenhulme. 2005. *Damaged Spent Nuclear Fuel at U.S. DOE Facilities, Experience and Lessons Learned*. INL/EXT-05-00760. November.

Connolly, M., L. Lacroix, R. Sindelar, M. Maxted, and J. Jarrell. 2019. *Aluminum Clad SNF: Technical Considerations and Challenges for Extended (>50 years) Dry Storage*. Proceedings WM2019 Conference, March 3 - 7, 2019.

Cooper, J. 2014. *Idaho Cleanup Project Progress Citizens Advisory Board April 2014*. Presentation to Idaho National Laboratory Site Environmental Management Citizens Advisory Board at its April 9, 2014, meeting.

DOE. 2007. "*Memorandum of Agreement for Acceptance of Department of Energy Spent Nuclear Fuel and High- Level Radioactive Waste* between the Assistant Secretary for Environmental Management (EM) U.S. Department of Energy (DOE), Washington, DC, and the Director Office of Civilian Radioactive Waste Management (RW) U.S. DOE, Washington, DC." Rev. 2. February.

DOE. 2008. *Civilian Radioactive Waste Management System Waste Acceptance System Requirements Document*. DOE/ RW-0351, Rev. 5, ICN 01. March.

References (continued)

DOE. 2009. *Yucca Mountain Repository License Application Safety Analysis Report*. DOE/RW-0573, Rev. 1. February.

DOE. 2010. "*Memorandum of Understanding Closure of RW and Maintenance of the Yucca Mountain Site* between the Under Secretary of Energy and the National Nuclear Security Administration, Office of Environmental Management, Office of Legacy Management, General Counsel, and Office of Nuclear Energy." September.

DOE. 2017. *Aluminum-Clad Spent Nuclear Fuel: Technical Considerations and Challenges for Extended (> 50 years) Dry Storage*.

INL (Idaho National Laboratory). 2007. *Spent Fuel Database*. 06-G2013-07. October 15.

Maxted, M. and D. Eisele. 2013. *L-Basin Used Nuclear Fuel Program Update*. Presentation to the Nuclear Materials Committee of the Savannah River Site Citizen Advisory Board at its April 23, 2013, meeting.

McCormack, R.L. 2010. *Hanford Spent Nuclear Fuel Overview*. Presentation to the National Spent Nuclear Fuel Program at its March 24, 2010, meeting.

McCormack, R.L. 2014. *Multi-Canister Overpack*. Presentation to the Nuclear Waste Technical Review Board at its August 6, 2014, meeting.