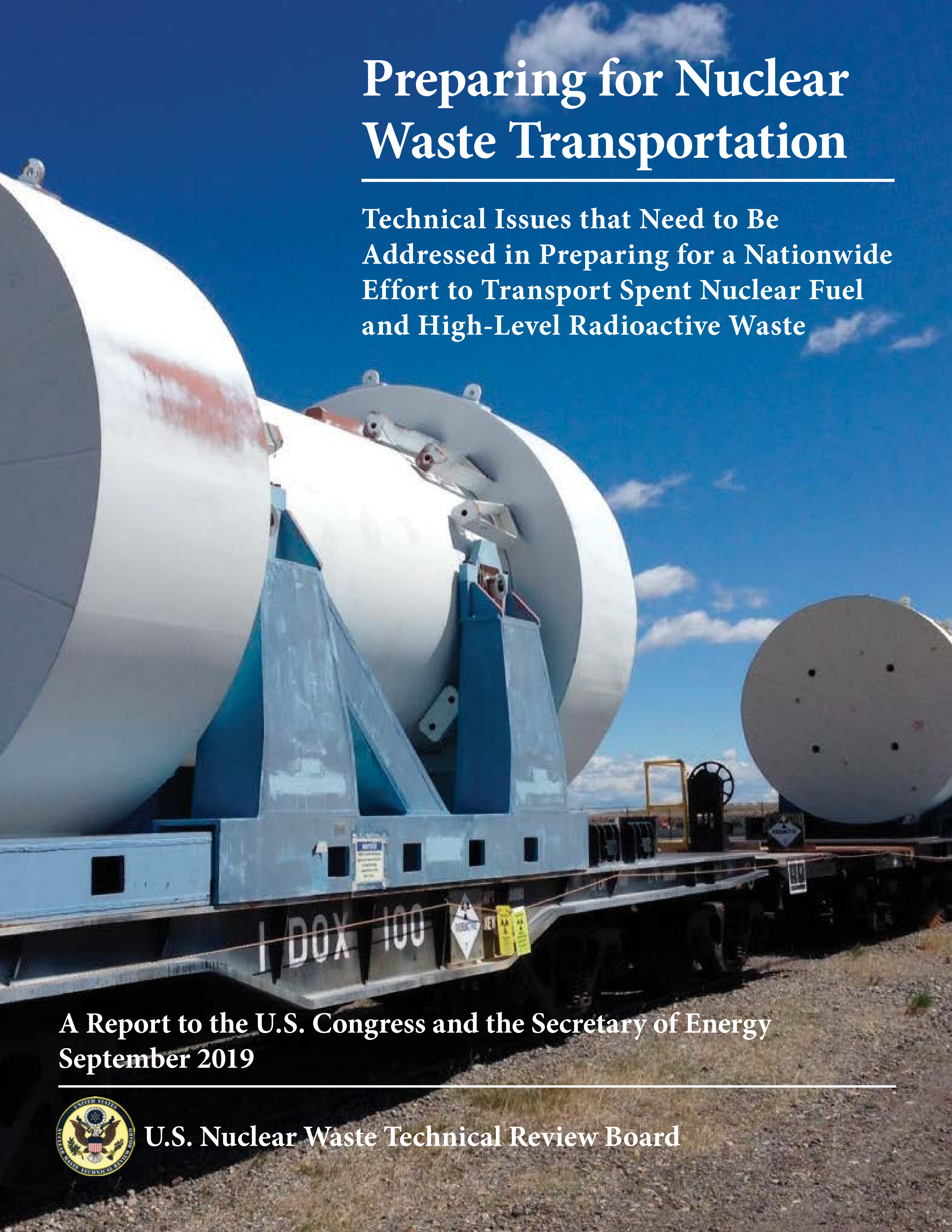

Preparing for Nuclear Waste Transportation

Technical Issues that Need to Be Addressed in Preparing for a Nationwide Effort to Transport Spent Nuclear Fuel and High-Level Radioactive Waste

A Report to the U.S. Congress and the Secretary of Energy
September 2019

U.S. Nuclear Waste Technical Review Board

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U.S. Nuclear Waste Technical Review Board

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September 2019

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U.S. Nuclear Waste Technical Review Board

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
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September 2019

The Honorable Nancy Pelosi
Speaker
United States House of Representatives
Washington, DC 20515

The Honorable Chuck Grassley
President Pro Tempore
United States Senate
Washington, DC 20510

The Honorable Rick Perry
Secretary
U.S. Department of Energy
Washington, DC 20585

Dear Speaker Pelosi, Senator Grassley, and Secretary Perry:

Congress created the U.S. Nuclear Waste Technical Review Board in the 1987 Nuclear Waste Policy Amendments Act (NWPAA) (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 Board has undertaken a review of the Department of Energy's (DOE) research and analyses supporting the development of a nationwide program to transport commercial spent nuclear fuel (SNF) and DOE-managed SNF and high-level radioactive waste (HLW). The Board's review is presented in its report to the U.S. Congress and the Secretary of Energy on *Preparing for Nuclear Waste Transportation – Technical Issues that Need to be Addressed in Preparing for a Nationwide Effort to Transport Spent Nuclear Fuel and High-Level Radioactive Waste*.

The Board's review includes a focused discussion and evaluation of technical issues that DOE needs to address in developing a nationwide effort to transport SNF and HLW. The SNF and HLW will eventually be transported to a nuclear waste repository for disposal and may be transported to a interim storage site prior to being transported to the repository site. However, the exact destination is not considered in this report, nor are potential transportation routes. The review concentrates on the technical and integration issues that will have to be resolved before each type of SNF and HLW can be transported, regardless of the destination. Because institutional and social issues are not included in the Board's jurisdiction, those issues are not evaluated in this report.

Based on the information and findings developed in the report, the Board makes three recommendations:

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1. *As DOE continues analyses and research for a nationwide waste management and transportation system, the Board recommends that DOE ensure that the issues in Table 2-1 of this report are addressed. The Board also recommends that the issues in Table 2-1 and any other issues identified by DOE be prioritized and carefully sequenced to support the integrated operation of a nationwide transportation program*.

2. *The Board recommends that DOE give higher priority to evaluating the removal of commercial SNF from shutdown nuclear power plant sites and to evaluating DOE sites storing DOE-managed SNF and HLW. DOE should also share the results of the evaluations with operators of waste storage sites, so they can apply lessons learned, retain critical site transportation infrastructure, and be better prepared for the eventual transportation of the wastes*.

3. *The Board recommends that, for planning purposes, DOE should allow for a minimum of a decade to develop new cask and canister designs for SNF and HLW storage and transportation, or DOE should conduct its own detailed evaluation of the time needed to complete design, licensing, fabrication, and testing of new casks and canisters*.

The Board trusts that Congress and the Secretary will find the information in this report useful and looks forward to continuing its ongoing technical and scientific review of DOE activities related to nuclear waste management and disposal.

Sincerely,

Jean M. Bahr
Chair

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Acronyms

AAR	Association of American Railroads
ANL	Argonne National Laboratory
BWR	boiling water reactor
CFR	Code of Federal Regulations
CISCC	chloride-induced stress corrosion cracking
CoC	Certificate of Compliance
DOE	U.S. Department of Energy
DOE-EM	DOE Office of Environmental Management
DOE-NE	DOE Office of Nuclear Energy
DOT	U.S. Department of Transportation
DWPF	Defense Waste Processing Facility
ENSA	Equipos Nucleares S.A. (Spain)
EPRI	Electric Power Research Institute
ESA	Execution Strategy Analysis
ESCP	Extended Storage Collaboration Program
FY	fiscal year
GAO	Government Accountability Office
GNS	GNS mbH (formerly Gesellschaft für Nuklear-Service mbH) (Germany)
GTCC	greater-than-class-C
GWd/MTU	gigawatt-days per metric ton of uranium (measure of nuclear fuel burnup)
HDRP	High Burnup Dry Storage Cask Research and Development Project
HFIR	High Flux Isotope Reactor
HLW	high-level radioactive waste
IAEA	International Atomic Energy Agency

INL	Idaho National Laboratory
IRP	Integrated Research Project
IRSN	Institute for Radiological Protection and Nuclear Safety (France)
ISFSI	Independent Spent Fuel Storage Installation
ISG	Interim Staff Guidance
KKG	Kernkraftwerk Gösgen (Switzerland)
MCO	multi-canister overpack
MOEF	Multi-Objective Evaluation Framework
MPC	Multi-Purpose Canister
MSB	Multi-Assembly Sealed Basket
MTHM	metric tons of heavy metal
NAS	National Academy of Sciences
NDE	nondestructive examination
NEI	Nuclear Energy Institute
NGSAM	Next Generation System Analysis Model
NQA	Nuclear Quality Assurance
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act
NWTRB	U.S. Nuclear Waste Technical Review Board
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PWR	pressurized water reactor
R&D	research and development
SCALE	Standardized Computer Analyses for Licensing Evaluation
SNF	spent nuclear fuel
SNL	Sandia National Laboratories
SRS	Savannah River Site
START	Stakeholder Tool for Assessing Radioactive Transportation
TAD	Transportation, Aging, and Disposal (canister)
TEPP	Transportation Emergency Preparedness Program
TRU	transuranic
TSC	Transportable Storage Canister
UNF-ST&DARDS	Used Nuclear Fuel Storage, Transportation & Disposal Analysis Resource and Data System

VCC	vertical concrete cask
WGA	Western Governors' Association
WIEB	Western Interstate Energy Board
WIPP	Waste Isolation Pilot Plant
WNA	World Nuclear Association

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Acknowledgments

The Board wishes to express its appreciation to Brian Gutherman, of Gutherman Technical Services, for his technical review of this report.

Credits for Cover Photographs

Front cover

U.S. Department of Energy: Rail casks for transporting commercial spent nuclear fuel

Back cover (left to right)

U.S. Nuclear Regulatory Commission: Spent nuclear fuel assembly being loaded into a dry-storage cask

Holtec, International: Holtec HI-STAR 100 dual-purpose cask for storing and transporting commercial spent nuclear fuel

U.S. Department of Energy: Rail casks for transporting commercial spent nuclear fuel

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Executive Summary

Purpose of Report

The U.S. Nuclear Waste Technical Review Board (Board) was established by Congress in the Nuclear Waste Policy Amendments Act of 1987 to perform an independent and ongoing evaluation of the technical and scientific validity of U.S. Department of Energy (DOE) activities related to the disposition of spent nuclear fuel (SNF[1]; see Figure ES-1) and high-level radioactive waste (HLW[2]; see Figure ES-2), including the disposal, transportation, and packaging of the waste. For the purposes of this report, the terms "waste" or "nuclear waste" may be used to refer to SNF and HLW.[3] The Board also is charged with providing independent expert advice to Congress and the Secretary of Energy on technical issues associated with nuclear waste management.

The purpose of this report is to document the initial Board review of DOE activities related to the eventual transportation of SNF and HLW. This initial review focuses on identifying technical issues that will need to be addressed in preparing a national effort to transport SNF and HLW to a waste repository or interim storage site. The exact destination is not considered in this report, nor are potential transportation routes. Subsequent Board review efforts may concentrate on more narrowly focused topics, such as DOE's development of system analysis tools that can be used to design and evaluate alternative waste management systems, including transportation systems.

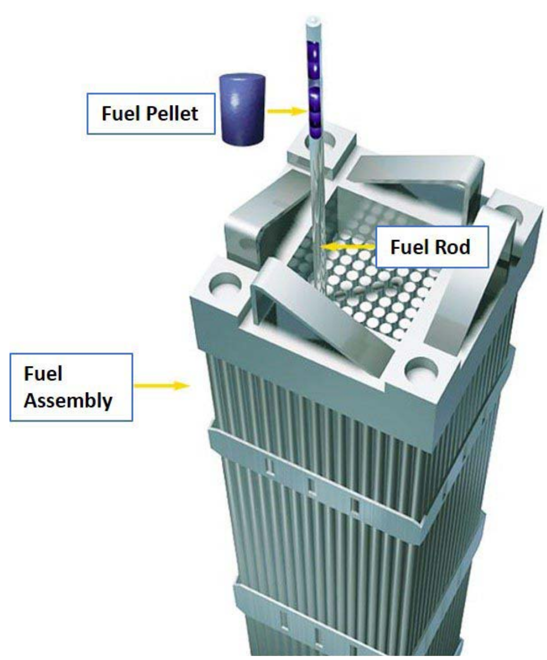


Figure ES-1. Simplified schematic of a nuclear fuel rod and fuel assembly.
After use in a nuclear reactor, the fuel is called "spent nuclear fuel." For scale, a fuel rod is approximately the same diameter as a pencil. (Source: Adapted from Duke Energy)

[1] "Spent nuclear fuel" (also known as "used nuclear fuel") means fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing.

[2] "High-level radioactive waste" means the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation.

[3] Throughout this report, the shorthand terminology of "waste" or "nuclear waste" means commercial and DOE-managed SNF and HLW, and does not include other types of radioactive waste, such as low-level waste or transuranic waste.

Figure ES-2. Treated simulated HLW.
Sample of simulated HLW that has been mixed with a glass-forming silica mixture at high temperature and then cooled into a glass form—a process called "vitrification." (Source: NWTRB)

Background

During the past several years, policy-makers in the Administration and the U.S. Congress have considered options for the disposition of SNF and HLW. Some of the options discussed have included disposal in a deep geologic repository, as specified in the Nuclear Waste Policy Act of 1982 (NWPA; as amended), and/or consolidated interim storage of waste at one or more private or federal facilities. Regardless of the approach adopted, any change from the status quo of on-site storage at the originator's site will require transportation of radioactive waste from where it is being held to locations where policy-makers decide it should go.

In the U.S., commercial nuclear power plants, DOE, and the U.S. Navy produce, package, and store SNF or HLW at many sites. As of April 2019, SNF and HLW were stored at more than 80 locations in 35 states. For decades, small-scale shipments of SNF have occurred, most notably, periodic shipments of naval SNF by the U.S. Navy.[4] DOE has also transported small quantities of packaged HLW between facilities within the boundaries of DOE sites, but not off site. However, transporting large quantities of SNF and HLW has not been done and will require significant planning and coordination by DOE, the agency responsible for waste transportation under the NWPA. All shipments of SNF and HLW must meet safety requirements promulgated by the Department of Transportation and the Nuclear Regulatory Commission (NRC).

In the mid-2000s, the Committee on Transportation of Radioactive Waste, appointed by the National Academy of Sciences (NAS), National Research Council, evaluated the implications of launching a major radioactive waste transportation campaign. In 2006, the Committee issued its report, *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States*. The report identified no fundamental technical barriers to safely transporting SNF and HLW in the U.S. and highlighted "social and institutional challenges," such as selecting routes, agreeing to a waste acceptance queue for transport, and addressing social risks (e.g., stress and anxiety), that should be satisfactorily resolved before a large-scale transportation campaign can widely be viewed as socially acceptable.

While the Board agrees with the NAS finding that there are no "fundamental technical barriers to the safe transport of SNF and HLW in the U.S.," the Board observes that unresolved technical issues could significantly delay or impede the implementation of a national transportation program for radioactive waste. In this report, consistent with its statutory mandate, the Board focuses on the technical issues that need to be addressed by DOE in preparing a large-scale transportation effort. However, the Board recognizes the important social and institutional challenges, including securing adequate funding to transport the waste and supporting an organization responsible for implementing the effort.

[4] Naval SNF is considered a subset of DOE-managed SNF, but packaging, transporting, and storing naval SNF are responsibilities of the U.S. Navy. Furthermore, the U.S. Navy has a mature SNF transportation program that is fully operational; therefore, the U.S. Navy has already resolved the issues identified in this report.

Size and Scope of the U.S. Nuclear Waste Management Program

The large size, broad scope, and geographic distribution of the U.S. SNF and HLW program make resolving the technical and integration issues associated with a nationwide transportation effort a significant challenge. SNF and HLW inventories in the U.S. include a diverse collection of waste forms, waste storage containers, storage conditions, storage locations, waste transportation containers, and licensing requirements.[5] Current waste storage sites also include several unique challenges, such as varying degrees of accessibility for large transport vehicles or railcars. Addressing the unresolved technical and integration issues associated with these program elements prior to initiating transportation will require a well-planned and well-integrated effort.

It is important to note that, while all technical issues must be resolved before the nation's entire inventory of waste can eventually be transported, not all technical issues must be resolved before the first of the waste can be transported. In fact, some technical issues affecting existing waste may be resolved relatively quickly, allowing the waste to be moved early in the process. While this waste is being moved, more difficult technical issues can be addressed over time. Setting priorities and determining the most efficient sequencing of activities necessary to address the issues will be among the challenges DOE faces.

Possible Scenarios Regarding Commercial SNF

Before DOE can begin a national transportation effort, it must determine whether it will accept only bare commercial SNF assemblies (i.e., SNF assemblies not sealed inside SNF canisters) from nuclear utilities (Scenario 1 in this report) or whether it will accept SNF assemblies pre-packaged in casks or canisters (Scenario 2 in this report). See Figure ES-3 for an example of a commercial SNF dual-purpose (storage and transportation) canister. DOE's decision will directly affect the technical issues to be addressed before a transpor-

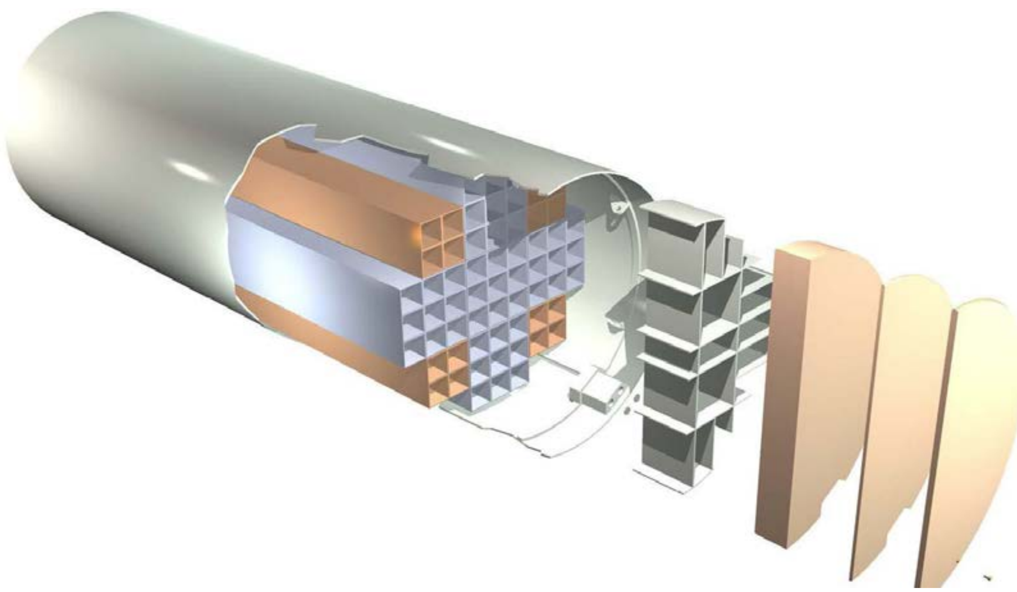


Figure ES-3. Example of a commercial SNF canister.
Graphical representation of a commercial SNF dual-purpose (storage and transportation) canister. For a 61-assembly canister, such as this, the overall diameter is approximately 1.7 m (67 in) and the overall length is approximately 5.0 m (196 in). (Source: Savannah River National Laboratory)

[5] The term "licensing" is used to mean completing the NRC regulatory approval process. For transporting radioactive materials, licensing means obtaining NRC approval of the transportation Certificate of Compliance for a particular radioactive material package, including its contents.

tation campaign begins. If DOE chooses to accept both bare SNF assemblies and SNF already packaged in casks and canisters, DOE will need to address the technical issues that apply to both scenarios. This report discusses these possible scenarios and their respective implications for SNF transportation.

This report also includes evaluations of the issues associated with packaging DOE-managed SNF and HLW into canisters and preparing the canisters for transportation. While the two scenarios discussed above related to commercial SNF do not apply directly to DOE-managed SNF and HLW, many of the technical issues that need to be addressed for commercial SNF are the same as those to be addressed for DOE-managed SNF and HLW.

DOE Activities to Support Transporting Nuclear Waste

Although DOE is not yet actively planning to begin SNF and HLW transportation, it is conducting several evaluation, research, and development activities that will support a future nationwide transportation campaign. DOE, through its national laboratories, is developing a suite of computer-based system analysis tools that allow it to evaluate different alternatives for implementing an integrated waste management system, including SNF and HLW transportation. DOE also has sponsored detailed site evaluations, including reviews of the steps necessary to remove commercial SNF from six nuclear power plant sites where all reactors have been shut down and where SNF remains on site in dry storage (these sites are commonly called "shutdown sites").

During the development of the license application for the Yucca Mountain project, DOE proposed that a multi-purpose, standardized canister would be used to store, transport, and dispose of DOE-managed SNF (excluding naval SNF). DOE continues research and development activities for this "DOE standardized canister" design. DOE also has made significant progress in developing a special railcar that can transport commercial SNF sealed inside a variety of SNF transportation cask designs. This railcar, called the "Atlas railcar," is designed to meet all federal requirements and rail industry guidance for transporting commercial SNF.

DOE has recognized that nuclear programs in other countries have significant experience in transporting SNF and HLW by truck, rail, and ocean-going vessels. In 2016, DOE sponsored a study of the worldwide SNF transportation experience; the results are documented in a report by Kevin Connolly and Ronald Pope, *A Historical Review of the Safe Transport of Spent Nuclear Fuel* (Oak Ridge National Laboratory, August 31, 2016). The experience in other countries may provide lessons learned and inform the development of a transportation program in the U.S.

Identifying the Technical Issues

The list of all Board-identified technical issues that need to be addressed in preparing a nationwide effort to transport SNF and HLW is provided in Table ES-1. Table ES-1 includes simple, brief descriptions of the issues. A detailed discussion of each issue is included in Appendix A. The Board has identified many of these technical issues in correspondence to DOE following past Board public meetings. For example, see the letter from the Board to DOE dated December 8, 2016, with recommendations following the Summer 2016 Board Meeting, including several recommendations to improve integration among offices within DOE.

Table ES-1. Board-Identified Technical Issues to Be Addressed in Preparing a Nationwide Effort to Transport SNF and HLW

Technical Issues Affecting All SNF and HLW and All Scenarios
1. Identify and mitigate (if needed) potential physical effects of transporting SNF, SNF casks and canisters, and HLW canisters to ensure they will meet transportation requirements and future storage requirements.
2. Identify requirements for verifying the condition of the waste forms (SNF and HLW) at the time of transport; develop and implement inspection procedures and equipment, if needed; and correct identified deficiencies.
3. Identify and implement waste handling and loading needs (e.g., facilities, equipment, procedures, training) at all waste storage sites.
4. Identify less-than-adequate transportation infrastructure (e.g., roads, rail lines, barge docks) at all waste storage sites; make needed upgrades.
5. Ensure the readiness of the technical aspects of emergency preparedness and response programs and organizations.
6. For waste forms and packaging not already approved for transportation, identify, develop, and validate computer models/programs (if not already done) to be used for structural, thermal, containment, shielding, and criticality evaluations in support of licensing for transportation; ensure the models/programs and input data meet the NRC requirements for quality assurance/quality control; and complete all necessary evaluations.
7. Complete the design, development, and implementation of integrated waste management system analysis and routing tools.
Scenario 1—Technical Issues Affecting Commercial SNF (if DOE accepts unpackaged, bare SNF assemblies)
8. Complete the design, licensing, fabrication, and testing of new SNF packages and transportation equipment on a timescale that supports the transportation schedule.
9. Identify and implement programs for designing, procuring, installing, and operating repackaging facilities and equipment at all sites, as necessary.
10. Identify and mitigate (if needed) potential adverse effects of repackaging operations on SNF assemblies to ensure the SNF will meet transportation requirements.
Scenario 2—Technical Issues Affecting Commercial SNF (if DOE accepts SNF assemblies already packaged in casks or canisters)
11. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to casks or canisters during dry storage that may affect the ability of the casks or canisters to meet transportation requirements.
12. Identify and remedy (if needed) types of dry-storage casks and canisters for SNF that are not approved for transportation as noted below: ▪ The cask or canister structural design or neutron absorber structural design does not meet transportation requirements. ▪ The cask or canister is not yet approved by the NRC (although similar casks or canisters are approved).
13. Identify and correct (if needed) individual dry-storage casks and canisters with contents or physical conditions that do not meet the requirements specified in the NRC-approved transportation Certificate of Compliance.
14. Identify inspection requirements, procedures, and equipment needed to verify the condition of all casks and canisters before transportation; perform inspections; and rectify identified problems, if needed.
15. Complete the design, licensing, fabrication, and testing of all needed transportation casks and associated components.
Technical Issues Affecting Commercial SNF (regardless of SNF packaging)
16. Identify and mitigate (if needed) degradation mechanisms in commercial SNF occurring over extended periods of dry storage that may affect the ability of SNF to meet transportation requirements.
17. Determine what burnup credit can be taken for all SNF types other than pressurized water reactor SNF (for which burnup credit is allowed by the NRC in its Interim Staff Guidance-8, Rev. 3).
18. Complete the design, licensing, fabrication, and testing of a commercial SNF railcar (e.g., the DOE Atlas railcar).

Table ES-1. Board-Identified Technical Issues to Be Addressed in Preparing a Nationwide Effort to Transport SNF and HLW (continued)

Technical Issues Affecting DOE-Managed SNF (naval SNF excluded)
19. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to dry-storage casks and canisters for DOE-managed SNF that may affect the ability of the casks or canisters to meet transportation requirements.
20. Complete existing designs, or develop new designs, for multi-purpose SNF canisters and complete the licensing, fabrication, and testing to accommodate all DOE-managed SNF that will not be processed at the Hanford Site, the Idaho National Laboratory, or the Savannah River Site.
21. Complete a new analysis to validate the structural integrity of the Hanford multi-canister overpack (MCO) design to support NRC approval of the MCO for transportation.
22. Define the transportation cask(s) to be used for DOE-managed SNF.
23. If not using an existing transportation cask, then design, license, fabricate, and test a new transportation cask for DOE-managed SNF.
Technical Issues Affecting DOE-Managed HLW
24. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to dry-storage canisters for DOE-managed HLW that may affect the canisters' ability to meet transportation requirements.
25. Finalize the decision on whether the sodium-bearing waste at the Idaho National Laboratory is remote-handled transuranic waste or HLW.
26. Complete the development and deployment of any required treatment process for calcined HLW at the Idaho National Laboratory.
27. Complete the design, licensing, fabrication, and testing of packaging for the Hanford cesium and strontium capsules.
28. Complete the design, licensing, fabrication, and testing of packaging for the ceramic and metallic HLW forms from the Idaho Fuel Conditioning Facility.
29. Define the transportation cask(s) to be used for DOE-managed HLW.
30. If not using an existing transportation cask, then design, license, fabricate, and test a new transportation cask for DOE-managed HLW.

Other relevant review efforts are documented in Board reports (e.g., see the Board reports *Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel*, December 2010; and *Management and Disposal of U.S. Department of Energy Spent Nuclear Fuel,* December 2017). Similar technical issues have been identified and documented in reports and presentations by DOE, the U.S. nuclear industry, and researchers and transporters overseas.

During its review, the Board considered DOE's priority ranking of technical information needs related to the extended storage and transportation of commercial SNF (e.g., see C.T. Stockman et al., *Used Nuclear Fuel Extended Storage and Transportation Research and Development Review and Plan*, Albuquerque, NM, Sandia National Laboratories, FCRD-UFD-2014-000050, August 9, 2014). The Board also considered other sources, such as an Electric Power Research Institute (EPRI) evaluation of technical issues related to the storage and transportation of commercial SNF (*Extended Storage Collaboration Program (ESCP): Progress Report and Review of Gap Analyses*, EPRI, Palo Alto, CA, 2011, 1022914). As DOE continues its evaluation of transporting nuclear waste, it may identify additional technical issues that need to be resolved.

Note that the first section of Table ES-1 applies to all wastes. The next three sections apply to the two scenarios for commercial SNF transportation, discussed above, and the last two sections include issues to be addressed before transporting DOE-managed

SNF and HLW. Table ES-1 represents a broad range of technical and integration issues to be addressed, but it does not necessarily reflect a comprehensive list of the actions that must be completed before a nationwide transportation effort can begin. DOE will have to complete its system-wide coordination and planning to ensure that all necessary preparation activities have been identified, prioritized, and properly sequenced.

How Long Will It Take DOE to Address the Technical Issues?

To effectively develop and implement an SNF and HLW management program, DOE will need to apply proven management methods, including program-wide coordination and effective advance planning. In a system as large and complex as the U.S. nuclear waste management system, many technical and non-technical issues, as discussed above, must be addressed in an integrated manner.

For a small portion of the existing packaged waste (e.g., certain commercial SNF in NRC-approved, dual-purpose [storage and transportation] canisters), few technical issues remain unresolved. For example, barring unforeseen problems, certain types of commercial SNF likely could be shipped within a year or two of resolving institutional issues, such as determining a destination and obtaining funding. For other wastes (e.g., unpackaged DOE-managed SNF), work on resolving the associated technical issues must begin long before the waste can be moved—in some cases, more than 10 years in advance.

To the extent that relevant information was available, the Board examined the length of time it may take to address the specific technical issues. During its Summer 2018 Board Meeting, the Board asked representatives of DOE, SNF cask vendors, and domestic and foreign nuclear utilities to estimate the length of time it could take to address the most difficult technical issues, based on their own experience or analysis. For a few specific issues, such as the development of a new SNF transportation cask (see Figure ES-4), nuclear industry representatives were able to provide, with relative confidence, an estimate of how long the development might take.

However, time estimates for addressing other technical issues were often not available due to a lack of information or because the associated uncertainties were too large. Ongoing research and development may provide more reliable information on these questions in the future.

For the technical issue of developing new SNF transportation cask systems, nuclear industry experience in cask development provides useful insights on the time needed to address this multi-faceted technical issue. Based on experience in other countries, such as Switzerland, and the experiences of the U.S. Navy and U.S. nuclear cask vendors, the Board finds that a period of at least 10 years should be allotted to develop and license a new transportation cask. This duration is variable and could be shorter if the package design is not complex and the range of contents envisioned to be shipped in the package is limited. The period may be longer if special design features are included that will prompt a more detailed review by the NRC, or time is added to accommodate suspended or reduced federal funding for the project.

The issue of new cask development is one of 30 technical issues identified by the Board that need to be addressed in developing a large transportation program. Although some of the issues may be addressed more quickly and more easily than the development of a new transportation cask, others could take considerably longer. For example, if DOE

Figure ES-4. SNF rail transportation casks.
DOE used these casks for the rail transport of commercial SNF from the West Valley Demonstration Project in New York to the Idaho National Laboratory. Currently approved rail casks average approximately 7.1 m (23.3 ft) in length, 3.3 m (10.8 ft) in diameter, and 125 metric tons (275,000 lb) in weight when loaded. (Source: DOE)

decides to construct a repackaging facility for commercial SNF or for DOE-managed SNF, that effort could take much longer than 10 years. Furthermore, coordinating the resolution of all 30 technical issues in parallel will require significant planning, integration, and interaction with other federal agencies, the nuclear industry, state and local agencies, and others.

Findings and Recommendations

1. Technical Issues Should Be Addressed in an Integrated and Comprehensive Manner. The complexity and scale of the nation's SNF and HLW management program make resolving technical and integration issues a challenge. SNF and HLW inventories in the U.S. include a diverse collection of waste forms, waste storage containers, storage locations and conditions, waste transportation containers, and licensing requirements. Different waste storage sites also have varying degrees of accessibility for large transport vehicles or railcars. Addressing the unresolved technical and integration issues associated with these program elements prior to initiating waste transportation will require a well-planned and well-integrated effort, applied over an extended time.

Table 2-1 of this report (same as Table ES-1) lists 30 technical issues that need to be addressed. Not all the issues must be resolved before the first of the waste can be transported, but all technical issues must be resolved before the nation's entire inventory of waste can eventually be transported. As DOE continues to assess and evaluate the readiness of SNF and HLW to be transported, it may find additional technical issues to address. Careful prioritization of the issues will be needed, including the development of prioritization criteria and agreement from affected government agencies, like the NRC, and affected local, state, and tribal organizations.

***Finding 1**. The Board finds that many interrelated technical and integration issues must be addressed in preparing for a nationwide effort to transport SNF and HLW to their eventual destination. The technical issues must be prioritized and their resolution properly sequenced to ensure that the overall program will be operationally feasible and unhindered by delays.*

***Recommendation 1.** As DOE continues its analyses and research for a nationwide waste management and transportation system, the Board recommends that DOE ensure the issues in Table 2-1 of this report are addressed. The Board also recommends that the issues in Table 2-1 and any other issues identified by DOE be prioritized and carefully sequenced to support the integrated operation of a nationwide transportation program.*

2. Evaluations of Storage Sites for Nuclear Waste Should Continue. The Board commends DOE for its proactive efforts to inspect and evaluate the readiness to remove commercial SNF from nuclear power plant sites where all reactors have been shut down but where commercial SNF remains in dry storage (shutdown sites). To support the full integration of a transportation program for SNF and HLW, similar evaluations will need to be conducted at DOE sites that store DOE-managed SNF and HLW.

***Finding 2.** The Board finds that DOE's effort to evaluate the readiness to move commercial SNF from shutdown nuclear power plant sites has gathered important information that will be needed to support the removal of commercial SNF from these sites for transportation. However, not all shutdown sites have been fully evaluated. Furthermore, DOE has not conducted similar reviews at DOE facilities that store DOE-managed SNF and HLW.*

***Recommendation 2.** The Board recommends that DOE give higher priority to evaluating the removal of commercial SNF from shutdown nuclear power plant sites and to evaluating DOE sites that store DOE-managed SNF and HLW. DOE should also share the results of the evaluations with operators of waste storage sites, so they can apply lessons learned, retain critical site transportation infrastructure, and be better prepared for the eventual transportation of the wastes.*

3. Advance Planning for the Development of Casks and Canisters for SNF and HLW Is Needed. To implement an integrated, nationwide waste management program, DOE will need to complete the development and licensing of existing canister designs (e.g., the DOE standardized canister) and develop new canister designs for some DOE-managed HLW. DOE will also have to develop and obtain NRC approval of transportation casks for all DOE-managed SNF and HLW. Additional types of new casks may be required to transport some commercial SNF that cannot be transported in existing transportation casks. Furthermore, past DOE efforts, such as the development of the Transportation, Aging, and Disposal canister in conjunction with the Yucca Mountain license application, have noted the advantages of developing a waste management program based on standardized, multi-purpose canisters for commercial SNF. These standardized canisters may also be new designs.

***Finding 3.** The Board finds that DOE will have to complete existing canister designs or develop new cask and canister designs for storing and transporting SNF and HLW. The Board also finds that developing new cask or canister designs for SNF or HLW could take longer than a decade. Therefore, DOE will need to allow for considerable advance planning and early coordination with NRC during the development of new cask and canister designs.*

Recommendation 3. *The Board recommends that, for planning purposes, DOE should allow for a minimum of a decade to develop new cask and canister designs for SNF and HLW storage and transportation, or DOE should conduct its own detailed evaluation of the time needed to complete the design, licensing, fabrication, and testing of new casks and canisters.*

1. Introduction

1.1 Purpose

The purpose of the report is to document the Board's review of the Department of Energy's (DOE's) preparedness to transport spent nuclear fuel (SNF) and high-level radioactive waste (HLW) to a waste repository (also known as a "deep-mined geologic repository") or an interim storage site for nuclear waste.[6] The exact destination is not considered in this report, nor are potential transportation routes. The Board review includes a focused discussion and evaluation of technical issues that need to be addressed in developing a nationwide effort to transport SNF and HLW. This report does not evaluate institutional or social issues. Although significant non-technical issues need to be addressed before starting a nationwide transportation effort, as explained below, this report will focus on technical and scientific issues only. The main audiences for this report are decision-makers in Congress and the Administration, including DOE. Other key audiences include DOE contractors, national laboratory personnel, the commercial nuclear power industry, and the public.

The magnitude of the transportation challenge in the U.S. is demonstrated, in part, by the widely distributed inventory of nuclear waste. In this country, commercial nuclear power plants, DOE, and the U.S. Navy generate, store, and package SNF at dozens of locations. DOE also manages HLW at four sites. According to DOE and the Nuclear Regulatory Commission (NRC), as of April 2019, SNF and HLW are stored at more than 80 locations in 35 states (SNL 2014; NRC 2019a). Although small-scale shipments of SNF and HLW have occurred for decades in the U.S., transporting large quantities of these materials, in a nationwide effort, has not been done and will require significant planning and coordination by DOE. The technical aspects of this planning and coordination are the main topics of this report.

1.2 Technical Scope and Review Approach

1.2.1 Scope

The Nuclear Waste Policy Amendments Act of 1987 directs the U.S. Nuclear Waste Technical Review Board (Board) to "evaluate the technical and scientific validity of activities undertaken by the Secretary [of Energy] … including activities relating to the packaging or transportation of high-level radioactive waste or spent nuclear fuel" (U.S. Congress 1987). The Board has addressed transportation issues several times in its history. For example, in 2010, the Board published the report *Evaluation of the Technical*

[6] Throughout this report, the terms "waste" or "nuclear waste" are used to mean commercial SNF and DOE-managed SNF and HLW. The Board also recognizes that reactor-related, greater-than-class-C (GTCC), low-level waste must be removed from waste storage sites and disposed of. For the purposes of this report, welded canisters holding GTCC waste are included with casks and canisters holding commercial SNF.

Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel (NWTRB 2010). In November 2013, the Board held a technical workshop in Washington, DC, focused on "Impacts of Dry-Storage Canister Designs on Future Handling, Storage, Transportation, and Geologic Disposal of Spent Nuclear Fuel." More recently, the Board completed a review of DOE-managed SNF, including naval SNF[7] (NWTRB 2017f). The Board continues to evaluate the impacts of the nuclear industry's use of large commercial SNF canisters that are designed for both storage and transportation.

This report documents a recent Board review of the technical issues that need to be addressed in preparing a nationwide program to transport SNF and HLW. In this report, the Board has focused on identifying and evaluating the full range of technical and integration issues that DOE will need to address as it evaluates options for a transportation program. Future Board review efforts may focus on more narrowly defined topics. These may include DOE activities to address specific technical issues that are difficult to resolve or DOE's development of system analysis tools that may be used to help design and evaluate alternative waste management systems, including transportation systems.

In this report, "technical issues," generally, are questions or problems that require scientific analysis, laboratory or field testing, engineering or manufacturing design work, computer model development, specialized technological knowledge or skills, or completion of engineering calculations for resolution. Although it is necessary to address some of the technical issues before beginning a nationwide transportation effort, social and institutional issues will also affect very significantly the successful implementation of a transportation program. Such non-technical issues are outside the Board's legislative mandate and, consequently, will not be evaluated in this report.

Examples of social and institutional issues that need to be addressed before beginning a major transportation effort include, among others, the following:

- Restrictions in the contract between DOE and the commercial nuclear utilities that may prevent the transport of certain commercial SNF in its current configuration (SNF packaged in large, sealed containers)
- A decision from the Administration and Congress to proceed with the disposition of SNF and HLW
- Local and state legal agreements that contain restrictions prohibiting the transport of radioactive wastes through the affected jurisdictions
- The need to update and finalize contracts and agreements with all necessary railroad, trucking, and barging companies
- Outreach, educational, and engagement efforts for affected local, state, and tribal groups
- Establishment of transportation routes after a destination (i.e., interim storage facility or waste repository) has been selected

One perspective on the differences between technical issues and the social or institutional challenges facing a transportation program is provided in a 2006 report by the National Academy of Sciences (NAS). The NAS, National Research Council, formed the Committee on Transportation of Radioactive Waste to conduct a three-year inquiry on the implications related to launching a major SNF and HLW transportation campaign. The Committee pub-

[7] Naval SNF is considered a subset of DOE-managed SNF, but packaging, transporting, and storing naval SNF are responsibilities of the U.S. Navy.

lished its findings in the report *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States* (NAS 2006). The report's first conclusion provides the Committee's perspective on what requirements will need to be met:

> The committee could identify no fundamental technical barriers to the safe transport of spent fuel and high-level radioactive waste in the United States. However, there are a number of social and institutional challenges to the successful initial implementation of large-quantity shipping programs that will require expeditious resolution. The challenges of sustained implementation should not be underestimated. (NAS 2006)

While the Board agrees with the NAS finding that there are no "fundamental technical barriers to the safe transport of SNF and HLW in the U.S.," the Board observes that unresolved technical issues could significantly delay or impede the implementation of a national transportation program for nuclear waste. This Board report focuses solely on technical and scientific questions that need to be addressed in developing a large-scale effort to transport SNF and HLW. However, as the NAS Committee report highlights, both the "technical barriers" and the "social and institutional challenges" should be resolved before a large-scale transportation campaign can widely be viewed as technically defensible and socially acceptable. The Government Accountability Office (GAO) has also evaluated the issues associated with transporting commercial SNF, and, like the NAS Committee, the GAO noted both technical and societal issues to be addressed (GAO 2014, 2015).

As noted above, both the size and scope of the nation's nuclear waste inventory are large. The variety of waste forms and waste packages are accompanied by a variety of waste-specific and package-specific issues to be addressed. It is important to note that, while all technical issues must be resolved before the nation's entire inventory of waste can eventually be transported, not all of the issues must be resolved before the first of the waste can be transported. This is because some technical issues affecting existing waste may be resolved relatively quickly, allowing the waste to be moved early in the process. Other technical issues, affecting other wastes, may be more difficult to resolve or may take longer to resolve. These more difficult technical issues can be addressed over time, while wastes unaffected by these difficult issues are being transported. Legal agreements with states, nuclear utilities, and others will need to be considered when determining the proper sequencing of activities. Prioritizing the issues and determining the most efficient sequencing of the activities necessary to address the issues will be among the challenges DOE faces as it works to develop an integrated waste management program and prepare for nuclear waste transportation.

1.2.2 Review Approach

The Board's review of transportation issues relied on past Board public meetings; Board reports and correspondence; and ongoing interactions with DOE, the U.S. Navy, the NRC, and representatives of the commercial nuclear industry. The Board also referred to reports and journal articles related to transporting SNF and HLW published by DOE, the NRC, the GAO, national laboratories, and nuclear industry groups, including organizations that operate overseas. More details of the relevant public meetings and interactions with DOE are provided in Section 2.2.

During the review, the Board considered DOE's priority ranking of technical information needs related to the extended storage and transportation of commercial SNF, which

DOE has updated several times (see Hanson et al. 2012; Stockman et al. 2014; Alsaed and Hanson 2017). A similar ranking effort by the Electric Power Research Institute (EPRI), completed as part of the Extended Storage Collaboration Program (EPRI 2011), was also reviewed. Although these two efforts identified key technical areas requiring more research to support transporting SNF and HLW, neither was meant to be a complete listing of all technical issues to be addressed before transportation could begin.

1.3 Background

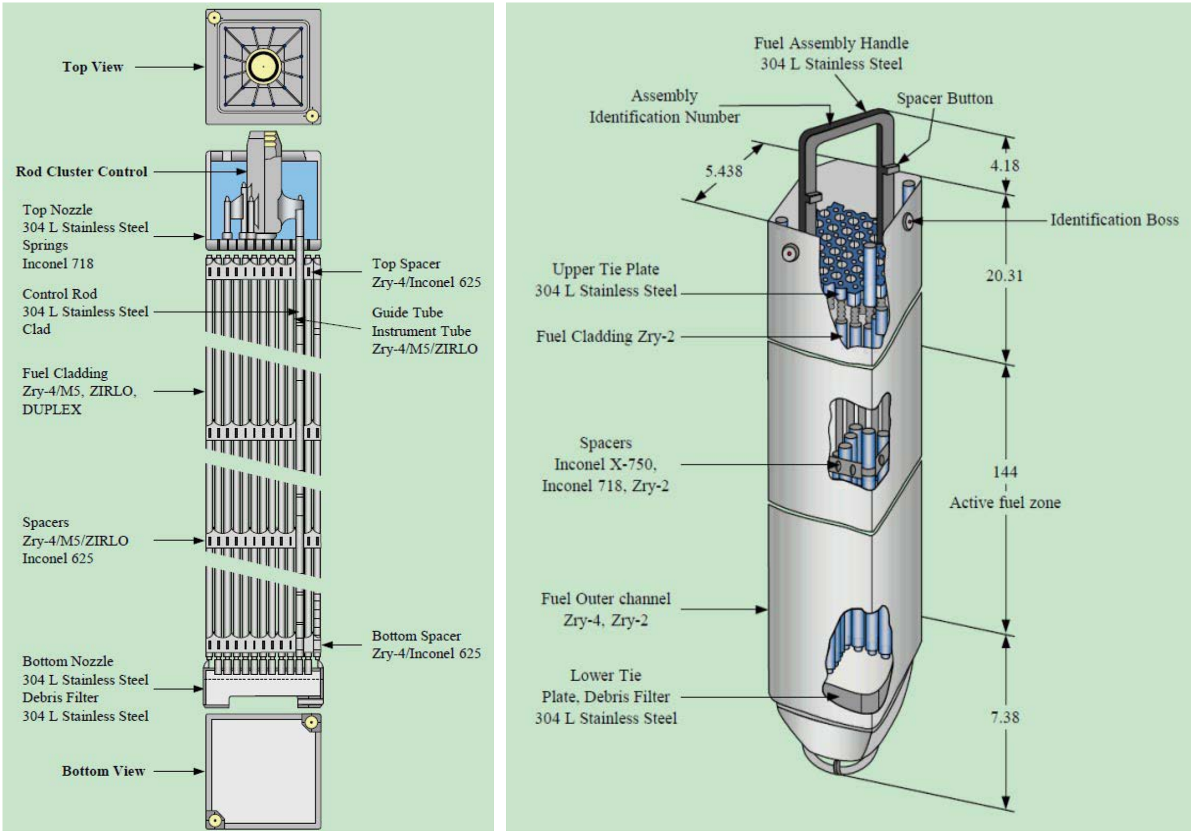
Nuclear Reactors. In the U.S., nuclear reactor development and operations began in the 1940s with the Manhattan Project, which focused on producing plutonium and other nuclear materials for nuclear weapons. By the 1950s, the Atomic Energy Commission (since split into DOE and the NRC) transferred nuclear reactor technology to commercial electricity production. In December 1957, the Shippingport reactor in Pennsylvania became the first nuclear reactor to produce electricity commercially in the U.S. As of April 2019, 98 commercial reactors produce approximately 20 percent of the electricity used in the country (NEI 2019). The U.S. uses two types of nuclear reactors to generate electricity: pressurized water reactors (PWRs) and boiling water reactors (BWRs). Of the 98 operating nuclear power reactors in the U.S., 65 are PWRs and 33 are BWRs (NRC 2019b).

During the period of commercial nuclear reactor development, the government (e.g., DOE and the U.S. Navy) and research institutions also built and operated more than 400 test, research, and nuclear propulsion reactors (IAEA 2019; NRC 2019b; WNA 2019b). The number and variety of these reactors are relevant because of the wide variety of SNF produced during their operation. Much of the SNF from these reactors was not reprocessed, as explained below, and will have to be included in DOE's plans for SNF packaging, transportation, and disposal.

Spent Nuclear Fuel. As defined by the Nuclear Waste Policy Act (as amended), "The term 'spent nuclear fuel' means fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing." When nuclear fuel in a reactor can no longer efficiently sustain a nuclear fission reaction or is no longer needed (e.g., in the case of research), the nuclear fuel is considered "spent" and is removed from the reactor. Immediately after removal from the reactor, the SNF is intensely radioactive and hot from the decay of radioactive fission products. The heat produced by SNF is called "decay heat." The SNF is stored underwater, in a nearby spent fuel pool. The water in the pool, which typically covers the SNF by 16 to 20 feet, provides shielding against the radiation that could harm facility workers and equipment. The water also provides cooling to remove the heat generated by the SNF.

When first removed from a nuclear reactor, SNF generally has the same physical form as fresh fuel and, unless damaged during handling or by corrosion, it maintains the same overall physical form. Today, more than 90 percent by volume of the combined solid waste forms (SNF and packaged HLW)[8] in the U.S. is commercial SNF (NWTRB 2017d). Therefore, commercial SNF provides a good example of the SNF that DOE will have to manage in the future. Figure 1-1 includes schematic drawings of an example PWR fuel assembly and an example BWR fuel assembly. In each case, a fuel assembly comprises a number of fuel rods containing uranium dioxide pellets sealed in cladding tubes that are held in a square lattice by the fuel assembly structure.

[8] This volume does not include untreated, liquid HLW stored in underground tanks at the Hanford Site and the Savannah River Site.



(a) (b)

Figure 1-1. Examples of nuclear reactor fuel assemblies.
(a) Example pressurized water reactor fuel assembly and (b) Example boiling water reactor fuel assembly. Dimensions in inches. (Strasser et al. 2014; courtesy of ANT International)

Notes: Zry-2 = zircaloy 2
Zry-4 = zircaloy 4
M5, ZIRLO, and DUPLEX are newer alloys used in nuclear fuel cladding

Commercial reactor SNF is produced as two major fuel types—BWR fuel and PWR fuel—which are similar in design. PWR fuel assemblies are approximately 4.1 m (13.5 ft) long, 20 cm by 20 cm (8 in by 8 in) square, and weigh approximately 650 kg (1,400 lb). BWR fuel assemblies are approximately 4.3 m (14 ft) long, 15 cm by 15 cm (6 in by 6 in) square, and weigh approximately 320 kg (700 lb). These similarities in commercial fuel design have allowed the storage and transportation containers for commercial SNF to remain similar (e.g., canister and cask layout and operation), with differences only in capacity and design details. These differences need to be considered in the technical and logistics evaluations for transporting commercial SNF, but generally, the differences concern only canister and cask size and weight. Some differences also exist in the radiation doses and temperatures associated with commercial SNF casks and canisters, but the doses and temperatures are tightly controlled by NRC regulation to be safe for facility workers and the public. For DOE SNF and HLW, many more different fuel designs, reactor designs, waste forms, and material conditions of the waste must be considered compared with commercial SNF (NWTRB 2017d).

For all types and sources of SNF (e.g., government, commercial, research), several different SNF management approaches are taken after the initial cooling period: (1) continue to store the SNF in the spent fuel pool until a disposition path is chosen or until pool storage capacity becomes limited; (2) package the SNF and transport it to a larger, consolidated spent fuel pool; (3) package the SNF and transport it to a reprocessing facility where the SNF is dissolved and uranium, plutonium, and other useful elements are recovered for future use; and (4) package the SNF, dry it, and move it to a dry-storage facility. This report will not address reprocessing activities or storage activities except as they may affect the technical aspects of transportation.

SNF Packaging. A variety of package (or container) designs are used and planned by nuclear equipment vendors, commercial nuclear utilities, and DOE to hold SNF during on-site transfer, dry storage, off-site transportation, and planned permanent disposal. Due to the large number of SNF container purposes and designs, and a corresponding large number of container names, a discussion about terminology is instructive.

Typically, the term "package" (or "container") is generic and might be used to mean any of a number of more specific SNF casks or canisters. However, the term is used in some specific applications. For example, when authorizing a container for transporting radioactive waste, the NRC approves a "Certificate of Compliance for Radioactive Material *Packages*" (emphasis added). In another example, DOE's license application for the Yucca Mountain waste repository included designs for SNF emplacement containers called "waste packages."

Within both DOE and the commercial nuclear industry, one may find a variety of terms for SNF containers, including "cans," "canisters," "casks," "baskets," "bundles," "modules," or "overpacks." The commercial nuclear industry has created the largest array of container names and designations—stemming largely from the independence of a free-market economy. Figure 1-2 provides a summary of the terminology used for commercial SNF containers.

For DOE-managed SNF, DOE has been sponsoring research and design work on a standardized, multi-purpose (storage, transportation, and disposal) SNF canister called the "DOE standardized canister." This canister is intended to accommodate many types of non-naval, DOE-managed SNF for storage, transportation, and disposal. For transportation, several of these DOE standardized canisters (as many as nine) could fit inside a transportation cask, depending on the design of the transportation cask. DOE has yet to finish research and development activities for the DOE standardized canister that will be needed to inform the design of any packaging facility that DOE develops (NWTRB 2017f).

A transportation cask, or overpack, for SNF is a robust, iron or steel container that includes shielding to reduce the radiation levels outside the cask and is sealed to prevent the release of radioactive materials. Transportation casks can be designed to hold welded canisters of SNF or bare SNF assemblies in a fuel basket inside the cask. The lid of the transportation cask is closed using bolted fasteners. Before transport, impact limiters are attached to both ends of the cask to absorb impact loads in accident conditions. For transportation purposes, the full combination of waste form, canister (if included), transportation cask, and impact limiters is called a "radioactive material package." The NRC must approve the Certificate of Compliance and associated Safety Analysis Report for each type of radioactive material package. This process is sometimes called "licensing."[9]

Figure 1-3 is a photo of two transportation casks used to ship commercial SNF from the West Valley Demonstration Project in New York to the Idaho National Laboratory in 2003.

[9] Throughout this report, the term "licensing" may be used to mean completing the NRC regulatory approval process. For transporting radioactive materials, licensing means obtaining NRC approval of the transportation Certificate of Compliance for a particular radioactive material package.

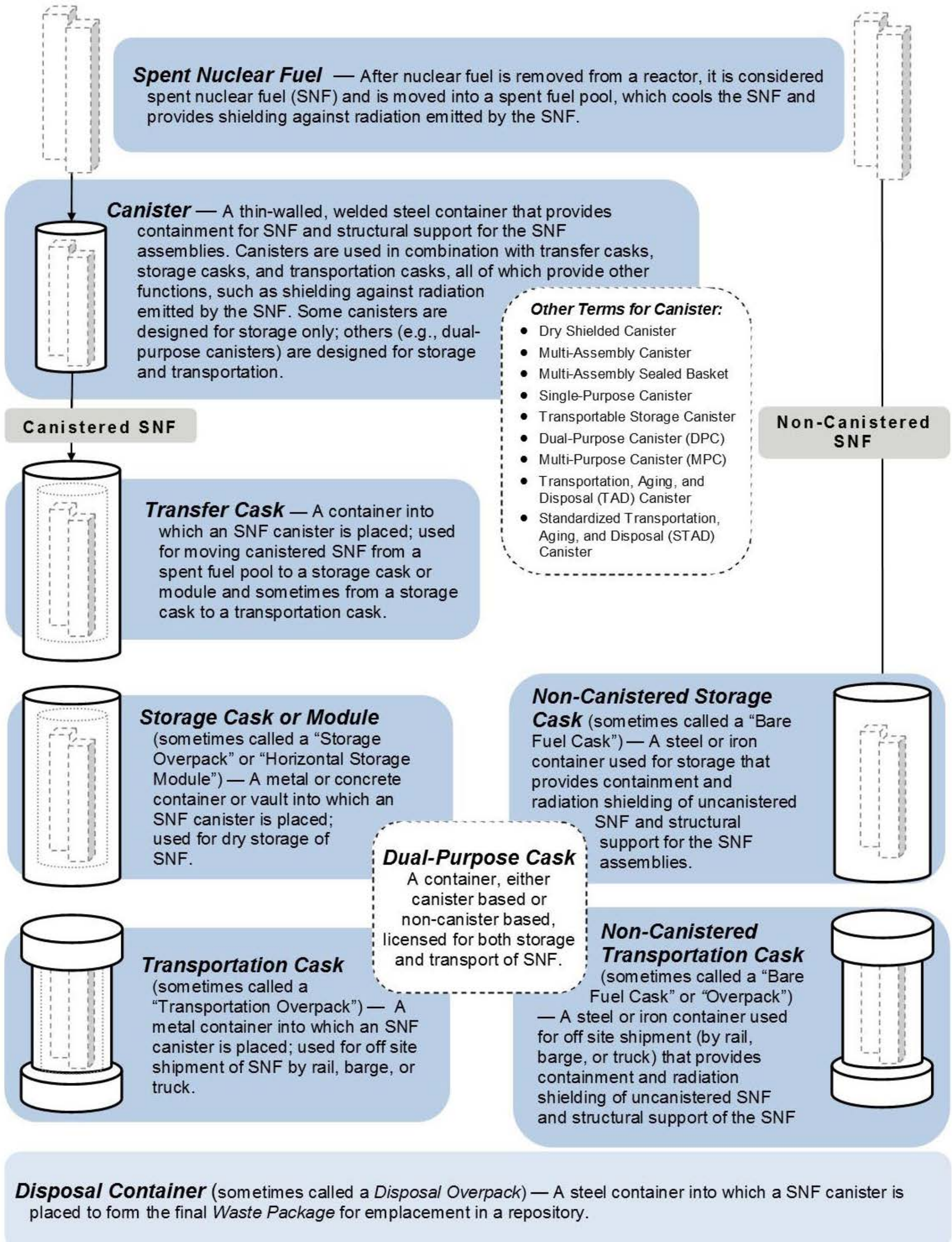


Figure 1-2. Terminology used in the nuclear industry for containers holding commercial SNF.

These two 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) were designed as dual-purpose casks (storage and transportation) by Transnuclear, Inc. (now Orano TN). The casks, still loaded with SNF, are in storage at the Idaho National Laboratory.

Figure 1-3. SNF rail transportation casks.
DOE used these casks for the rail transport of commercial SNF from the West Valley Demonstration Project in New York to the Idaho National Laboratory. Currently approved rail casks average approximately 7.1 m (23.3 ft) in length, 3.3 m (10.8 ft) in diameter, and 125 metric tons (275,000 lb) in weight when loaded. (Photo source: DOE 2019)

High-Level Radioactive Waste. HLW is defined by the Nuclear Waste Policy Act (as amended) as the following:

> The term "high-level radioactive waste" means—
>
> (A) the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and
>
> (B) other highly radioactive material that the [Nuclear Regulatory] Commission, consistent with existing law, determines by rule requires permanent isolation.

In the U.S., large production-scale SNF reprocessing facilities were built and operated at the Hanford Site in Washington State, the Savannah River Site in South Carolina, the Idaho National Laboratory in Idaho, and the West Valley Demonstration Project in New York State. The most prevalent method of SNF reprocessing has been to dissolve the SNF (including the SNF cladding, in the case of aluminum-clad fuel) in nitric acid, and then to separate the various product elements (e.g., uranium, plutonium) from the waste elements (e.g., aluminum, fission product elements) using chemical treatment processes. After the desired product elements are recovered, the remaining highly radioactive liquid waste—by definition, HLW—is transferred to underground, steel tanks for storage, awaiting further treatment and stabilization.

The Hanford Site manages approximately 210,000 m^3 (7,400,000 ft^3) of liquid, salt cake, and solid HLW in underground storage tanks. None of the Hanford HLW has been treated for ultimate disposal (see the following section on HLW treatment processes). However, some cesium and strontium was removed from the Hanford HLW tanks and packaged into capsules to be used as radiation sources. These cesium and strontium capsules are still considered HLW, and DOE stores 1,936 of these capsules at the Hanford Site. The Savannah River Site manages approximately 136,000 m^3 (4,800,000 ft^3) of liquid HLW in underground storage tanks. The Savannah River Site also stores approximately 3,560 m^3 (126,000 ft^3) of treated HLW in approximately 4,150 welded stainless steel canisters, placed in below-grade vaults. The Idaho National Laboratory manages approximately 3,400 m^3 (120,000 ft^3) of liquid waste (called "sodium-bearing waste") in underground storage tanks[10] and stores approximately 4,400 m^3 (160,000 ft^3) of treated HLW in above-grade, or slightly below-grade, steel bins. The West Valley Demonstration Project stores 275 welded canisters filled with treated HLW on an outdoor, concrete storage pad. The treated HLW at West Valley comprises 245 m^3 (8,650 ft^3).

HLW Treatment. Various treatment and packaging approaches have been used to stabilize HLW into a solid form suitable for disposal. The most common treatment method has been to blend the liquid HLW with glass-forming materials and melt the blend in a high-temperature melter (a process called "vitrification," which produces vitrified HLW). The vitrification process immobilizes the highly radioactive components of HLW (i.e., actinide isotopes and fission products) in the glass matrix, which serves to inhibit the release of those radioactive materials (see Figure 1-4).

The molten HLW-glass mixture is poured into a stainless steel canister and allowed to cool and solidify. The canister is then welded shut and moved to a dry-storage facility, awaiting final disposal. For more details about vitrified HLW, see the Board's Fact Sheet, *Vitrified High-Level Radioactive Waste* (NWTRB 2017e).

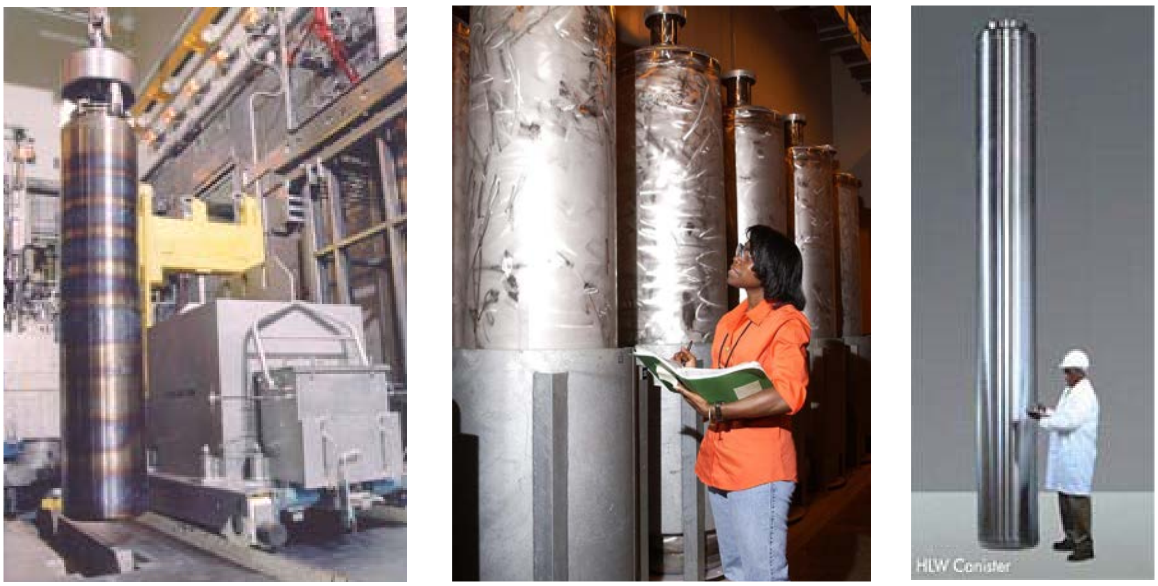
DOE has also used HLW treatment methods other than vitrification. For example, most of the liquid HLW at the Idaho National Engineering Laboratory (now the Idaho National Laboratory [INL]) was treated in a process called "calcination." In calcination, the liquid HLW is fed into a high-temperature furnace and dried to a granular powder form, similar to powdered laundry detergent. The calcined HLW at INL was then stored in large steel bins in bunkers designed to shield against the waste's radioactivity. For more details about calcined HLW, see the Board's Fact

Figure 1-4. Treated simulated HLW.
Sample of simulated HLW that has been mixed with a glass-forming silica mixture at high temperature and then cooled into a glass form—a process called "vitrification." (Source: NWTRB)

[10] At the Idaho National Laboratory, the liquid waste is called "sodium-bearing waste" because of its high sodium content. DOE may categorize, or designate, this waste as transuranic waste to be disposed of at the Waste Isolation Pilot Plant in New Mexico. However, if DOE is unable to make that designation, then the waste will be considered HLW.

Sheet, *Calcined High-Level Radioactive Waste* (NWTRB 2017b) on the Board's website at www.nwtrb.gov.

HLW Packaging. DOE has used a variety of HLW packaging, varying by site and by HLW treatment process. However, common features of HLW canisters include fabrication from stainless steel for durability and corrosion resistance, and welded lids to confine the radioactive materials. The HLW canisters used during HLW vitrification at the West Valley Demonstration Project and the Savannah River Site have nominal outside dimensions of 0.61 m (2 ft) in diameter by 3 m (10 ft) in length (DOE 2012). At the Hanford Waste Immobilization and Treatment Plant, DOE plans to use an HLW canister that is 0.61 m (2 ft) in diameter and 4.5 m (15 ft) in length. Figure 1-5 shows the canisters for vitrified HLW that are in use or planned for use in the U.S.



(a) (b) (c)

Figure 1-5. HLW canisters.
(a) West Valley Demonstration Project HLW canister (DOE: Zadins 2011); (b) Defense Waste Processing Facility HLW canister (DOE-Savannah River 2009); (c) Waste Immobilization and Treatment Plant HLW canister (Source: Jantzen 2013).

For HLW forms other than vitrified HLW, such as calcined HLW and cesium and strontium capsules, DOE plans to use various other canister designs. The canisters for these HLW forms vary significantly in size and shape. For example, the existing cesium and strontium capsules at the Hanford Site are approximately 7 cm (3 in) in outside diameter and 53 cm (21 in) long. HLW canisters are discussed in more detail under Technical Issue #29 in Appendix A of this report.

1.4 Options Being Considered for the Disposition of SNF and HLW

Legal Requirements for the Disposition of SNF and HLW. In the U.S., SNF and HLW are required by the Nuclear Waste Policy Act (NWPA; as amended) to be disposed of in a deep-mined geologic repository. The scope of materials covered by the NWPA includes commercial SNF, DOE-managed SNF, and naval SNF. It also includes HLW of both commercial and defense origin. The NWPA (as amended) defines "disposal" of SNF and HLW as "emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery" (NWPA, Title I, Section 2, [9]). Furthermore, "repository" means "any system licensed by the [NRC] that is intended to be used for, or may be used for, the permanent deep geologic disposal of high-level radioactive waste and spent nuclear fuel" (NWPA, Title I, Section 2, [18]).

Disposal of SNF and HLW. In 1987, the NWPA was amended to specify, among other things, that the Yucca Mountain Site in Nevada would be selected, if technically suitable, as the first deep-mined geologic repository for SNF and HLW in the U.S. DOE submitted to the NRC a license application for the Yucca Mountain Site in 2008. However in 2010, DOE did not request funding for licensing the repository or for the Office of Civilian Radioactive Waste Management, which was the DOE office responsible for implementing the NWPA (as amended). Since then, there has been no further funding.

Interim Storage of Commercial SNF. A majority of commercial SNF is being stored at the site of the reactor where it was used. The balance is in storage at the Morris, Illinois, Independent Spent Fuel Storage Installation (about 3,200 assemblies) and at several national laboratories, primarily the Idaho National Laboratory. Several options for consolidated interim storage of SNF have been considered over the years. The NWPA provides for one or more federal Monitored Retrievable Storage facilities, but the provisions for developing such a facility were significantly restricted in the 1987 amendments to the Act. For example, "construction of such facility may not begin until the [NRC] has issued a license for the construction of a repository."[11] The NWPA does not preclude development of a private storage facility and, in 2006, a consortium of nuclear utilities obtained a license from the NRC to construct a private storage facility in Utah, but construction of the facility was blocked by the Bureau of Indian Affairs and essential permits were denied by the State of Utah.

In 2013, DOE published its *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste* (DOE 2013a)[12] and again suggested the possibility of establishing interim storage for commercial SNF. DOE proposed a pilot-scale consolidated interim storage facility to be operational by 2021, followed by a full-scale consolidated interim storage facility to be operational by 2025. The pilot-scale facility was to be sized to accommodate SNF from commercial nuclear power plant sites where the reactors have been shut down but where commercial SNF remains in dry storage (these sites are known in the nuclear industry as "shutdown sites"). Although DOE's strategy envisioned the development of interim storage facilities, an amendment to the NWPA (or other new legislation) is required to allow DOE to enter into a commercial agreement with a private entity for interim storage of commercial SNF.

Based, in part, on the 2013 strategy published by DOE, two private entities, with proposed sites in Texas and New Mexico, began to develop consolidated interim storage facilities to store commercial SNF. Both entities submitted license applications to the NRC to build and operate SNF storage facilities; as of April 2019, the NRC is reviewing the applications. Several issues must be addressed before the proposed consolidated interim storage facilities can move beyond the design and licensing phase. These issues include a lack of clarity on the funding source for construction of the projects, responsibility for transporting the SNF, future ownership of the SNF, and whether Congress will approve DOE's involvement with the projects.

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[11] Nuclear Waste Policy Amendments Act of 1987. P.L. 100-203, Title V, Subtitle A (December 22, 1987).

[12] The 2013 *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste* was developed and published by a previous Administration. The Board notes that current DOE activities are not consistent with the implementation of this strategy.

Alternatives Being Considered. Since 2010, when funding for licensing a Yucca Mountain repository for disposing of SNF and HLW was stopped, policy-makers in Congress and the Administration have considered funding and legislative options for managing and disposing of SNF and HLW. Those options include resuming the licensing of the Yucca Mountain repository and/or developing a federal consolidated interim storage facility or smaller pilot facility for temporary storage of SNF. As of May 2019, no funding requests or legislative proposals for nuclear waste storage or disposal have passed both the U.S. House of Representatives and the U.S. Senate. In the meantime, the House of Representatives in its fiscal year 2019 report on *Energy and Water Development* appropriations included the following language: "The Committee is aware of the Department's ongoing research and development efforts regarding the safe transportation of spent nuclear fuel and encourages the Department to continue this important work to ensure that this fuel can be safely moved at the earliest opportunity" (U.S. Congress 2018).

1.5 Common Questions About Transporting SNF and HLW

The questions and answers provided below represent questions that might be expected from those who are not familiar with the details of SNF, HLW, or nuclear waste management and transportation. The Board is providing these questions and answers in a simplified form, using plain language, to communicate the issues in a transparent, easy-to-understand manner. Nearly all of the answers provided below have more detailed and complex answers that are discussed in the body of this report and in Appendix A. For simplicity, this question and answer section contains minimal reference callouts. Also note that when the phrase "interim storage facility" is used, it is meant in a generic sense—it does not imply a specific monitored retrieval storage facility (that may be operated by the government) or a consolidated interim storage facility (that might be operated by a commercial company).

What needs to be done to commercial SNF assemblies before they can be transported from active nuclear power plant sites or from shutdown reactor sites?

For SNF assemblies to be transported, they must be dried and packaged in a robust container that is approved by the NRC for transportation. At active commercial nuclear power plant sites, commercial SNF assemblies are stored wet in spent fuel pools, or dry in dry-storage canisters or casks placed on outdoor concrete pads (some sites use both wet and dry storage). At most shutdown sites, SNF is kept in dry storage. The steps necessary to prepare SNF for transportation depend on the condition of the SNF and the condition of the storage casks or canisters. In a relatively simple case, SNF stored in a spent fuel pool may be loaded directly into a transportation overpack already approved by the NRC for transportation.

In a more complicated case, some SNF assemblies are stored in welded canisters that are not approved by the NRC for transportation. The entity that owns this SNF (the utility or DOE) will have to work with the owner of the relevant transportation package Certificate of Compliance (CoC) to provide a technical case that supports the safe transportation of the SNF, and gain NRC approval for its transportation. It may be possible, in this case, for the CoC holder to request from NRC an exemption from some of the transportation requirements. Otherwise, the SNF will have to be removed from the welded canisters and repackaged into canisters or bare fuel casks that are approved by the NRC for transportation.

What needs to be done to DOE-managed SNF and HLW before these wastes can be moved from DOE facilities?

The various types of existing DOE-managed SNF are stored in a variety of configurations and conditions. Some types of this SNF have been prepared, to varying degrees, for transportation (for more detail, see NWTRB 2017f). N-Reactor SNF at the Hanford Site in Washington State is the largest quantity of DOE-managed SNF, by mass, comprising 2,100 metric tons of a total of 2,500 metric tons of SNF managed by DOE nationwide. The N-Reactor SNF has been dried and packaged in welded, stainless steel canisters that are intended to be ready for transportation. In addition to the N-Reactor SNF, there are more than 250 different types of DOE-managed SNF and much of this SNF must be dried and packaged or repackaged into containers that can be approved for transportation. Finally, DOE must select, purchase, and obtain NRC approval for a transportation cask to be used to ship all DOE-managed SNF.

DOE also stores liquid, salt cake, and solid HLW in large underground tanks; HLW dry powder (known as "calcine") in steel silos; cesium and strontium in metal alloy capsules; and processed HLW glass inside welded, stainless steel canisters. To prepare the HLW for transportation, DOE currently plans to treat and package liquid HLW in a process called "vitrification," which results in a glass waste form in a canister. According to plans that are not yet final, the HLW dry powder at the Idaho National Laboratory is to be retrieved, treated, and packaged. Finally, DOE must select, purchase, and obtain NRC approval for a transportation cask to be used to ship all DOE-managed HLW.

Are casks or overpacks for transporting the wastes currently available?

In the U.S., small transportation casks (or overpacks) have been used periodically to transport commercial SNF or to transport small quantities of research reactor SNF and SNF test specimens. In these cases, transportation casks approved by the NRC have been used and are available. For DOE to begin a large, nationwide transportation program for SNF and HLW, larger transportation casks will be needed. As of April 2019, approximately 10 types of large transportation casks have been approved by the NRC, but few casks have been fabricated and none are fully prepared for transportation—they still need certain attachments, such as impact limiters.

Have modes of transport been identified and developed?

DOE has evaluated the steps needed to remove commercial SNF from some shutdown sites, where the nuclear reactors have been shut down and, in some cases, demolished. To remove SNF from these shutdown sites, DOE identified transportation options that include truck, barge, or rail transport. For a larger, nationwide program to transport SNF and HLW, DOE has identified rail as the preferred means of transportation. Truck and barge transport of radioactive materials is well-established and has been widely used for small quantities of SNF and larger shipments of less hazardous wastes like low-level radioactive waste. Except for shipments of naval SNF, rail transport has been used to a lesser degree for SNF because truck transport has been sufficient to handle the smaller quantities of SNF. DOE is designing a special railcar, called the "Atlas railcar," to transport commercial SNF in larger quantities; DOE expects to deliver the first railcar by 2022.

Are different actions required for preparing to move SNF and HLW to a waste repository than would be required for moving SNF and HLW to an interim storage facility?

In a general sense, there will likely be little difference between preparing to transport SNF and HLW to a repository or preparing to transport SNF and HLW to an interim storage facility.

What technical issues, if any, may be associated with moving SNF or HLW twice (to an interim storage facility from reactor sites and then from the interim storage site to a waste repository)?

It is not clear whether any technical problems will be associated with moving SNF and HLW more than once. DOE, the NRC, and the nuclear industry are all pursuing research programs to more fully understand the condition of high burnup SNF[13] and SNF canisters during extended storage, transportation, and subsequent storage (if needed). Early results of some of these research programs have been published and a few additional results may be available in 2019, but some results—especially results of long-term storage testing—will not be available for at least 10 years. Preliminary results from this research indicate that there are no appreciable negative effects on SNF from extended storage and transportation. For HLW and HLW canisters, there is less concern about the effects of storage and transportation.

What technical issues, if any, may prevent the transportation of waste now or in the future?

Depending on the waste type, varying degrees of technical issues need to be resolved before the waste can be transported. In some cases, such as commercial SNF stored in dual-purpose casks (approved for both storage and transportation), the only significant technical/engineering steps that remain to prepare for transportation are fabricating impact limiters for the casks and completing a railcar to carry the casks. In other cases, several technical issues may have to be resolved before commercial SNF can be transported. For example, some commercial SNF is stored in welded canisters that do not include neutron absorbers to help prevent criticality in a postulated transportation accident (as noted above, the transportation package CoC must show how certain accidents, like a criticality accident, are prevented). Therefore, these canisters are not approved by the NRC for transportation. In these cases, DOE (or the nuclear utility) will have to develop and implement compensatory measures to ensure criticality safety, or it will have to repackage the SNF into casks or canisters that can be approved by the NRC for transportation. In some cases in which an SNF or HLW container does not meet the NRC's transportation requirements, the container owner may be able to request from the NRC an exemption from some of the transportation requirements.

[13] Fuel burnup is a measure of the energy generated in a nuclear reactor per unit mass of nuclear fuel; it is typically expressed in units of gigawatt-days per metric ton of uranium (GWd/MTU). In the United States, nuclear fuel utilized beyond 45 GWd/MTU is defined by the NRC as high burnup fuel. In a separate review effort, the Board is evaluating DOE research activities to address uncertainties regarding the characteristics of high burnup fuel and its behavior during extended storage and eventual transportation.

How much (by mass or volume) of the different types of waste is ready to be transported?

Only small quantities of certain waste materials in certain specific situations can be moved in the near term. For example, DOE continues to transport, on an infrequent basis, small quantities of foreign and domestic research reactor SNF to the Savannah River Site in South Carolina for storage. In 2017, DOE also transported a small quantity of commercial SNF to Oak Ridge National Laboratory in Tennessee for testing. Furthermore, the U.S. Navy continues to transport naval SNF from decommissioned and refueled ships to the Idaho National Laboratory. In general, the transportation infrastructure, transportation equipment, and regulatory approvals do not yet exist to support the near-term transportation of commercial SNF and DOE-managed SNF and HLW.

Generally, what steps must be taken to prepare to transport SNF and HLW?

Several technical/engineering steps and non-technical steps must be taken before a large-scale transportation effort can begin. The steps to be taken include, but are not limited to, the following:

Technical/engineering steps:

- For all waste types, dedicated railcars must be fabricated and transportation infrastructure must be created or refurbished.
- For all commercial SNF, impact limiters for transportation casks must be fabricated.
- For nearly all commercial SNF, transportation casks must be fabricated.
- For approximately 20 percent of commercial SNF, existing SNF storage casks and canisters must be approved by the NRC for transportation (or the SNF must be repackaged into new casks or canisters).
- For an unknown but significant number of commercial SNF storage cask and canister types that are already approved for transportation, the CoCs for transporting the casks and canisters must be amended and NRC-approved to broaden the scope of allowable contents (e.g., a wider range of fuel types, higher initial enrichments, and higher fuel assembly burnups).
- For all DOE-managed SNF, transportation casks must be fabricated.
- For many types of DOE-managed SNF—the SNF must be dried and packaged for transportation.
- For all DOE-managed HLW, transportation casks must be fabricated.
- For many types of DOE-managed HLW, the HLW must be treated and packaged for transportation.

Non-technical steps (applicable to all waste types):

- For an interim storage facility, the U.S. government or a private company must select, approve, fund, and develop the interim storage site.
- For a waste repository, the U.S. government must approve, fund, and develop a site for the waste repository.

- The concerns of local, state, and tribal jurisdictions in which the waste is to be stored or disposed of should be addressed.
- The NRC must complete all licensing steps in support of the construction and operation of an interim storage site, or a waste repository site, or both.
- DOE must work with a shipper to determine shipping routes, obtain required approvals for selected routes, and complete agreements to fund and support emergency response organizations in state, local, and tribal jurisdictions through which the waste will be transported.

2. Identification and Evaluation of the Technical Issues to Be Addressed

2.1 DOE Activities to Support Transporting SNF and HLW

Although DOE is not yet actively planning for SNF and HLW transportation, it is conducting several evaluation, research, and development activities that will support a future nationwide transportation campaign. DOE, through its national laboratories, is developing a suite of computer-based system analysis tools that allow it to evaluate different alternatives for implementing an integrated waste management system, including SNF and HLW transportation. DOE has briefed the Board regarding the design and intended use of several of these tools, as described further in Section 2.2. More detailed descriptions of the DOE system analysis tools are provided in Appendix A, Technical Issue #7.

DOE has also sponsored detailed site evaluations at some nuclear power plant sites where all reactors have been shut down and where SNF remains on site in dry storage (these sites are commonly called "shutdown sites"). For example, see Maheras et al. (2017). Some of these site evaluations included reviews of all steps necessary to remove commercial SNF from the site (Areva 2017a, 2017b, 2017c, 2017d, 2017e, 2017f).

During the development of the license application for the Yucca Mountain project, DOE proposed that a multi-purpose, standardized canister would be used to store, transport, and dispose of DOE-managed SNF (excluding naval SNF). DOE continues research and development activities for this "DOE standardized canister" design. DOE also has made significant progress in developing a special railcar to transport commercial SNF sealed inside a variety of SNF transportation cask designs. This railcar, called the "Atlas railcar," is designed to meet all federal requirements and rail industry guidance for transporting commercial SNF (Schwab 2016).

To address the thermal, stress, and hydrogen effects in high burnup SNF during extended storage and transportation, DOE and EPRI sponsored a research effort called the "High Burnup Dry Storage Cask Research and Development Project" (HDRP; EPRI

2014). This dry-storage test began in late 2017 and will last for 10 years, so data about the condition of the SNF after storage will not be available until 2027, at the earliest. The HDRP is discussed further in Appendix A, Technical Issue #16.

DOE has recognized that nuclear programs in other countries have significant experience in transporting SNF and HLW by truck, rail, and ocean-going vessels. In 2016, DOE sponsored a study of the worldwide SNF transportation experience; the results are documented in a report by Kevin Connolly and Ronald Pope, *A Historical Review of the Safe Transport of Spent Nuclear Fuel* (Connolly and Pope 2016). The experience in other countries may provide lessons learned and inform the development of a transportation program in the U.S.

In 2017, DOE coordinated with the Spanish nuclear equipment company Equipos Nucleares S.A. (ENSA) to obtain a Spanish SNF transportation cask for testing. The transportation cask was loaded with surrogate SNF assemblies; instrumented with accelerometers to measure vibration and shock loads; and shipped by truck, barge, ocean-going ship, and rail on a round trip from Spain to the U.S. and back to Spain. This "multi-modal" transportation test provided valuable insights to the conditions commercial SNF may experience during transportation (McConnell et al. 2018). Researchers at Sandia National Laboratories have conducted similar testing to measure shocks and vibrations in surrogate SNF assemblies on shaker tables and during truck transport. Further details of this testing are provided in Appendix A, Technical Issue #1.

2.2 Board Review Activities

Meetings with DOE and National Laboratories. To fulfill its legislatively mandated mission, the Board interacts regularly with representatives of DOE, DOE contractors, and national laboratory scientists. For example, the Board participates in periodic staff-to-staff updates with DOE staff members to discuss the status of DOE activities related to SNF and HLW management, packaging, and transportation. These regular communications with DOE are a key source of information supporting the Board's evaluation of the technical issues to be addressed in preparing a large SNF and HLW transportation program. The Board also requested and reviewed several DOE documents that informed the Board's evaluation.

On the topic of computer-based system analysis tools[14] that DOE is using in its evaluation of SNF and HLW transportation options, limited documentation has been published. To obtain more detailed information about these analysis tools, the Board requested presentations from DOE and participated in two fact-finding meetings at DOE national laboratories.

On June 25, 2015, representatives from the DOE Office of Nuclear Energy (DOE-NE) briefed the Board and its staff on a transportation routing tool called the "Stakeholder Tool for Assessing Radioactive Transportation" (START). The next relevant meeting was a fact-finding meeting, held December 12, 2017, at Argonne National Laboratory, where DOE personnel and laboratory analysts briefed a team of Board members and staff members on the DOE-sponsored computer-based tool called the "Next Generation System Analysis Model" (NGSAM). Another fact-finding meeting was held May 8,

[14] The computer-based system analysis tools being developed by DOE are discussed in more detail in Appendix A, Technical Issue #7.

2018, at Oak Ridge National Laboratory (ORNL), and included laboratory presentations on the data management and analysis tool called the "Used Nuclear Fuel Storage, Transportation & Disposal Analysis Resource and Data System" (UNF-ST&DARDS). As of May 2018, DOE personnel informed the Board that the remaining two system analysis tools, the Multi-Objective Evaluation Framework (MOEF) and the Execution Strategy Analysis (ESA), are not mature enough to warrant a presentation to the Board. All five of the system analysis tools mentioned above are described in more detail in Appendix A, Technical Issue #7.

The DOE Office of Environmental Management (DOE-EM) is responsible for packaging, storing, and planning for the disposal of DOE-managed SNF and HLW, and the Board interacts with DOE-EM on a periodic basis to remain informed about DOE-EM activities related these wastes. DOE-EM funds its contractor at INL to maintain a database for DOE-managed SNF but has not developed system analysis tools like those being developed within DOE-NE.

Summer 2015 Board Meeting. On June 24, 2015, the Board held its Summer 2015 public meeting in Golden, Colorado. The topic of the meeting was transportation of SNF, with a focus on technical issues affecting transportation, as well as licensing and integration issues. The Board heard presentations from representatives of DOE, national laboratories, the NRC, stakeholder groups, and nuclear utilities, including a nuclear utility in Switzerland.

In conjunction with the meeting, several Board members and staff members toured the Transportation Technology Center, near Pueblo, Colorado. This center, operated by Transportation Technology Center, Inc., tests individual railcars and combinations of railcars over a variety of speeds, rail conditions, and operating conditions. At the time of the Board visit, DOE was planning to test its Atlas railcar at the center; in June 2018, DOE began single-car testing with it first Atlas railcar (Schwab 2019).

Following the meeting, the Board issued a letter to DOE, dated August 31, 2015 (NWTRB 2015). Key findings and recommendations identified by the Board included, among others:

- 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.
- 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.
- The Board recommends that DOE expedite its efforts to finalize and publish documentation (e.g., documentation for START) supporting its integration and planning tools associated with the transportation of SNF.

Summer 2016 Board Meeting. To further explore DOE's effort regarding transporting SNF and HLW, the Board's Summer 2016 meeting focused on developing an integrated program for managing and disposing of canisters for SNF and HLW. The meeting was held August 24, 2016, in Washington, DC, and featured speakers from DOE, national laboratories, the U.S. Naval Nuclear Propulsion Program, and the nuclear industry. Of particular interest was the presentation from a U.S. Navy representative summarizing the safe rail shipment of more than 850 casks of naval SNF during the past 60 years (Miles 2016).

Following the meeting, the Board issued a letter dated December 8, 2016, to the Assistant Secretary for DOE-EM and the Acting Assistant Secretary for DOE-NE (NWTRB 2016). Key findings and recommendations included, among others:

- The Board encourages DOE-NE to expand the use of its system analysis tools so that it can include in its analyses the SNF managed by DOE-EM, all HLW, and SNF from the Naval Nuclear Propulsion Program.
- Based on the presentations, it is not clear to the Board how DOE-NE responsibilities for planning the transportation of commercial SNF are integrated with DOE-EM responsibilities in the areas of packaging certification and transpor-tation of wastes or with Naval Nuclear Propulsion Program transportation of naval SNF.
- To address the need to develop an integrated system for managing and disposing of SNF and HLW in the United States, the Board recommends that DOE, as a matter of priority, do the following:
    - Establish a comprehensive database of SNF and HLW: Develop a single database that contains all the information on SNF and HLW necessary to support developing an integrated management and disposal system, or the software necessary to successfully integrate the separate databases that contain the necessary information.
    - Develop an integrated (end-to-end) system analysis tool for waste management: Develop new, or modify existing, system analysis tools, as described earlier, to allow successful analysis of the full scope of the integrated waste management system.

Summer 2018 Board Meeting. Building on information obtained from the document reviews and the meetings mentioned above, the Board planned and conducted a public meeting on the topic of technical issues to be addressed in preparing for a large SNF and HLW transportation effort. The public meeting was held June 13, 2018, in Idaho Falls, Idaho. Speakers included past and present transportation system managers at DOE and DOE-NE staff involved in analyzing the options for transporting SNF and HLW. The past Packaging and Transportation Manager for the DOE Carlsbad Field Office at the Waste Isolation Pilot Plant (WIPP) provided details and lessons learned from transporting transuranic waste to WIPP from many locations around the country. The Board also heard from representatives of the Nuclear Energy Institute (NEI), Holtec International, a utility in Switzerland, stakeholder groups, and the NRC.

The presentations and discussions at the public meeting confirmed the technical issues to be addressed that are identified in Table 2-1 of this report (issues already identified by the Board); no new technical issues were identified. During the meeting, the presenters were asked to identify which technical issues they believed were the highest priority and which technical issues would take the longest to resolve. Although DOE-NE representatives have stated that the technical issues do not pose a challenge, the former Director of the Office of National Transportation for the Yucca Mountain Program provided an informative list of the technical issues of greatest concern, to be resolved when preparing for a large SNF and HLW transportation effort:

- Transporting high burnup SNF
- Obtaining approved transport certificates (from the NRC) for DOE SNF
- Managing the uncertainties about the formulation of vitrified HLW affecting transportation CoCs
- Managing the overall complexity of the transportation system
- Resolving the lack of transportation integration with storage and disposal, especially between the private sector and the federal government; the proposed use of a Transport, Aging, and Disposal (TAD) canister was a flawed attempt to address this challenge—something new is needed (Lanthrum 2018)

The former Director of the Office of National Transportation also provided a list of issues produced in response to the question, "What are the top-priority technical issues you recommend that DOE focus on now to prepare for an efficient and effective transportation program?" His list of priority issues, both technical and non-technical, is reproduced here:

- Improved integration of transportation with storage and disposal requirements.
    - Between the private and federal systems
    - For multiple repositories
    - Determining how and where that integration will take place
- Better integration of [DOE-EM] and repository program plans for transportation and disposal
- Begin negotiations with the Association of American Railroads on how operat-ing aspects of the AAR-S-2043[15] Standard will be implemented
- Complete negotiated settlements with remaining railroads (Lanthrum 2018)

An NEI representative described the efforts of NEI's Transportation Task Force. To fully examine the steps necessary to begin transporting commercial SNF, the Transportation Task Force is planning a transportation table-top exercise that aims to address the logistical and operational issues associated with moving commercial SNF from dry storage at a shutdown site to a hypothetical interim storage facility. The Board will stay attuned to any new technical issues or other relevant information that are identified during this exercise.

Although the focus of the public meeting was on technical issues to be addressed, several presenters noted that some social and institutional issues must be addressed before a large transportation campaign can be successfully implemented. The types of social and institutional issues most frequently mentioned during the public meeting were the following:

- There is a need for early and continuous engagement and collaboration between DOE and stakeholders at the state, tribal, and local levels as well as other organizations such as nuclear utilities and rail carriers that are essential to ensuring an effective nationwide transportation program.
- Lack of adequate and predictable funding adversely affects the development of a transportation program, including, for example, advance procurement of casks

[15] The AAR-S-2043 Standard, "Performance Specification for Trains Used to Carry High-Level Radioactive Material," provides design and performance requirements for railcars intended to carry high-level radioactive materials, including SNF. AAR-S-2043 specifies stringent requirements for railcar coupling systems, brakes, nondestructive examinations of railcar components, and railcar dynamic load tests.

and other essential equipment, full stakeholder engagement, and emergency preparedness and response planning.

- The WIPP transportation approach for transuranic waste represents a useful model and provides relevant lessons for developing a nationwide transportation program for SNF and HLW. However, transuranic waste is transported to WIPP by road, while transportation of commercial SNF is expected to occur mostly by rail, so the differences between highway and rail transport will need to be considered in applying WIPP experience in developing the SNF and HLW transportation program.

A listing of preliminary Board observations resulting from the June 2018 public meeting is included in a letter from the Board to the DOE Assistant Manager for Environmental Management and the Principal Deputy Assistant Secretary for Nuclear Energy (NWTRB 2018).

Nuclear Waste Transportation Experience in Other Countries. As the Board evaluates the efforts of DOE in preparing a nationwide waste management system that includes transporting SNF and HLW, the Board looks to the experiences in other countries for important lessons to consider. The Board has benefited from several interactions with organizations that manage nuclear waste programs in other countries, and it has gained a better understanding of the policies, programs, and practices of managing, transporting, and planning for disposal of nuclear wastes in those countries.

The Board also arranged presentations by representatives of nuclear utilities in Switzerland on SNF transportation planning. A representative of the Swiss utility Axpo gave a presentation on "Management and Transportation of Spent Nuclear Fuel in Switzerland" at the Summer 2015 Board Meeting (Williams 2015) and a representative of the Gösgen Nuclear Power Plant (Kernkraftwerk Gösgen [KKG]) gave a presentation on the "Management of Spent Nuclear Fuel and High-Level Waste as an Integrated Program in Switzerland" at the Summer 2018 Board Meeting (Whitwill 2018). Details of the latter presentation are discussed further in Appendix A, Technical Issue #8.

DOE has recognized the value of learning from the experience in other countries and has commissioned a study of worldwide experience in transporting SNF (Connolly and Pope 2016). In their report, Connolly and Pope summarize and tabulate worldwide SNF transportation activities and include descriptions of the most significant transportation accidents involving SNF. However, the chief conclusion of the report is "that transportation of SNF has been accomplished routinely and safely in many countries around the world, including the U.S., for decades."

Another useful source of information about lessons learned in other countries is the biannual reports entitled *Safety of the Transport of Radioactive Materials for Civilian Use in France*, published by the French Institute for Radiological Protection and Nuclear Safety (IRSN). The most recent report, which covers the period 2014–2015, provides statistics on transporting SNF and other nuclear materials in France and describes recent upset conditions (IRSN 2017).

Several other resources are available regarding the transportation of SNF and HLW overseas. Nuclear waste transportation programs exist in the United Kingdom, France, and Japan, among others, and most of the shipping is accomplished by companies such as Orano TN, Edlow International, International Nuclear Services/Pacific Nuclear

Transport Limited, and Gesellschaft für Nuklear-Service mbH. These companies have decades of experience in arranging the necessary equipment and logistics, and then licensing and conducting SNF and HLW shipments.

2.3 Identifying the Technical Issues

As described in Section 2.2, the technical issues that need to be addressed before beginning a major transportation effort for SNF and HLW in the U.S. have been identified by the Board during past Board public meetings, technical workshops, and Board reports (NWTRB 2012, 2014, 2015, 2016, 2017f, 2018). Additional relevant technical issues have been identified and documented in reports and presentations by DOE (e.g., Stockman et al. 2014), the U.S. nuclear industry (EPRI 2011), and researchers in other countries. Drawing from these sources, the Board has compiled a list of technical issues to be addressed in preparing for transporting SNF and HLW (see Table 2-1, also repeated as Table A-1). Table 2-1 includes simple, brief descriptions of the issues. A detailed discus-sion of each issue is included in Appendix A. Where the technical issues have common attributes, or will affect transportation in common ways, the issues have been grouped together and listed as a single technical issue in Table 2-1 (e.g., degradation of SNF can-isters includes damage to canisters [scratches, dents] and corrosion of canisters [general corrosion, pitting corrosion]).

The Board recognizes there are several uncertainties about the path forward for the U.S. SNF and HLW management system and there are alternative approaches for proceeding, particularly for preparing to transport commercial SNF and the destinations involved. Although this report does not address issues specific to an eventual destination, the Board recognizes that the alternatives being considered include one or more interim storage facilities, a waste repository, or some combination of these. Among the alternatives are options for privately funded and operated interim storage facilities, including the possibility of privately funded transportation of commercial SNF. Although the Board's findings and recommendations apply to DOE and not to privately funded operations, it is reasonable to assume that a privately funded transportation program would have to resolve the technical issues the Board has identified.

Well in advance of the start of transportation of commercial SNF, DOE will have to reach agreement with the nuclear utilities about how it will receive the SNF—that is, whether it will accept unpackaged, bare SNF assemblies (Scenario 1 in this report), SNF packaged in dry-storage casks or canisters (Scenario 2 in this report), or both. DOE's decision will directly affect the technical issues to be resolved before a transportation campaign can begin. Most notably, if DOE accepts only unpackaged, bare SNF assemblies, then SNF sealed in dry-storage casks or canisters will have to be repackaged into new casks or canisters provided by DOE. At some locations, this approach would require the approval, design, and construction of a new repackaging facility.

Because DOE has not yet decided on acceptable packaging conditions of commercial SNF, Table 2-1 is organized to account for the various possibilities, including Scenario 1 and Scenario 2 mentioned above. DOE could choose to accept from the nuclear utilities some bare SNF assemblies that are stored in spent fuel pools and some SNF assemblies that are packaged in dry-storage casks and canisters. In this case, DOE would have to address the technical issues listed in both Scenario 1 (except for the repackaging issues) and Scenario 2.

Another section in Table 2-1 lists the technical issues that must be addressed for all SNF and HLW and in all scenarios—the issues in this section must be addressed regardless of the waste to be transported. An additional two sections list the unique issues that must be addressed before DOE can begin transporting DOE-managed SNF and HLW. In summary, Table 2-1 includes the following sections:

- Technical Issues Affecting All SNF and HLW and All Scenarios
- Scenario 1—Technical Issues Affecting Commercial SNF (if DOE accepts unpackaged, bare SNF assemblies)
- Scenario 2—Technical Issues Affecting Commercial SNF (if DOE accepts SNF assemblies already packaged in casks or canisters)
- Technical Issues Affecting Commercial SNF (regardless of SNF packaging)
- Technical Issues Affecting DOE-Managed SNF (naval SNF excluded)
- Technical Issues Affecting DOE-Managed HLW

Table 2-1. Board-Identified Technical Issues to Be Addressed in Preparing a Nationwide Effort to Transport SNF and HLW

Technical Issues Affecting All SNF and HLW and All Scenarios
1. Identify and mitigate (if needed) potential physical effects of transporting SNF, SNF casks and canisters, and HLW canisters to ensure they will meet transportation requirements and future storage requirements.
2. Identify requirements for verifying the condition of the waste forms (SNF and HLW) at the time of transport; develop and implement inspection procedures and equipment, if needed; and correct identified deficiencies.
3. Identify and implement waste handling and loading needs (e.g., facilities, equipment, procedures, training) at all waste storage sites.
4. Identify less-than-adequate transportation infrastructure (e.g., roads, rail lines, barge docks) at all waste storage sites; make needed upgrades.
5. Ensure the readiness of the technical aspects of emergency preparedness and response programs and organizations.
6. For waste forms and packaging not already approved for transportation: identify, develop, and validate computer models/programs (if not already done) to be used for structural, thermal, containment, shielding, and criticality evaluations in support of licensing for transportation; ensure the models/programs and input data meet the NRC requirements for quality assurance/quality control; and complete all necessary evaluations.
7. Complete the design, development, and implementation of integrated waste management system analysis and routing tools.
Scenario 1—Technical Issues Affecting Commercial SNF (if DOE accepts unpackaged, bare SNF assemblies)
8. Complete the design, licensing, fabrication, and testing of new SNF packages and transportation equipment on a timescale that supports the transportation schedule.
9. Identify and implement programs for designing, procuring, installing, and operating repackaging facilities and equipment at all sites, as necessary.
10. Identify and mitigate (if needed) potential adverse effects of repackaging operations on SNF assemblies to ensure the SNF will meet transportation requirements.
Scenario 2—Technical Issues Affecting Commercial SNF (if DOE accepts SNF assemblies already packaged in casks or canisters)
11. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to casks or canisters during dry storage that may affect the ability of the casks or canisters to meet transportation requirements.
12. Identify and remedy (if needed) types of dry-storage casks and canisters for SNF that are not approved for transportation as noted below: ▪ The cask or canister structural design or neutron absorber structural design does not meet transportation requirements. ▪ The cask or canister is not yet approved by the NRC (although similar casks or canisters are approved).
13. Identify and correct (if needed) individual dry-storage casks and canisters with contents or physical conditions that do not meet the requirements specified in the NRC-approved transportation Certificate of Compliance.
14. Identify inspection requirements, procedures, and equipment needed to verify the condition of all casks and canisters before transportation; perform inspections; and rectify identified problems, if needed.
15. Complete the design, licensing, fabrication, and testing of all needed transportation casks and associated components.
Technical Issues Affecting Commercial SNF (regardless of SNF packaging)
16. Identify and mitigate (if needed) degradation mechanisms in commercial SNF occurring over extended periods of dry storage that may affect the ability of SNF to meet transportation requirements.
17. Determine what burnup credit can be taken for all SNF types other than pressurized water reactor SNF (for which burnup credit is allowed by the NRC in its Interim Staff Guidance-8, Rev. 3).
18. Complete the design, licensing, fabrication, and testing of a commercial SNF railcar (e.g., the DOE Atlas railcar).

Table 2-1. Board-Identified Technical Issues to Be Addressed in Preparing a Nationwide Effort to Transport SNF and HLW (continued)

Technical Issues Affecting DOE-Managed SNF (naval SNF excluded)
19. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to dry-storage casks and canisters for DOE-managed SNF that may affect the ability of the casks or canisters to meet transportation requirements.
20. Complete existing designs, or develop new designs, for multi-purpose SNF canisters and complete the licensing, fabrication, and testing to accommodate all DOE-managed SNF that will not be processed at the Hanford Site, the Idaho National Laboratory, or the Savannah River Site.
21. Complete a new analysis to validate the structural integrity of the Hanford multi-canister overpack (MCO) design to support NRC approval of the MCO for transportation.
22. Define the transportation cask(s) to be used for DOE-managed SNF.
23. If not using an existing transportation cask, then design, license, fabricate, and test a new transportation cask for DOE-managed SNF.
Technical Issues Affecting DOE-Managed HLW
24. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to dry-storage canisters for DOE-managed HLW that may affect the canisters' ability to meet transportation requirements.
25. Finalize the decision on whether the sodium-bearing waste at the Idaho National Laboratory is remote-handled transuranic waste or HLW.
26. Complete the development and deployment of any required treatment process for calcined HLW at the Idaho National Laboratory.
27. Complete the design, licensing, fabrication, and testing of packaging for the Hanford cesium and strontium capsules.
28. Complete the design, licensing, fabrication, and testing of packaging for the ceramic and metallic HLW forms from the Idaho Fuel Conditioning Facility.
29. Define the transportation cask(s) to be used for DOE-managed HLW.
30. If not using an existing transportation cask, then design, license, fabricate, and test a new transportation cask for DOE-managed HLW.

Each of the technical issues identified in Table 2-1 is explained, in detail, in its own section of Appendix A. Throughout this report, the technical issues will be identified by their numbers (Technical Issue #1, Technical Issue #2, etc.). Note that some technical issues include multiple sub-issues (e.g., Technical Issue #12), and these sub-issues are explained and evaluated in the corresponding section of Appendix A. While Table 2-1 represents a broad range of technical and integration issues to be addressed, it does not necessarily reflect a comprehensive list of the actions that must be completed before a nationwide transportation effort can begin. DOE will have to complete its system-wide coordination and planning to ensure that it has identified all necessary preparation activities.

2.4 Timeframe Needed to Address Technical Issues Before Nuclear Waste Can Be Transported

To effectively develop and implement a nuclear waste management program, DOE will need to apply proven management methods, including program-wide coordination and effective advance planning. In a system as large and complex as the U.S. SNF and HLW management system, knowing which issues and tasks must be addressed first and how long each task will last are crucial for effectively and efficiently managing the system.

For a small portion of the existing, packaged waste (e.g., certain commercial SNF in approved, dual-purpose [storage and transportation] canisters), few technical issues remain unresolved. For example, barring unforeseen problems, certain types of commercial SNF likely could be shipped within a year or two of resolving institutional issues, such as determining a destination and obtaining funding. For other wastes (e.g., unpackaged DOE-managed SNF), work on resolving the difficult technical issues must begin long before the first waste can be moved—an example is provided below.

For the technical issue of developing new transportation cask systems, nuclear industry experiences in SNF cask development offer illustrative examples of the time needed to address this multi-faceted technical issue. For some types of SNF and HLW, a new transportation cask system will have to be developed, including cask design, licensing, fabrication, testing, and, finally, implementation in the field. The Board gathered information on several such efforts that have been completed or are planned. Three specific examples are summarized below (and more detail is provided in Appendix A, Technical Issue #8).

U.S. Navy M-290 Transportation Cask. In 2005, the U.S. Navy began to make plans for the new M-290 transportation cask that could hold longer naval SNF from decommissioned aircraft carriers (Schwab 2016). In May 2013, the Navy submitted safety documentation for the M-290 cask to the NRC and requested an NRC review leading to certification of the cask for transportation (Miles 2013). In parallel, the Navy began to fabricate and test the cask. In December 2014, the NRC approved the M-290 cask for transportation (NRC 2014c). The Navy's experience shows that developing a new-design transportation cask takes approximately 10 years.

KKG (Kernkraftwerk Gösgen-Däniken AG, Switzerland) Experience. Although the licensing process for SNF storage and transportation casks in Switzerland is not identical to that in the U.S., it is similar, and recent experience by KKG offers a good example of the time needed to develop a new dual-purpose commercial SNF cask. During the Summer 2018 Board Meeting, the Board asked a KKG representative to explain the process needed to develop a new SNF cask. The KKG representative provided a time breakdown of the entire process, from initial concept in 2013 to expected loading of the SNF in the new casks in 2027. The Swiss experience shows that developing and licensing a new commercial SNF cask can take as long as 15 years (Whitwill 2018).

DOE's Notional Plan to Prepare for Commercial SNF Transportation. During the Summer 2018 Board Meeting, DOE presented a "Summary Schedule for Transportation" (Boyle 2018). This summary schedule applies to the preparations needed before DOE can begin to transport commercial SNF.[16] Within the schedule, the time required to select and procure several transportation casks, that can carry many existing commercial SNF canisters, is approximately four years. However, this time estimate applies to completing work on existing cask designs that the NRC has already approved for transportation. The four-year time estimate covers only efforts to complete amendments to the CoCs and to fabricate the casks and associated equipment.

[16] Dr. Boyle included a legal caveat at the beginning of his presentation: "This is a technical presentation that does not take into account the contractual limitations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961). Under the provisions of the Standard Contract, DOE does not consider spent nuclear fuel in multi-assembly canisters to be an acceptable waste form, absent a mutually agreed to contract amendment. To the extent discussions or recommendations in this presentation conflict with the provisions of the Standard Contract, the Standard Contract provisions prevail."

Because of its limited scope, the DOE time estimate of four years to complete preparations of existing transportation cask designs is not indicative of the full time needed to develop and gain approval of a new cask design. Given the experiences of the U.S. Navy and commercial nuclear cask vendors, the Board finds that at least a decade should be allotted to design, license, fabricate, and test a new transportation cask (for more detail on this topic, see Appendix A, Technical Issue #8). This duration is variable and could be shorter if the package design is not complex and the range of contents envisioned to be shipped in the cask is limited. The period may be longer if special design features are included that will prompt a more detailed review by the NRC or if contingency planning is added to the schedule (e.g., to allow for suspended or lowered federal funding for the project).

The issue of new cask development is one of 30 Board-identified technical issues that need to be addressed before a large transportation effort can begin. Although some of the issues may be addressed more quickly and more easily than the development of a new transportation cask, coordinating the resolution of all 30 issues in parallel will require significant planning, integration, and interaction with several other federal agencies and nuclear industry groups.

2.4.1 Sequence of Events Needed to Prepare Commercial SNF for Transportation

Although precise dates and lengths of time for beginning and implementing a nationwide transportation program are not yet available, an expected sequence of events can be identified to better understand the needed planning process. Figure 2-1 shows the expected sequence of events that will have to be completed to prepare for the transportation of commercial SNF in the potential scenario in which DOE accepts bare SNF assemblies from the commercial nuclear power plant sites (Scenario 1, which is described in more detail in Section 2.3 and in Appendix A, Section A2.1). Figure 2-2 shows the expected sequence of events that will have to be completed to prepare for the transportation of commercial SNF in the potential scenario in which DOE accepts packaged SNF from the commercial nuclear power plant sites (Scenario 2, which is described in more detail in Section 2.3 and in Appendix A, Section A2.2).

In the possible case in which DOE accepts some bare SNF assemblies from commercial nuclear utilities (as in Scenario 1) and some SNF in existing dry-storage casks and canisters (as in Scenario 2), DOE would need to complete the sequence of events in both Figure 2-1 and Figure 2-2, as appropriate. Although not shown in these figures, DOE would have to complete a similar sequence of events to prepare to ship DOE-managed SNF and DOE-managed HLW from each site that stores these wastes.

The technical issues to be addressed often are specific to a particular SNF cask or canister (e.g., Technical Issue #13, "Identify and correct [if needed] individual dry-storage casks and canisters with contents or physical conditions that do not meet the requirements specified in the NRC-approved transportation Certificate of Compliance") or are specific to a particular site (e.g., Technical Issue #3, "Identify and implement waste handling and loading needs [e.g., facilities, equipment, procedures, training] at all waste storage sites"). Therefore, the sequence of events represented in Figures 2-1 and 2-2 will usually have to be addressed and completed on a case-by-case basis at each site that stores waste, and sometimes, for each waste type at a given site.

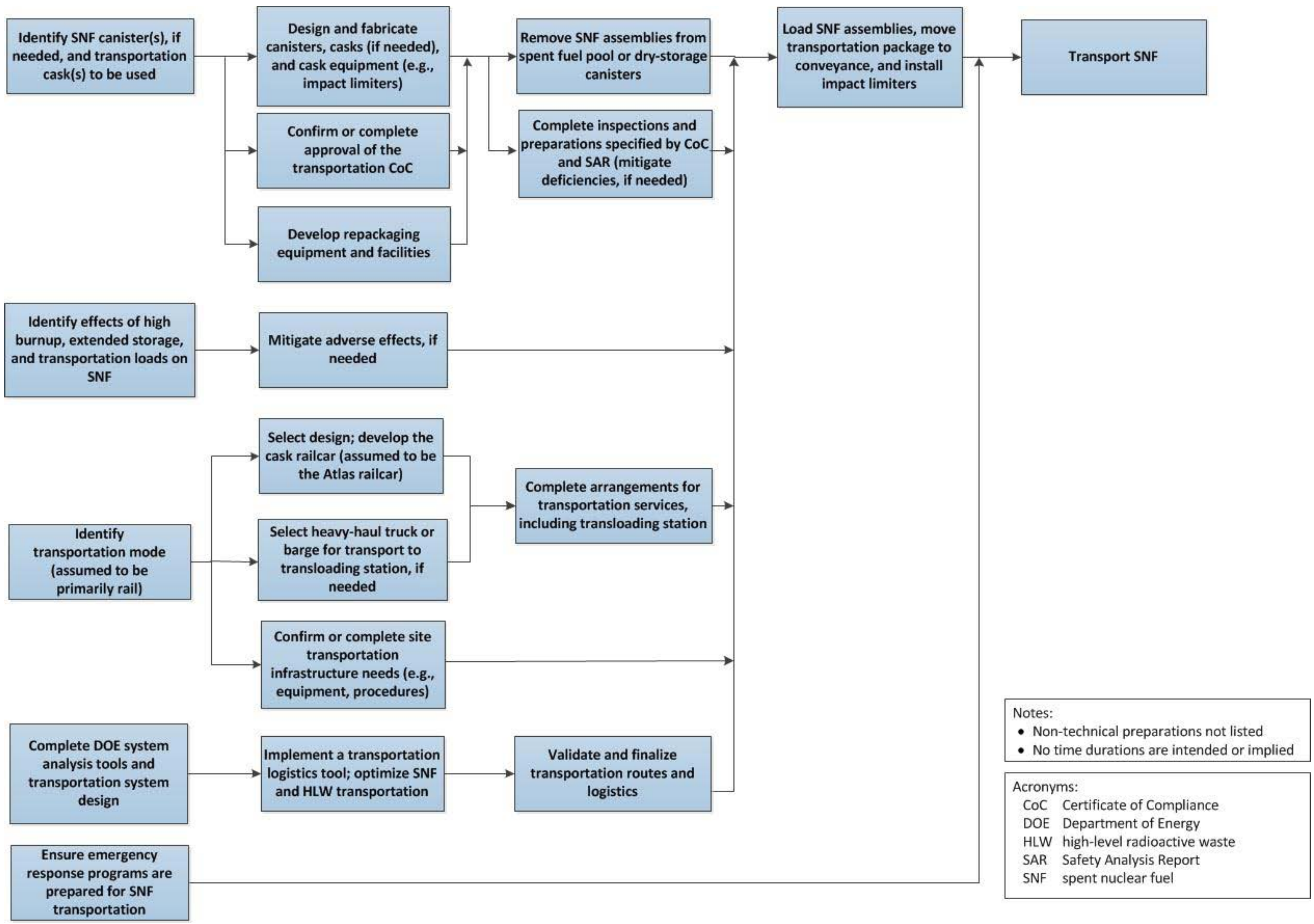

Figure 2-1. Sequence of events in Scenario 1: Technical issues affecting commercial SNF (if DOE accepts unpackaged, bare SNF assemblies).

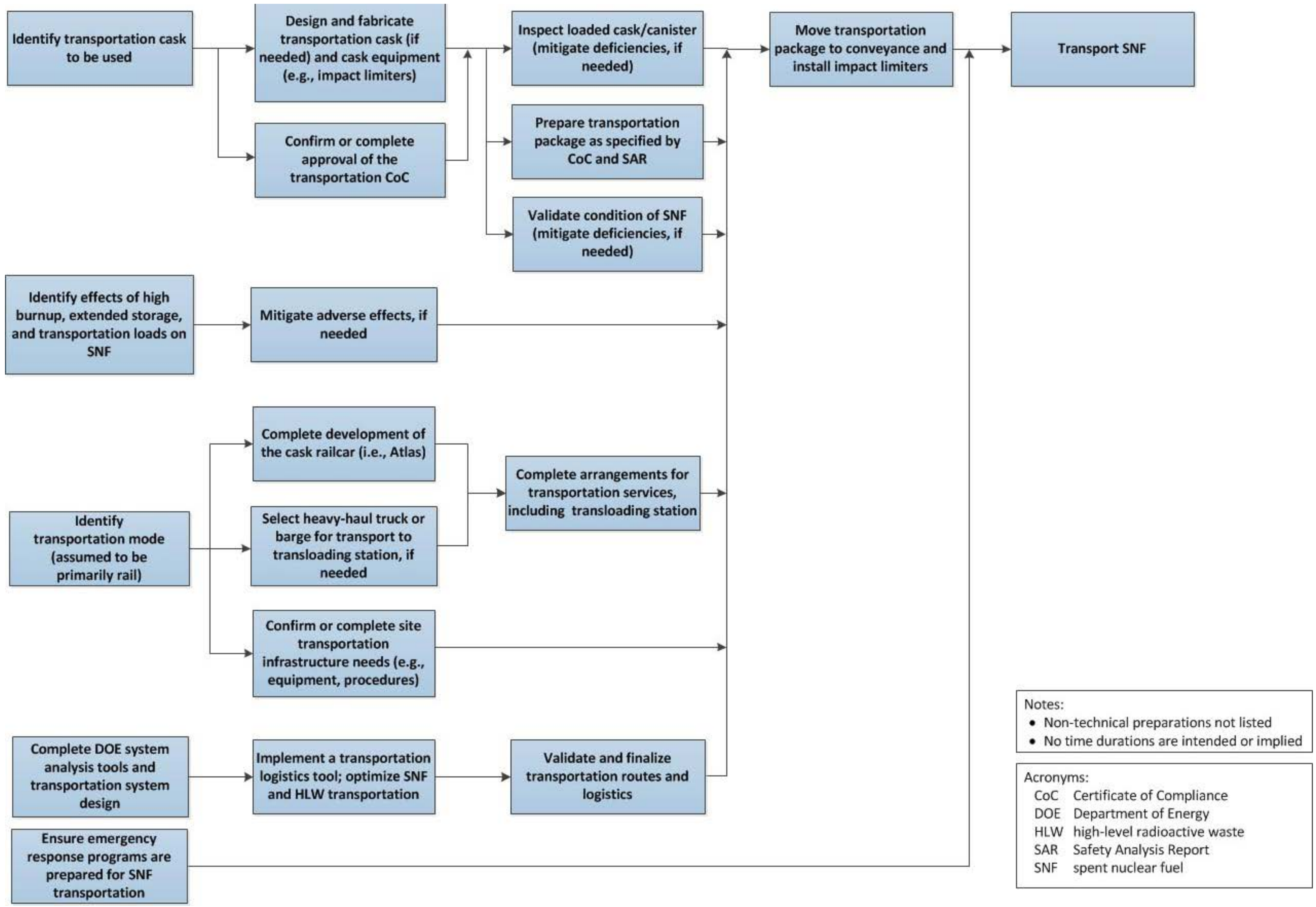

Figure 2-2. Sequence of events in Scenario 2: Technical issues affecting commercial SNF (if DOE accepts SNF assemblies already packaged in casks or canisters).

3. Observations, Findings, and Recommendations

3.1 Observations

Based on reviews of DOE documents, fact-finding meetings with national laboratory and DOE personnel, and the presentations given at Board public meetings, the Board makes the following observations:

1. DOE's preliminary evaluations of removing commercial SNF from shutdown sites, which involved working with site personnel, utilities, and local stakeholders, have generated valuable information and are important to continue. As these studies have shown, considerable planning and coordination will be required to refurbish or reestablish the capabilities to handle and load SNF containers, reconstitute needed site infrastructure (e.g., electrical power, radiological controls), and rebuild the roadways and/or rail lines necessary to support SNF transportation. Eventually, similar evaluations will need to be completed at the DOE sites that store DOE-managed SNF and HLW.
2. The current effort by DOE-NE to perform analyses and assess options for a nationwide transportation program does not appear to be well-integrated with activities of DOE-EM. Furthermore, the current assessment of options for the transportation program does not include sufficient consideration of the SNF and HLW materials and packages that DOE-EM manages.
3. The WIPP transportation approach for transuranic waste represents a useful model and provides relevant lessons for developing a nationwide transportation program for SNF and HLW. However, transuranic waste is transported to WIPP by road, while transportation of commercial SNF is expected to occur mostly by rail, so the differences between highway and rail transport will need to be considered in applying WIPP experience in developing the SNF and HLW transportation program. The Board notes that DOE-NE representatives have been interacting with DOE-EM representatives to understand the lessons learned from the recent restart in transuranic waste shipments to WIPP.
4. The U.S. Navy's nuclear material transportation program as well as the programs in other countries, such as France, the United Kingdom, and Japan, have demonstrated proficiency and an excellent safety record in transporting SNF and HLW. These programs represent many decades of experience in planning,

logistics, public outreach, and emergency preparedness and response and offer valuable lessons that can be applied to developing and operating a nationwide transportation program for SNF and HLW.

5. DOE will need to complete existing designs or develop new designs for casks and canisters that enable DOE to store and transport DOE-managed SNF and HLW. Additional types of new casks and canisters may be required to transport some commercial SNF. Furthermore, past DOE analyses have noted the advantages of developing a waste management program based on standardized, multi-purpose cask and canisters designs. Because DOE will need to develop new cask and canister designs, the Board observes that more than a decade may be needed to procure and obtain NRC approval of new types of casks and canisters, based on U.S. Navy and nuclear industry experiences. Therefore, considerable advance planning and early coordination with NRC during the development and licensing of new cask and canister designs will be needed.
6. The development of a nationwide program for transporting SNF and HLW must include close coordination with local, state, and tribal emergency planning and response organizations. Due to the varying requirements among jurisdictions and the length of time needed for some jurisdictions to develop and implement the required technical aspects of emergency preparedness and response programs, significant advance planning by DOE will be needed.
7. The Board commends DOE-NE for the advances it has made in developing its system analysis and planning tools are to be commended. These tools will be a major asset in designing the transportation program, particularly as tool development continues and as DOE gains access to the detailed technical information necessary to conduct realistic system analyses. However, exactly how some of the tools will be employed needs further clarification.
8. As noted by the Committee on Transportation of Radioactive Waste, in its report *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States* (NAS 2006), social and institutional issues may be the most challenging issues to resolve. DOE must comprehensively and effectively address issues such as public outreach and transportation route planning.
9. Certain technical issues require the completion of significant research and development to support the eventual transportation of certain types of nuclear wastes. One example is the application of "burnup credit" to a broad population of commercial SNF that cannot be transported without that credit. Another example is the design, procurement, and licensing of a repackaging capability for commercial SNF that is stored in casks and canisters that cannot be transported (or if DOE accepts only bare SNF assemblies from nuclear utilities to be loaded in a DOE-provided transportation cask). Although some progress has been made on these types of issues, much more work is needed before they will be resolved.

3.2 Findings and Recommendations

1. **Technical Issues Should Be Addressed in an Integrated and Comprehensive Manner.** The complexity and scale of the nation's SNF and HLW management program make resolving technical and integration issues a challenge. SNF and HLW inventories in the U.S. include a diverse collection of waste forms, waste

storage containers, storage locations and conditions, waste transportation containers, and licensing requirements. Different waste storage sites also have varying degrees of accessibility for large transport vehicles or railcars. Addressing the unresolved technical and integration issues associated with these program elements prior to initiating waste transportation will require a well-planned and well-integrated effort, applied over an extended time.

Table 2-1 of this report (same as Table ES-1) lists 30 technical issues that need to be addressed. Not all the issues must be resolved before the first of the waste can be transported, but all technical issues must be resolved before the nation's entire inventory of waste can eventually be transported. As DOE continues to assess and evaluate the readiness of SNF and HLW to be transported, it may find additional technical issues to address. Careful prioritization of the issues will be needed, including developing prioritization criteria and agreement from affected government agencies, like the NRC, and affected local, state, and tribal organizations.

Finding 1. *The Board finds that many interrelated technical and integration issues must be addressed in preparing for a nationwide effort to transport SNF and HLW to their eventual destination. The technical issues must be prioritized and their resolution properly sequenced to ensure that the overall program will be operationally feasible and unhindered by delays.*

Recommendation 1. *As DOE continues its analyses and research for a nationwide waste management and transportation system, the Board recommends that DOE ensure the issues in Table 2-1 of this report are addressed. The Board also recommends that the issues in Table 2-1 and any other issues identified by DOE be prioritized and carefully sequenced to support the integrated operation of a nationwide transportation program.*

2. **Evaluations of Storage Sites for Nuclear Waste Should Continue.** The Board commends DOE for its proactive efforts to inspect and evaluate the readiness to remove commercial SNF from nuclear power plant sites where all reactors have been shut down but where commercial SNF remains in dry storage (shutdown sites). To support the full integration of a transportation program for SNF and HLW, DOE will need to conduct similar evaluations at DOE sites that store DOE-managed SNF and HLW.

   Finding 2. *The Board finds that DOE's effort to evaluate the readiness to move commercial SNF from shutdown nuclear power plant sites has gathered important information that will be needed to support the removal of commercial SNF from these sites for transportation. However, not all shutdown sites have been fully evaluated. Furthermore, DOE has not conducted similar reviews at DOE facilities that store DOE-managed SNF and HLW.*

   Recommendation 2. *The Board recommends that DOE give higher priority to evaluating the removal of commercial SNF from shutdown nuclear power plant sites and to evaluating DOE sites that store DOE-managed SNF and HLW. DOE should also share the results of the evaluations with operators of waste storage sites, so they can apply lessons learned, retain critical site transportation infrastructure, and be better prepared for the eventual transportation of the wastes.*

3. **Advance Planning for the Development of Casks and Canisters for SNF and HLW Is Needed.** To implement an integrated, nationwide waste management program, DOE will need to complete the development and licensing of existing canister designs (e.g., the DOE standardized canister) and develop new canister designs for some DOE-managed HLW. DOE will also have to develop and obtain NRC approval of transportation casks for all DOE-managed SNF and HLW. Additional types of new casks may be required to transport some commercial SNF that cannot be transported in existing transportation casks. Furthermore, past DOE efforts, such as the development of the TAD canister in conjunction with the Yucca Mountain License Application, have noted the advantages of developing a waste management program based on standardized, multi-purpose canisters for commercial SNF. These standardized canisters may also be new designs.

   Finding 3. *The Board finds that DOE will have to complete existing canister designs or develop new cask and canister designs for storing and transporting SNF and HLW. The Board also finds that developing new cask or canister designs for SNF or HLW could take longer than a decade. Therefore, DOE will need to allow for considerable advance planning and early coordination with NRC during the development of new cask and canister designs.*

   Recommendation 3. *The Board recommends that, for planning purposes, DOE should allow for a minimum of a decade to develop new cask and canister designs for SNF and HLW storage and transportation, or DOE should conduct its own detailed evaluation of the time needed to complete the design, licensing, fabrication, and testing of new casks and canisters.*

Appendix A.
Detailed Descriptions of Technical Issues That Need to Be Addressed in Preparing a Nationwide Effort to Transport Spent Nuclear Fuel and High-Level Radioactive Waste

This appendix provides detailed descriptions of the technical issues the Board identified that need to be addressed in preparing a nationwide effort to transport SNF and HLW. The list of Board-identified issues is provided in Table A-1. The technical issues are listed in six distinct groups or sections depending on the waste, or the packaging of the waste, as follows:

- Technical Issues Affecting All SNF and HLW and All Scenarios
- Scenario 1—Technical Issues Affecting Commercial SNF (if DOE accepts unpackaged, bare SNF assemblies)
- Scenario 2—Technical Issues Affecting Commercial SNF (if DOE accepts SNF assemblies already packaged in casks or canisters)
- Technical Issues Affecting Commercial SNF (regardless of SNF packaging)
- Technical Issues Affecting DOE-Managed SNF (naval SNF excluded)
- Technical Issues Affecting DOE-Managed HLW

The six groups are reflected in six separate sections of Appendix A and each of the 30 technical issues is described within the applicable section.

Table A-1. Board-Identified Technical Issues to Be Addressed in Preparing a Nationwide Effort to Transport SNF and HLW

Technical Issues Affecting All SNF and HLW and All Scenarios
1. Identify and mitigate (if needed) potential physical effects of transporting SNF, SNF casks and canisters, and HLW canisters to ensure they will meet transportation requirements and future storage requirements.
2. Identify requirements for verifying the condition of the waste forms (SNF and HLW) at the time of transport; develop and implement inspection procedures and equipment, if needed; and correct identified deficiencies.
3. Identify and implement waste handling and loading needs (e.g., facilities, equipment, procedures, training) at all waste storage sites.
4. Identify less-than-adequate transportation infrastructure (e.g., roads, rail lines, barge docks) at all waste storage sites; make needed upgrades.
5. Ensure the readiness of the technical aspects of emergency preparedness and response programs and organizations.
6. For waste forms and packaging not already approved for transportation: identify, develop, and validate computer models/programs (if not already done) to be used for structural, thermal, containment, shielding, and criticality evaluations in support of licensing for transportation; ensure the models/programs and input data meet the NRC requirements for quality assurance/quality control; and complete all necessary evaluations.
7. Complete the design, development, and implementation of integrated waste management system analysis and routing tools.
Scenario 1—Technical Issues Affecting Commercial SNF (if DOE accepts unpackaged, bare SNF assemblies)
8. Complete the design, licensing, fabrication, and testing of new SNF packages and transportation equipment on a timescale that supports the transportation schedule.
9. Identify and implement programs for designing, procuring, installing, and operating repackaging facilities and equipment at all sites, as necessary.
10. Identify and mitigate (if needed) potential adverse effects of repackaging operations on SNF assemblies to ensure the SNF will meet transportation requirements.
Scenario 2—Technical Issues Affecting Commercial SNF (if DOE accepts SNF assemblies already packaged in casks or canisters)
11. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to casks or canisters during dry storage that may affect the ability of the casks or canisters to meet transportation requirements.
12. Identify and remedy (if needed) types of dry-storage casks and canisters for SNF that are not approved for transportation as noted below: ▪ The cask or canister structural design or neutron absorber structural design does not meet transportation requirements. ▪ The cask or canister is not yet approved by the NRC (although similar casks or canisters are approved).
13. Identify and correct (if needed) individual dry-storage casks and canisters with contents or physical conditions that do not meet the requirements specified in the NRC-approved transportation Certificate of Compliance.
14. Identify inspection requirements, procedures, and equipment needed to verify the condition of all casks and canisters before transportation; perform inspections; and rectify identified problems, if needed.
15. Complete the design, licensing, fabrication, and testing of all needed transportation casks and associated components.
Technical Issues Affecting Commercial SNF (regardless of SNF packaging)
16. Identify and mitigate (if needed) degradation mechanisms in commercial SNF occurring over extended periods of dry storage that may affect the ability of SNF to meet transportation requirements.
17. Determine what burnup credit can be taken for all SNF types other than pressurized water reactor SNF (for which burnup credit is allowed by the NRC in its Interim Staff Guidance-8, Rev. 3).
18. Complete the design, licensing, fabrication, and testing of a commercial SNF railcar (e.g., the DOE Atlas railcar).

Table A-1. Board-Identified Technical Issues to Be Addressed in Preparing a Nationwide Effort to Transport SNF and HLW (continued)

Technical Issues Affecting DOE-Managed SNF (naval SNF excluded)
19. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to dry-storage casks and canisters for DOE-managed SNF that may affect the ability of the casks or canisters to meet transportation requirements.
20. Complete existing designs, or develop new designs, for multi-purpose SNF canisters and complete the licensing, fabrication, and testing to accommodate all DOE-managed SNF that will not be processed at the Hanford Site, the Idaho National Laboratory, or the Savannah River Site.
21. Complete a new analysis to validate the structural integrity of the Hanford multi-canister overpack (MCO) design to support NRC approval of the MCO for transportation.
22. Define the transportation cask(s) to be used for DOE-managed SNF.
23. If not using an existing transportation cask, then design, license, fabricate, and test a new transportation cask for DOE-managed SNF.
Technical Issues Affecting DOE-Managed HLW
24. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to dry-storage canisters for DOE-managed HLW that may affect the canisters' ability to meet transportation requirements.
25. Finalize the decision on whether the sodium-bearing waste at the Idaho National Laboratory is remote-handled transuranic waste or HLW.
26. Complete the development and deployment of any required treatment process for calcined HLW at the Idaho National Laboratory.
27. Complete the design, licensing, fabrication, and testing of packaging for the Hanford cesium and strontium capsules.
28. Complete the design, licensing, fabrication, and testing of packaging for the ceramic and metallic HLW forms from the Idaho Fuel Conditioning Facility.
29. Define the transportation cask(s) to be used for DOE-managed HLW.
30. If not using an existing transportation cask, then design, license, fabricate, and test a new transportation cask for DOE-managed HLW.

A1. Technical Issues Affecting All SNF and HLW and All Scenarios

Technical Issue #1. Identify and mitigate (if needed) potential physical effects of transporting SNF, SNF casks and canisters, and HLW canisters to ensure they will meet transportation requirements and future storage requirements.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all waste forms.

b. This issue must be addressed before the waste forms can be transported.

c. This issue applies for both normal conditions of transport and for accidents; it also applies for transport by rail, truck, and barge.

Description: The U.S. nuclear industry has some experience with transporting commercial SNF over long distances (e.g., cross-country) but has not done so with large quantities of SNF (e.g., thousands of metric tons). DOE has transported small quantities of various commercial SNF from reactor sites to DOE laboratories for post-irradiation examination and to DOE waste management facilities. DOE has also transported small quantities of foreign and domestic research reactor SNF from the U.S. and other countries to DOE-managed sites for storage. However, other countries have extensive experience with shipping commercial SNF and HLW. DOE researched past transportation efforts in the U.S.

and other countries and summarized them in a report on the worldwide SNF transportation experience (Connolly and Pope 2016). The chief conclusion of the report is "that transportation of SNF has been accomplished routinely and safely in many countries around the world, including the U.S., for decades."

No comprehensive examinations of U.S. commercial SNF have been conducted following transportation to determine if the SNF was damaged in transit. However, SNF handling, loading, and shipping operations can subject the SNF assemblies to vibration loads, small impulse loads (e.g., bumps in the road), and, in severe conditions such as an accident, strong shock loads. How these vibrations and impulse loads may affect the SNF and its ability to meet transportation requirements are not fully understood, but they are the subject of ongoing DOE research.

During normal conditions of transport, the NRC requires that "the geometric form of the package contents [e.g., SNF assemblies] would not be substantially altered" and that "the contents would be subcritical" (Title 10, Code of Federal Regulations, Part 71, Section 71.55[d]; 10 CFR 71.55[d]). Furthermore, in transportation accident conditions, the whole cask payload, including the SNF, must remain subcritical (10 CFR 71.55[e]). Additional NRC publications in the form of Standard Review Plans and Interim Staff Guidance documents provide more detailed (and optional) guidance about how licensees might meet the requirements of 10 CFR Part 71.

To learn more about how transportation vibration and shock loads may affect SNF, DOE has sponsored several research efforts. For example, researchers at ORNL conducted a series of tests to examine the effects of cyclic bending on SNF, including high burnup SNF and SNF in which hydride reorientation had been induced in the cladding. The team used a test device called the "Cyclic Integrated Reversible-Bending Fatigue Tester" to apply the cyclic bending loads. They found that the presence of cladding hydrides, which have been reoriented in the radial direction, can reduce the bending fatigue life of the SNF cladding (Wang et al. 2017; Wang, Wang, and Yan 2016).

DOE also sponsored research at Sandia National Laboratories (SNL) to examine the effects of transportation vibrations on SNF. SNL conducted tests, using surrogate SNF assemblies, on shaker tables and on trucks driving on typical roads (McConnell et al. 2013). The SNL researchers measured the vibration inputs and resulting vibrations of surrogate SNF assemblies over a wide spectrum of vibration frequencies. The results show low strains on the surrogate SNF assemblies as a result of vibrations expected during normal conditions of transport (McConnell et al. 2013).

In 2017, DOE coordinated with the Spanish nuclear equipment company ENSA to obtain an ENUN-32P SNF transportation cask for testing. The transportation cask was loaded with surrogate SNF assemblies from the U.S., Korea, and Spain, instrumented with accelerometers to measure vibration and shock loads, and shipped by truck, barge, ocean-going ship, and rail on a round trip from Santander, Spain, to the Transportation Technology Center, near Pueblo, Colorado, and back to Spain. This test program ended in late 2017, and a report of the preliminary test results was published in January 2018 (McConnell et al. 2018). The basic conclusions, noted in the preliminary test results, were that "[s]trains on the surrogate fuel rods in all three assemblies were extremely low," and "[d]ata from the assembly tests establishes a technical basis for the safe transport of spent fuel under Normal Conditions of Transport." However, these are only preliminary conclusions; as of April 2019, the results of the final data analysis had not been published.

Although the SNL vibration testing and the rail testing with the ENSA cask both simulated transporting SNF, much of the data collected provide information about the structural performance of the cask or canister holding the SNF and may be applicable to canisters holding HLW during transportation. As with SNF, DOE will need to understand the effects of transportation loads on the HLW canisters; if the effects are significant, DOE may need to implement corrective actions prior to transporting the HLW.

The data from the DOE-sponsored test programs (e.g., SNL testing, ENSA cask testing) have improved DOE's overall understanding of the mechanical behavior of SNF during normal conditions of transport. However, the same kind of data is not expected to be needed for HLW. There are no expectations that the HLW form (vitrified borosilicate glass) will remain intact inside the HLW canisters. For example, in the Yucca Mountain license application, DOE assumed that the HLW glass will crack inside the waste canister. Based on a description of the HLW glass degradation model used to support the Yucca Mountain license application (Bechtel SAIC 2004), DOE assumed that the effective sur-face area of the HLW glass will increase by a factor of 17 due to cracking during cool-ing, handling, and transportation.

Technical Issue #2. Identify requirements for verifying the condition of the waste forms (SNF and HLW) at the time of transport; develop and implement inspection procedures and equipment, if needed; and correct identified deficiencies.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all SNF and possibly some HLW forms.

b. This issue must be addressed before waste can be transported.

Description: Many waste forms, both SNF and HLW, have been stored for many years, awaiting disposition. As an example, operators at the Surry nuclear power plant site in Virginia were the first to move commercial SNF into dry storage in 1986, when the NRC licensed the first Independent Spent Fuel Storage Installation (ISFSI). Many other nuclear power plant sites followed suit, and as of June 2019, more than 129,000 commercial SNF assemblies are in dry storage at 77 ISFSIs in 33 states (UxC 2019; NRC 2019a). Today, many commercial SNF assemblies have been in dry storage for 25 years; some have been in dry storage for more than 30 years.

Before nuclear waste (in this case, SNF and HLW) can be transported, DOE or the licensee (the organization holding the CoC for transportation) must ensure that the condition of the waste matches the description of the waste provided in the associated CoC. Specifically, the NRC requires (per 10 CFR 71.33, "Package Description"):

"The application must include a description of the proposed package in sufficient detail to identify the package accurately and provide a sufficient basis for evaluation of the package. The description must include— (b) With respect to the contents of the package—

(1) Identification and maximum radioactivity of radioactive constituents;

(2) Identification and maximum quantities of fissile constituents;

(3) Chemical and physical form;

(4) Extent of reflection, the amount and identity of non-fissile materials used as neutron absorbers or moderators, and the atomic ratio of moderator to fissile constituents;

(5) Maximum normal operating pressure;

(6) Maximum weight;

(7) Maximum amount of decay heat; and

(8) Identification and volumes of any coolants."

If the waste has been recently loaded for storage (and inspected during loading), then the licensee has a firm basis for assuring the NRC that the condition of the waste is known and meets the limits of the relevant CoC for transportation. However, for some waste, especially SNF that has been in dry-storage casks or canisters (unopened and uninspected) for 25 to 30 years, assuring the NRC that the condition of the waste is known could prove more difficult.

Inspections following dry storage of low burnup PWR SNF for 15 years at the Idaho National Laboratory indicated no appreciable change in the condition of the SNF (EPRI 2002). However, the impact of longer periods of storage or of storing high burnup SNF are not fully understood and are subject to greater uncertainty (see Technical Issue #16). DOE is funding a research effort, led by EPRI and supported by Orano TN (formerly Areva), to study the effects of long-term storage on high burnup SNF (EPRI 2014). While this effort is expected to provide some useful information about the condition of high burnup SNF after 10 years of dry storage, this information may not be available before DOE (or another shipper) begins to ship commercial SNF, so DOE (or another shipper) may have to use other means to verify the condition of the SNF.

Therefore, before transporting high burnup SNF or SNF that has been in dry storage for extended periods, the licensee will have to prove through previous inspection records, testing, or computer modeling that the physical and chemical form of the SNF meets the limits specified in the relevant CoC. If these methods are not sufficient, and the licensee chooses to pursue an inspection approach, then inspection requirements, procedures, and equipment will have to be developed before the inspections can be conducted. If the licensee chooses the computer modeling approach, then several other technical issues arise, as discussed in Technical Issue #6.

For HLW, the waste form is not likely to be required to maintain a robust physical form to meet transportation requirements. For example, vitrified HLW glass is a hot liquid when it is poured into stainless steel HLW canisters and the vitrified glass is known to fracture as it cools and solidifies in the canister. In a study sponsored by DOE, researchers found that the effective surface area of the HLW glass could increase by a factor of 17 due to this fracturing (Bechtel SAIC 2004). Therefore, NRC approval of the transportation of HLW forms is expected to rely on the integrity of the HLW canisters and the transportation cask system, but not on the physical form of the HLW itself.

Technical Issue #3. Identify and implement waste handling and loading needs (e.g., facilities, equipment, procedures, training) at all waste storage sites.

Assumptions, Conditions, Applicability:

a. This issue applies to all wastes under all scenarios.

b. There will be significant differences in the scope and nature of this issue among sites depending on the waste storage conditions at the site and on the condition of facilities and equipment at the site (e.g., operating site or shutdown site).

Description: For all sites storing commercial SNF, DOE-managed SNF, or HLW, the necessary waste handling and loading equipment will need to be in place before the waste can be moved. For sites still loading or planning to load SNF or HLW into dry-storage casks and canisters, many of the needed facilities and equipment are in place (some sites may lack the infrastructure that supports off-site transportation of waste). However, for other sites, particularly shutdown commercial reactor sites and DOE sites holding DOE-managed SNF, most of the waste loading capabilities will have to be added or reconstituted. Furthermore, these sites will have to confirm or reestablish all the management and operations systems necessary to support nuclear activities, to which many federal requirements for safety and security apply. The scope of this effort will include programs for the following (among others):

- Funding and budget control
- Management, oversight, and corrective action plans
- Staffing, training, and qualification
- Procedure development and validation
- Worker safety
- Radiological controls
- Criticality safety
- Fire protection
- Emergency preparedness and response
- Radioactive waste management
- Safeguards and security

In the case of commercial SNF, DOE has not finalized its decision about how SNF will be loaded for transport (i.e., as bare SNF assemblies or as SNF casks and canisters). However, several studies have been conducted to evaluate the readiness of some commercial nuclear power plant sites to support shipments of SNF. For example, DOE has examined the general state of SNF storage conditions at 14 shutdown sites and assessed the existing SNF handling capabilities as well as the upgrades and improvements needed to support removing SNF from those sites (Maheras et al. 2017). DOE also commissioned more detailed evaluations of the condition of SNF storage at six shutdown sites, focusing on the specific steps that will need to be taken to prepare each site's SNF for shipment. Each site evaluation also reviewed transportation mode and route options, culminating in the selection of a preferred mode and route for transporting SNF from each site (see, for example, Areva 2017a).

To address the scenario in which DOE accepts bare SNF assemblies for transport, DOE commissioned a study of the time, effort, and equipment required to transfer bare SNF assemblies from dry-storage casks and canisters into Storage, Transportation, Aging, and Disposal canisters at operating nuclear power plant sites (EnergySolutions 2015).

For DOE-managed SNF and HLW, all waste storage sites are still operated by DOE and its contractors. However, many of these sites do not have the equipment and systems in place to support a major campaign to ship SNF or HLW off site. In some cases, DOE has begun to plan for off-site shipment. For example, at the Idaho National Laboratory, DOE designed an SNF loading and shipping facility for non-naval SNF (the Idaho Spent Fuel Facility). However, the Idaho Spent Fuel Facility is not funded and has not advanced beyond the design phase. The effort to prepare for shipments of SNF and HLW from the DOE sites will be similar in scope and complexity to that described above for commercial SNF sites.

Estimate of the Time It Will Take to Address the Technical Issue: Maheras et al. (2017) provides estimates of the time needed to complete all steps necessary to prepare to transport SNF from shutdown sites (excluding steps to upgrade transportation infrastructure). Because many variables and assumptions are associated with each specific site, the assessment team developed two sets of time estimates: conservative (longer) time estimates and optimistic (shorter) time estimates for removing SNF from a hypothetical site that holds either five or 10 SNF dry-storage casks. To remove all SNF from the hypothetical site, the optimistic time estimate was 6.2 years and the conservative time estimate was 11.2 years (Maheras et al. 2017).

Technical Issue #4. Identify less-than-adequate transportation infrastructure (e.g., roads, rail lines, barge docks) at all waste storage sites; make needed upgrades.

Assumptions, Conditions, Applicability:

a. This issue applies to all wastes in all scenarios.

b. This issue must be addressed, where needed, before SNF or HLW can be transported.

Description: For DOE-managed SNF, HLW, and commercial SNF, if the corresponding waste storage sites have not established and maintained the transportation infrastructure that can support off-site shipping, then that infrastructure will have to be established or refurbished to operability. The transportation infrastructure noted here differs from the waste handling systems and equipment noted in Technical Issue #3.This issue specifically addresses rail lines and associated railway switches, trestles, and the like to support rail transport; water access ramps, docks, and the like to support barge transport; and roads, bridges, and the like to support heavy-haul truck transport.

Most commercial nuclear power plant sites where the nuclear reactors have been shut down and defueled continue to store SNF at dry-storage facilities. At some of these sites, the reactors, as well as all other support facilities, have been dismantled and removed from the site, leaving only the SNF storage facility. Previously usable transportation routes such as paved roads, railways, and barge docks are not being maintained any more than is necessary to allow for infrequent, periodic surveillance of the SNF storage facility.

By contrast, an operational nuclear power plant site either maintains a robust transportation infrastructure that can support shipments of large plant components, such as steam generators, condensers, and dry-storage casks and canisters for SNF, or has the resources to refurbish such infrastructure if it has not been maintained. Depending on the site, heavy components may arrive by rail, heavy-haul truck, or barge, and the associated transportation route must be available, when needed.

To support the removal of SNF or HLW from waste storage sites, DOE will have to work with the site operator to ensure that the necessary transportation routes are available and capable of supporting the preferred mode of transportation. For shutdown commercial nuclear power plant sites, DOE has completed general assessments of the condition of transportation infrastructure at the sites (Maheras et al. 2017). DOE also completed more detailed assessments at six shutdown sites (Areva 2017a, 2017b, 2017c, 2017d, 2017e, 2017f). The results of these assessments show that, at some sites, significant work will have to be done to bring the transportation infrastructure back into good working order.

To illustrate the work to be done, DOE's review of the Big Rock Point Site (Areva 2017e) noted the following conditions:

> Big Rock Point is not currently rail-served. Originally, the plant had rail access when it was being built in the early 1960s, which was used to move some SNF from the site in the 1960's, but the switch and track were removed in 1988. (p. 2–9)
>
> The [Big Rock Point] site currently only has road access, although reports indicate that it had rail and barge access at one time. … The previously used heavy haul roadway no longer exists on the site, and the current access road from the

ISFSI to the highway was not built to support heavy haul transfers, and may need to be rebuilt or enhanced. (p. 2–9)

A traditional route survey would be conducted by the trucking company/shipping services providers. … The route survey would identify any encumbrance along the route, weight and dimensional restrictions, determine any grade changes, turning radius restrictions, soil compaction, etc., to plan the movement. Overhead wires, bridges, gates dimensions, etc., would be measured and noted for planning purposes. The positioning and placement of the off-site [heavy-haul truck] for the loading and unloading processes would be coordinated with the crane company. Overweight and over width permits would be required for any [heavy-haul truck] transport off-site. (p. 6–8)

Technical Issue #5. Ensure the readiness of the technical aspects of emergency preparedness and response programs and organizations.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all waste forms in all scenarios.

b. Although the immediate responsibility for emergency preparedness and response lies with the local, state, and tribal jurisdictions through which SNF and HLW will be transported, DOE will have to ensure the affected emergency response programs and organizations are properly prepared and notified prior to transporting SNF and HLW.

c. In the case of shipments of commercial SNF and HLW, the conditions and extent of DOE's involvement in local emergency preparedness and response will be specified in the DOE policy on Section 180(c) implementation.[17]

Description: In considering the various technical elements involved in transporting hazardous materials, one of the most crucial is emergency preparedness. A robust, proactive approach to emergency preparedness is vital for achieving and maintaining readiness. A variety of technical issues related to emergency preparedness and response must be completed before transportation begins. Important examples include the following:

- Technical analysis of potential emergency scenarios and their consequences, including natural, technological, natech (natural-hazard-triggering technological disasters), cyber, and other potential threats (including new and emerging threats)
- Emergency response planning, to include the following:
  - o Identification of what tracking/alerting technologies, devices, methods, or pro-tocols may be needed to enable automated, real-time, remote monitoring of shipments by the transportation coordination center
  - o Identification of what technologies, devices, methods, or protocols may be needed to enable effective emergency communication with responders and the public
  - o Identification of technical competencies, capabilities, and criteria needed for the selection, training, assignment, and evaluation of couriers and other key transport personnel
  - o Identification of technical competencies and capabilities needed by emergency response agencies/organizations in jurisdictions along transportation routes
  - o Identification of detection/monitoring equipment, personal protective equipment, and other technical equipment needed by couriers and other key transport per-sonnel, and by emergency response personnel in jurisdictions along transportation routes
  - o Development of realistic drills/exercises to ensure the following:
    - Technical proficiency of couriers and other key transport personnel
    - Technical proficiency of emergency response personnel
    - Effective technical coordination

[17] Section 180(c) of the Nuclear Waste Policy Act (as amended) requires DOE to provide funding and technical assistance to local, state, and tribal emergency response organizations in jurisdictions through which commercial SNF will be transported. In 2008, DOE issued, for public comment, a draft policy on the implementation of the Section 180(c) requirements (DOE 2008), but that policy has not yet been finalized.

- Mechanisms to ensure effective identification and dissemination of technical lessons learned, including rapid incorporation into planning and training

High-Level Requirements. The characteristics listed above, as well as various other necessary attributes of effective emergency preparedness and response programs, will be facilitated by close adherence to the requirements found in federal regulations and DOE's own internal directives. High-level requirements for emergency planning and emergency response associated with transporting hazardous materials can be found in the following:

- 29 CFR 1910.38, "Emergency Action Plans"
- 29 CFR 1910.120, "Hazardous Waste Operations and Emergency Response"
- 40 CFR Part 355, "Emergency Planning and Notification"
- 49 CFR Parts 171–177, "Hazardous Materials Regulations"
- DOE Order 151.1D, *Comprehensive Emergency Management System*
- DOE Order 153.1, *Departmental Radiological Emergency Response Assets*
- DOE Order 460.1C, *Packaging and Transportation Safety*
- DOE Order 460.2A, *Departmental Materials Transportation and Packaging Management*
- Executive Order 12656, *Assignment of Emergency Preparedness Responsibilities*

DOE Program Requirements. More specific requirements applicable to DOE shipments of radioactive materials are promulgated by the DOE Office of Environmental Management, Office of Packaging and Transportation, in DOE Manual 460.2-1A, *Radioactive Material Transportation Practices Manual*. This manual contains detailed requirements in the following areas related to emergency preparedness and response (listed by the relevant manual chapter):

2. Transportation Planning
3. Emergency Planning
5. Routing
7. Carrier/Driver Requirements
8. Shipment Pre-Notification
9. Transportation Operational Contingencies
10. Tracking
13. Emergency Notification
14. Emergency Response
15. Recovery and Cleanup

For example, Chapter 3, "Emergency Planning," requires the following actions, among others, to be taken by DOE prior to transporting radioactive materials:

- Discuss emergency response roles, responsibilities, capabilities, notification procedures, and information needs with state and tribal governments along transportation corridors used for DOE radioactive material/waste shipments. DOE Regional Transportation Emergency Preparedness Program (TEPP) Coordinators are available to provide planning information and assistance to state and tribal contacts within their region.

- Provide TEPP planning tools to state and tribal authorities to assist them in planning and preparing for response to transportation accidents/incidents involving DOE radioactive material and performing needs assessments.
- Coordinate with site transportation programs to identify planned radioactive material shipments to assist state and tribal organizations in planning for the various shipments.
- Coordinate information with TEPP coordinators in other regions affected by shipping routes that traverse more than one region.
- Coordinate with program offices, transportation managers, and public information officers during the development of transportation plans and develop the emergency plans for shipping campaigns originating in their region.

Requirements Specific to the NWPA. Additional important requirements are specified in the NWPA. For transportation of commercial SNF and HLW, the NWPA (as amended), Section 180(c), "Transportation," states the following:

> The Secretary shall provide technical assistance and funds to States for training for public safety officials of appropriate units of local government and Indian tribes through whose jurisdiction the Secretary plans to transport spent nuclear fuel or high-level radioactive waste. … Training shall cover procedures required for safe routine transportation of these materials, as well as procedures for dealing with emergency response situations.

To provide specific details for how the Section 180(c) requirements will be met, DOE issued, for public comment, a draft policy on Section 180(c) implementation (DOE 2008). However, this policy has not yet been finalized and implemented. Of note in the draft policy is the statement by DOE that "State and Tribal governments have primary responsibility to protect the public health and safety in their jurisdictions." Therefore, DOE is currently focusing on the specific responsibilities it was assigned in Section 180(c) to "provide technical assistance and funds" to help prepare local emergency response organizations for shipments of SNF and HLW.

All of the aforementioned components have a role to play in fostering readiness. In addition, because the landscape of hazards and threats is dynamic and can change, preparedness and response efforts need to remain open to new information and adaptable to new challenges.

Perspectives of State and Local Jurisdictions. During the Summer 2018 Board Meeting, a Western Interstate Energy Board (WIEB) representative presented information to the Board indicating that state and local jurisdictions would like to see better engagement from DOE in fulfilling the NWPA requirements for DOE discussed above. Among other concerns, the state and local groups would like DOE to be more proactive in supporting emergency preparedness and response programs. The WIEB and the Western Governors' Association (WGA) have both published policy statements (WIEB 2018; WGA 2018) expressing their expectations that DOE will fulfill its obligations under Section 180(c) of the NWPA to provide technical assistance and funds to local, state, and tribal jurisdictions in support of emergency preparedness and response programs.

Lessons Learned From Transporting Nuclear Materials in France. France has been using nuclear power for electricity production since the 1970s and, as of November 2018, operated 58 commercial nuclear power plants (WNA 2019a). Because France recycles its nuclear fuel to recover uranium and plutonium to fabricate new nuclear fuel, France has extensive experience in transporting SNF—the SNF is transported on a regular basis from operating nuclear power plants to the La Hague reprocessing facility on the northwest coast of France.

Because France has been transporting SNF regularly for more than 40 years, the French have accumulated a great deal of experience and lessons learned regarding transportation incidents and accidents, including the actions necessary by emergency preparedness and response organizations. To record this experience, the IRSN publishes a biannual report entitled *Safety of the Transport of Radioactive Materials for Civilian Use in France*. The most recent edition of this report was published in September 2017 (IRSN 2017).

In its report *Safety of the Transport of Radioactive Materials for Civilian Use in France; Lessons Learned by IRSN From Analysis of Significant Events Reported in 2012 and 2013* (IRSN 2015), IRSN offers several lessons regarding emergency preparedness and response. Two key good practices are the following:

- "[L]ocal and national emergency response exercises periodically organised are an opportunity for IRSN to gain feedback and use it to improve the technical and operational measures it has put in place to fulfil this task" (IRSN 2015).
- "To enhance public safety in the event of a serious accident occurring in France or beyond French borders, … and to deal with the possibility of accidents during the transportation of radioactive materials, … the French government has produced the national emergency response plan for major nuclear or radiological accidents" (IRSN 2015).

Technical Issue #6. For waste forms and packaging not already approved for transportation, identify, develop, and validate computer models/programs (if not already done) to be used for structural, thermal, containment, shielding, and criticality evaluations in support of licensing for transportation; ensure the models/programs and input data meet the NRC requirements for quality assurance/quality control; and complete all necessary evaluations.

Assumptions, Conditions, Applicability:

a. This technical issue applies, where needed, to all waste forms in all scenarios.

b. For waste forms (SNF or HLW) that are included in the approved "Contents" list of a 10 CFR Part 71, "Certificate of Compliance for Radioactive Material Packages," that is already approved by the NRC, no further action is required and this issue does not apply.

c. For some waste forms (SNF or HLW), the licensee may take a conservative approach by assuming a worst case (or bounding) condition for the waste form; in this case, detailed computer modeling of the waste form and its characteristics may not be required to obtain NRC approval for transportation. However, the conservative approach must be approved by the NRC.

Description:

General Requirements for Transporting Radioactive Waste. To transport radioactive waste (for this report, the radioactive wastes considered are commercial SNF, DOE-managed SNF, and HLW), the waste owner or licensee must first ensure that the waste and its associated packaging meet all applicable requirements promulgated by the NRC, the Department of Transportation (DOT), and, in some cases, DOE. These requirements are extensive and cover topics including, but not limited to, safety, security, and environmental protection.

The NRC safety requirements for transporting radioactive waste are found in 10 CFR Part 71, which, in turn, ensures that radioactive material shipments meet the DOT requirements contained in 49 CFR Parts 171–177, "Hazardous Materials Regulations." The requirements promulgated by 10 CFR Part 71 include maximum radiation dose rates, maximum temperatures, material limits to prevent criticality, and a number of package tests (i.e., drop, puncture, fire, and immersion tests) that must be passed to ensure the shipping package can withstand normal conditions of transport and certain accident conditions. More specific limits for each type of radioactive material shipping package are contained in the CoC for Radioactive Material Packages that applies to that package (in this context, a "package" is a transportation cask or overpack and its contents). The radioactive material owner must work with the package vendor to submit an application to the NRC and receive an NRC-approved CoC before a radioactive material package can be used for transportation.

Computer Programs Used to Support Applications for a Certificate of Compliance. To meet the stringent requirements of 10 CFR Part 71, the licensee must submit, in its application to the NRC, documentation that provides a strong technical basis demonstrating, among other things, the safety of the radioactive material package. This documentation is usually submitted in the form of a "Safety Analysis Report for Packaging." The NRC provides further detailed guidance regarding the format and content of applications for a CoC in Regulatory Guide 7.9, *Standard Format and Content of Part 71 Applications for Approval of Packages* *for Radioactive Material*. The relevant technical sections of Regulatory Guide 7.9 are the following:

> Chapter 2: Structural Evaluation
>
> Chapter 3: Thermal Evaluation
>
> Chapter 4: Containment
>
> Chapter 5: Shielding Evaluation
>
> Chapter 6: Criticality Evaluation

To receive NRC approval, the licensee usually performs the evaluations noted above with sophisticated computer models and programs. In most cases, these computer models and programs are well-established and recognized by the NRC, having been thoroughly verified and validated. The nuclear industry can choose from a large variety of publicly available and private (proprietary) computer programs to complete the required evaluations. The NRC has also developed a suite of computer programs that it uses to independently verify and validate the results submitted by the licensee.

For example, the Standardized Computer Analyses for Licensing Evaluation (SCALE) computer code system, developed at Oak Ridge National Laboratory, is sometimes used by licensees to complete the shielding and criticality evaluations noted above. For thermal evaluations, available computer models include, among others, Fluent by ANSYS, Inc., COMSOL Multiphysics® by COMSOL, Inc., and COBRA-SFS developed by Pacific Northwest National Laboratory. Similarly, several well-established computer programs are available to complete structural and containment evaluations.

Data Inputs and Quality Assurance. All computer models and programs rely on accurate, validated input data reflecting a range of information that may include initial conditions, limiting conditions, and material characteristics. Using accurate input data and starting assumptions are important to ensure accurate results and establish the range of applicability for the computer model or program (i.e., the parameter space over which the model or program provides accurate results). To guide licensees on how to ensure accurate input data, the NRC issued Regulatory Guide 7.10, *Establishing Quality Assurance Programs for Packaging Used in Transport of Radioactive Material*. The quality of data is addressed in Section 3 (Guidance on "Package Design Control"):

> Computer-aided design (CAD) is extensively used in current design applications. Designs developed using CAD methods are prepared and stored electronically. Thus, applicable [quality assurance] procedures that address software verification/validation, management of electronic records, and quality control of electronic data should address the control of electronic data in design applications to ensure authenticity and technical accuracy.

The NRC does not require a specific quality assurance program to be used, but the quality assurance program must meet all requirements of 10 CFR Part 71. However, Regulatory Guide 7.10 does offer an endorsement of one quality assurance program:

> The NRC has also endorsed the use of ANSI/ASME NQA-1-1983, "Quality Assurance Program Requirements for Nuclear Power Facilities," as a standard that, when properly applied and supplemented (as necessary) to meet all applicable criteria, should result in the development of a [quality assurance] program that is acceptable to the NRC staff.

To support its application for a CoC for transportation, the licensee will have to ensure that the computer codes and input data used in the application meet the quality assurance guidance noted above. The quality assurance program must be applied to all input data collected from the waste's point of origin (e.g., a nuclear power plant site) to the point of final disposition. Furthermore, analysts using the computer codes must be shown to be trained and competent in those codes.

Status of Commercial SNF Packages Approved for Transportation. As of June 2019, the nuclear industry has loaded more than 3,000 casks and canisters with more than 129,000 commercial SNF assemblies for dry storage (UxC 2019). Of these loaded casks and canisters, approximately 80 percent are approved by the NRC for both storage and transportation. For these casks and canisters and the SNF they contain, all required analyses are complete and no new computer models/programs are needed.

The remaining 20 percent, comprising 603 casks and canisters, are approved for storage only (as of June 2019). Table A-2 lists the casks and canisters that are approved for storage and loaded with commercial SNF but are not approved for transportation.

Although the systems listed in Table A-2 do not have NRC approval for transportation, some were designed for transportation but the system vendor has not yet begun the licensing process. A discussion of each system or family of systems is provided here:

Table A-2. Summary of Dry Cask Storage Systems With an NRC Storage Certificate but No Transportation Certificate

Vendor	System Designation	Number of Casks or Canisters in Operation
Orano TN	NUHOMS® 07P, 24P, 24PHB, 32P, 32PHB, 32PTH1-2W, and 52B canisters	318
Orano TN	TN-32, TN-40HT bare fuel casks	79
EnergySolutions	Multi-Assembly Sealed Basket (VSC-24 canister)	58
Holtec International	HI-STORM MPC-68M canisters	119
NAC International	I28 S/T bare fuel casks	2
GNS (formerly Gesellschaft für Nuklear-Service mbH)	CASTOR® V/21 and X/33 bare fuel casks	26
Westinghouse	MC-10 bare fuel casks	1
Total		**603**

Data as of June 4, 2019 (UxC 2019; Greene et al. 2013). Note that the total number of canisters includes canisters storing reactor-related, GTCC, low-level waste.

Orano TN—NUHOMS® (canister-based system): Five of the NUHOMS® canister designs listed in Table A-2 (07P, 24P, 24PHB, 32P, and 52B canisters) are older canisters that were designed for storage only. According to a study commissioned by DOE (Leduc 2012):

> [These] NUHOMS canisters are designated by TN as "storage only" canisters. These canisters have certain design features which make for a more difficult licensing process for the transport cask configuration in the transport accident sequence required to be evaluated in 10 CFR 71. Per the cask vendor, licensing of these canisters in transport may still be possible, especially if certain

> burn-up credit is allowed or moderator exclusion under 71.55 was obtained. Currently, the NUHOMs canisters [are] not credited with serving any containment function during transport.

Because these NUHOMS® canisters are similar in design to other NUHOMS® canisters that are approved for transportation, it is assumed that Orano TN possesses the computer programs and analytical tools necessary to support an application for transportation.

The 32PTH1-2W canister design is a variant of the 32PTH1 design already approved for transportation. This variant was required to accommodate the slightly larger fuel design used at the Crystal River and Davis-Besse nuclear power plant sites. Future transportation licensing is planned for this canister design.

Orano TN—Bolted-Lid Casks: The Orano TN bare fuel casks (also known as "bolted-lid casks") that are not approved for transportation are the TN-32 and the TN-40HT. However, given the design similarity between the TN-32 and TN-40HT and other TN casks approved for transportation, and given Orano TN's continued presence in both the storage and transport cask market, it is reasonable to assume that licensing the TN-32 and TN-40HT for transportation remains a possibility (Leduc 2012). Furthermore, Orano TN maintains a proven suite of computer models/programs to support applications for transportation and it is expected that no new computer models/programs will need to be developed to analyze the TN-32 and TN-40HT and their contents.

EnergySolutions—Multi-Assembly Sealed Basket (VSC-24): Although the VSC-24 canister was not originally designed for transportation, EnergySolutions submitted an application to the NRC for a CoC for transportation of the TS125 transportation cask that would hold the VSC-24 canister (UxC 2017). But the NRC had many questions about the license application and the effort was abandoned before completion. However, all analyses suggested by Regulatory Guide 7.9 were completed as part of the EnergySolutions application, and no further computer model development is expected to be needed.

Holtec International—MPC-68M: The MPC-68M canister design is a variant of the transport-approved MPC-68 design. The difference between the designs is that the MPC-68M basket structure and the neutron poison are combined in one material (METAMIC-HT™). Future transportation licensing is planned for this canister design and the relevant computer models are expected to need little or no change.

NAC International—I28 S/T: The NAC International I28 S/T bolted-lid cask is designed for the storage and transport of 28 PWR SNF assemblies. The cask is approved for storage-only use in the U.S. No application requesting approval for transportation has been submitted. However, since the cask is designed for transportation and is similar in design to the NRC-approved NAC-Storage Transport Cask (NAC-STC), it is expected that NAC International is prepared to support an application for transportation (Leduc 2012) and supply the analyses called for in Regulatory Guide 7.9, as discussed above.

GNS—CASTOR® V/21 and X/33: The GNS [formerly Gesellschaft für Nuklear-Service mbH] CASTOR® V/21 and X/33 bolted-lid casks are used to store SNF at the Surry nuclear power plant site. These casks are not approved for transportation. According to Leduc (2012):

> Early fracture toughness concerns at the NRC prevented the licensing for transport of monolithic nodular cast iron casks like the CASTOR casks in the U.S. However, in the last 20 years, European experience with testing, analysis, use and licensing of nodular cast iron casks has garnered international acceptance of this cask type by the International Atomic Energy Agency. Since then the NRC has indicated that they would accept license applications for nodular cast iron shielded casks like the CASTORs. Any such submittal would be a first-time licensing cycle for this cask type and no vendor has yet approached the NRC with a submittal of [an application for a] transport license for this cask type.

Given the lack of technical support for the CASTOR® casks in the U.S., DOE or the affected nuclear utility (Dominion) will have to assess the availability of computer models/programs that can provide the needed analyses to support an application for transportation. If no suitable computer model/program exists, then a new one will have to be developed. Alternatively, the SNF assemblies in the CASTOR® casks could be removed and repackaged into a cask or canister that is approved for transportation.

Westinghouse—MC-10: The MC-10 bolted-lid cask is used to store SNF at the Surry nuclear power plant site. It is not designed or approved for transportation. According to a DOE study (Leduc 2012):

> Shipment of the single Westinghouse MC-10 in dry storage at Surry is also problematic since Westinghouse, although still active in radioactive material packaging, is not an active vendor supplying dry cask storage systems in the U.S. It is unclear whether the work necessary to ship this cask would be more beneficial than repackaging of its contents into a cask system with a licensed transport configuration.

The licensing status of the MC-10 is similar to that of the CASTOR® casks discussed above. If DOE attempts to have the MC-10 approved for transportation, it will have to assess the availability of computer models/programs that can provide the needed analyses to support an application for transportation.

DOE-Managed SNF and HLW. For DOE-managed SNF and HLW, there is a much wider range of variability in waste types, waste packaging, and waste conditions. In some cases, such as the Hanford N-Reactor SNF packaged in multi-canister overpacks (MCOs), evaluations necessary to support an application for transportation have been completed at least once (McCormack 2014). Some of the evaluations of the structural capacity of the MCO will have to be repeated using new data, but the necessary computer models/programs are available.

For the broader range of DOE-managed SNF and HLW, DOE will have to assess existing computer models/programs to determine if they are applicable to the waste forms. If the existing computer models/programs are not applicable, DOE will have to develop new models or programs and identify the appropriate input data to complete the evaluations needed to support an application for transportation of the wastes.

Technical Issue #7. Complete the design, development, and implementation of integrated waste management system analysis and routing tools.

Assumptions, Conditions, Applicability:

a. This issue applies to all wastes under all scenarios.

b. DOE plans to use the system analysis tools to develop alternative approaches for implementing the waste management system (including transportation) and evaluate the alternatives. For final implementation of a transportation program, DOE may need to rely on the expertise of a commercial shipping company with experience in managing very large, integrated shipping operations.

Description: For DOE to manage a nationwide shipping program that includes commercial SNF, DOE-managed SNF, and HLW in an effective and efficient manner, it will need to apply an integrated approach to the effort. To assist in planning the program, DOE has been developing several system analysis tools that are summarized in Table A-3 and discussed in more detail below. The current suite of system analysis tools will assist in planning and designing an integrated waste management system, but DOE will likely have to utilize a separate logistics tool to manage the system's operation, including transporting the SNF and HLW.

Table A-3. DOE System Analysis Tools

Tool	Function
Used Nuclear Fuel Storage, Transportation & Disposal Analysis Resource and Data System (**UNF-ST&DARDS**)	▪ Unified database (including SNF characteristics at an average assembly level) ▪ Analysis of SNF: ◦ Criticality safety ◦ Thermal profiles ◦ Radiation fields
Next Generation System Analysis Model (**NGSAM**)	▪ System architecture analysis; addresses system logistics: ◦ Pool and dry storage ◦ Transportation ◦ Possible consolidated interim storage facility ◦ Repository acceptance
Multi-Objective Evaluation Framework (**MOEF**)	▪ Evaluation (comparison) of alternative system architectures
Execution Strategy Analysis (**ESA**)	▪ System cost and programmatic risk analysis ▪ What-if analysis
Stakeholder Tool for Assessing Radioactive Transportation (**START**)	▪ Transportation route comparison and selection

<u>Used Nuclear Fuel Storage, Transportation & Disposal Analysis Resource and Data System—UNF-ST&DARDS.</u> The UNF-ST&DARDS tool is a comprehensive data and analysis system for evaluating many aspects of SNF management, including SNF pool storage, dry cask loading, dry cask storage, transportation, and disposal. The tool consists of a suite of integrated modules that includes a database of commercial SNF information (the Unified Database) and computer modeling tools such as COBRA-SFS and SCALE/ORIGEN that can be used to conduct criticality, thermal, shielding, and containment analyses of SNF storage and transportation cask systems.

Analysts at ORNL, under contract to DOE, developed the UNF-ST&DARDS as part of a larger suite of tools to assist DOE in analyzing its nationwide waste management system. UNF-ST&DARDS is populated with commercial SNF data from the GC-859 database (previously, the RW-859 database, in the Office of Civilian Radioactive Waste Management). The GC-859 database includes information submitted by the nuclear utilities on Form GC-859, Nuclear Fuel Data, in accordance with Appendix B of the Nuclear Waste Policy Act. The information in the database is extensive, including a wide range of SNF assembly and dry-storage cask or canister characteristics. Also included in the UNF-ST&DARDS database are data regarding dry cask storage systems (overpacks, modules, etc.) for SNF. New data on dry-storage systems have been manually transferred into the database from the relevant Safety Analysis Reports for each of the dry-storage systems. More details about UNF-ST&DARDS and its capabilities can be found in the September 2017 issue of *Nuclear Technology* (ANS 2017).

Until 2017, little public information was available regarding UNF-ST&DARDS. To learn more about the tool, the Board arranged a fact-finding meeting to ORNL in May 2018, to meet with the analysts who developed UNF-ST&DARDS and with DOE representatives. The Board fact-finding team made several observations regarding the development and use of UNF-ST&DARDS:

- Although the configuration and analysis capabilities of UNF-ST&DARDS for applications associated with commercial SNF cask systems are mature, there are substantial gaps in the input data contained in the underlying database. This is because DOE has not collected data from nuclear utilities since 2013. Thus, the database on which UNF-ST&DARDS relies is incomplete and not up to date. For example, sufficiently detailed SNF loading maps (showing SNF assembly locations inside SNF casks or canisters) exist in the database for only 20 percent of all loaded SNF casks and canisters. The ORNL team identified the lack of high-quality data as the biggest challenge for the UNF-ST&DARDS project, and the team is devoting substantial effort to filling in missing data.
- To obtain the needed detailed data on commercial SNF, DOE is working to complete non-disclosure agreements with nuclear utilities and cask vendors. However, this has proved to be a slow process, in some cases hindered by existing contractual agreements (e.g., Standard Contracts).
- The ORNL team is following the quality assurance guidance of DOE in the development and use of UNF-ST&DARDS. However, if UNF-ST&DARDS is to be used to support a license application to the NRC, the associated quality assurance program will have to be upgraded to something equivalent to the American Society of Mechanical Engineers Nuclear Quality Assurance-1 (NQA-1) Standard. Even if the software could be qualified to NQA-1, some of the input data provided by the nuclear industry (e.g., GC-859 database) are not under any quality assurance or quality control programs.
- A significant effort on software verification and validation remains to be completed for UNF-ST&DARDS. Availability of validation data appears to be a limitation in completing this task.
- The GC-859 database does not include information regarding defense and commercial SNF held by DOE (e.g., SNF stored at Hanford, Idaho, and the Savannah River Site)—that information is maintained by DOE's National Spent Nuclear Fuel Program at the Idaho National Laboratory. Furthermore, the CG-859 database does not include information about defense HLW. These data will have to

be considered as DOE plans to implement the nationwide program to transport SNF and HLW.

Next Generation System Analysis Model—NGSAM. NGSAM is a system architecture analysis tool that supports the user (DOE) in examining and evaluating the logistics associated with managing SNF and HLW (Jarrell 2016). It can simulate different waste management scenarios and compare the associated costs, schedules, and infrastructure needs. For example, NGSAM can assist in evaluating the cost versus benefit of implementing an SNF repackaging facility or a consolidated interim storage facility. NGSAM can also be used to determine manpower and time requirements for SNF cask loading operations and transportation operations (via truck, train, or barge).

NGSAM uses data from the UNF-ST&DARDS database. It models dry-storage casks using specific data for each SNF assembly loaded in each cask and it will include thermal modeling of the SNF casks. The NGSAM tool will allow for the addition of a consolidated interim storage facility in its modeling and analysis. Development of NGSAM was initiated at Argonne National Laboratory (ANL) in 2014 and is continuing.

Like UNF-ST&DARDS, little public information about NGSAM is available. Therefore, the Board arranged a fact-finding meeting to ANL in December 2017, to meet with DOE representatives and with analysts who developed NGSAM. The ANL analysts presented information about the design and operation of the NGSAM tool and demonstrated its capabilities. The Board fact-finding team made the following observations:

- Thus far, the NGSAM tool has been limited to modeling the management of commercial SNF. Modeling of DOE-managed SNF and HLW is not included. To date, no significant effort has been made to coordinate with other DOE offices to obtain DOE SNF and HLW information contained in other databases (e.g., the National Spent Nuclear Fuel Program database).
- Fiscal year (FY) 2017 funding for the continued development of the NGSAM tool was significantly reduced, causing the team to stop further development and move into "maintenance mode" by the end of the year. FY 2018 funding was confirmed late in the year, causing further delays in the development of the NGSAM tool.
- DOE participants indicated that the final intended purpose of NGSAM has not yet been determined. There was broad consensus among both DOE and ANL personnel that NGSAM is useful in evaluating alternative designs for a waste management system but is not the correct tool to use to plan or coordinate system operations. For this function, a more appropriate tool would be a commercially available logistics program.
- Although some informal benchmarking and verification checks have been completed for NGSAM, no formal validation has been done so far. The Board team suggested that the tool could be validated against actual SNF transportation experience of the Naval Nuclear Propulsion Program in the U.S., or the experience of Orano (formerly Areva) in France. Development of a verification and validation plan, which currently does not exist, was also suggested.
- Within NGSAM, no automatic feedback mechanism exists. If difficulties or bottlenecks occur in downstream portions of the waste management system (e.g., at the waste repository surface facilities), the analyst must make manual adjust-

ments to the program and rerun the scenario. NGSAM could benefit from incorporating automatic feedback.

- Some of the information used in running NGSAM, such as the timescales required for SNF operations at utility sites, were based on reports prepared for DOE by teams that included companies working in the nuclear industry and facility operators. However, there has been no direct involvement in the development of NGSAM, to date, by nuclear utilities or transportation companies, or review by them, of the assumptions made about the sequencing of operations or the times required for their completion.
- The programming tools underlying NGSAM have been used in other contexts and settings for emergency and disaster planning. Examples of users include health departments, emergency management agencies, and the armed forces. Given this experience, it is likely that NGSAM's developers could incorporate emergency and disaster planning issues into the tool as it is further developed. The ability to assess the implications of different incidents, emergencies, and the like on the waste management system would be useful to planners and decision-makers and would increase the value added of NGSAM.

<u>Multi-Objective Evaluation Framework—MOEF.</u> MOEF "is a set of capabilities, methods, processes, and tools that provide a means to evaluate alternative scenarios and system architectures [for an integrated waste management system] where there are multiple conflicting objectives and differing stakeholder perspectives on a [proposed waste management system]" (Kalinina and Samsa 2016). MOEF takes as input, from the NGSAM tool, different waste management system architectures, or scenarios, and then evaluates them against several measurable objectives (e.g., minimize transporting SNF through heavily populated areas, remove SNF from all shutdown sites first). The MOEF tool is based on Multi-Attribute Utility theory, which is well-established in the business world. MOEF relies heavily on the knowledge and experience of subject matter experts (who can be technical experts, public stakeholders, or others). The five basic steps of MOEF implementation are the following:

1. Identify the stakeholders.
2. Determine the stakeholders' objectives.
3. Assign "performance measures" to each objective.
4. Create a "value function" that assigns a numerical value to each performance measure.
5. Assign weighting factors ("priorities") to each value function, and then add the values for comparison.

DOE has conducted mock evaluations using the MOEF tool to assess the effectiveness of the tool and to understand its strengths and weaknesses.

<u>Execution Strategy Analysis—ESA.</u> The ESA tool includes dynamic simulation software that can perform analyses of schedule risk and cost risk (but not health risk) and what-if analyses to examine alternative strategies for accomplishing SNF management objectives. The ESA tool is used in a closely coupled fashion with the MOEF tool, where the MOEF tool identifies the best possible alternatives based on stakeholder input, and then the ESA tool examines how well each alternative will perform—measured against

several risk factors. According to the lead analysts at ANL, the ESA tool "explicitly models and assesses the impacts of uncertainties (activity durations and costs), constraints (policy, legislation, regulatory), risks (technical, non-technical) and opportunities" in an integrated waste management system (Saraeva et al. 2017).

The ESA tool requires a significant amount of input data related to a particular nuclear waste management approach (sometimes called an "execution strategy"), provided by subject matter experts. This information includes key milestones and activities with associated interdependencies, durations and costs of each activity, and the related uncertainties. All this information is then fed into a dynamic simulation model—GoldSim—that uses Monte Carlo code elements to analyze the many steps (and their associated uncertainties) in a particular execution strategy. By this method, various strategies can be compared side by side and programmatic risks can be identified and minimized. The ESA tool is largely operational and sample runs have been completed.

Stakeholder Tool for Assessing Radioactive Transportation—START. DOE developed START to aid in making decisions about possible transportation routes for SNF and HLW. START is a web-based computer program that uses map-based technology (geographic information systems technology) to identify, evaluate, and select routes for transporting radioactive materials like SNF and HLW.

The maps and data available in START allow the user to evaluate various possible modes of transportation (e.g., rail, truck, barge) and various possible transportation routes throughout the United States. START allows the user to add "overlay" maps onto a base map, showing as many as 35 types of features. These features include, among others, the following:

- Shutdown nuclear power plant sites
- Operating nuclear reactors (commercial and research)
- DOE and other shipping facilities
- Fire departments
- Hospitals
- Highway bridges
- Railroad bridges
- Locations of DOE Transportation Emergency Preparedness Program personnel
- Marine (water) terminals
- Rail freight stations
- Schools
- Intermodal transportation transfer terminals
- Sensitive environmental areas
- Tribal lands

START offers the user tools to help evaluate possible transportation routes. For example, once a starting point and a destination are selected, the user can ask the START program to show possible routes that minimize one of the following parameters:

- Travel time

- Trip distance
- Population exposure (exposure to ionizing radiation from the waste shipment)
- Proximity to environmentally sensitive areas
- Proximity to large gathering areas

Planning and Logistics Experience in Other Countries. Appreciable experience has been gained worldwide in planning, arranging the logistics for, and implementing nuclear waste transportation programs. DOE recently commissioned a study of worldwide experience in transporting SNF (Connolly and Pope 2016). In their report, Connolly and Pope summarize and tabulate worldwide SNF transportation activities and include descriptions of the most significant transportation accidents involving SNF.

Several other resources are available regarding the transportation of SNF overseas. SNF transportation programs exist in the United Kingdom, France, Germany, and Japan, among other countries, and most of the shipping is accomplished by companies such as Orano TN, Edlow International, International Nuclear Services/Pacific Nuclear Transport Limited, and Gesellschaft für Nuklear-Service mbH. These companies have decades of experience in arranging logistics, licensing, and conducting SNF and HLW transportation activities.

A2. Technical Issues Affecting Commercial SNF

A2.1. Scenario 1—Technical Issues Affecting Commercial SNF (if DOE accepts unpackaged, bare SNF assemblies)

Scenario 1 is defined by the "Standard Contract" between DOE and the nuclear utilities (Title 10, Code of Federal Regulations, Part 961 [10 CFR Part 961]). The Standard Contract provides the terms and conditions under which DOE will accept SNF from commercial nuclear utilities. Unless modified, the Standard Contract is based on the premise that DOE will accept bare fuel assemblies from the utilities, have the SNF assemblies loaded into a transportation cask provided by DOE, and then transport the SNF in the DOE casks to either a consolidated interim storage facility or a waste repository.

Under the Standard Contract, SNF assemblies that have been stored in welded stainless steel canisters may not be acceptable as standard SNF. Although the Standard Contract has an allowance for DOE to accept "encapsulated" SNF as a type of "failed fuel," with certain conditions, this allowance applies to "(a)ssemblies encapsulated by Purchaser [the utility] prior to classification [under the terms of the contract]" (Section 961.11, Appendix E). Therefore, SNF in welded canisters, which was loaded after the Standard Contract was signed, may not be acceptable unless the Standard Contract is modified. The technical issues described in this section apply to the scenario (Scenario 1) in which DOE accepts only bare SNF assemblies from the nuclear utilities.

Technical Issue #8. Complete the design, licensing, fabrication, and testing of new SNF packages and transportation equipment on a timescale that supports the transportation schedule.

Assumptions, Conditions, Applicability:

a. This technical issue applies in the case in which DOE decides to design and procure its own bolted-lid (bare fuel) cask system for commercial SNF and does not adopt an existing commercial system that is already designed and approved for use.

b. Because some commercial SNF is stored wet in spent fuel pools and some is stored dry in bolted-lid casks or in welded canisters inside storage overpacks, the new DOE design (or designs) may have to accommodate loading of SNF wet (in the spent fuel pool) and, possibly, dry as part of a new dry repackaging facility (see Technical Issues #9 and #10).

c. For the discussion of this issue, the term "develop," as it applies to an SNF cask system, includes design, licensing (including completion of a Safety Analysis Report), fabrication, and testing (if needed).

Description: Nuclear industry experience shows that the time needed to develop new packaging (e.g., a multi-purpose canister) or transportation equipment (e.g., a transportation overpack) for SNF or HLW can be long, ranging from a few years to more than 10 years. The overall development effort may take a long time for several reasons:

- Extensive safety and security regulations apply to nuclear materials transport, and meeting all the requirements necessitates extensive design work and safety documentation.

- Once an application for a transportation CoC is submitted, the NRC review and approval process may take many years—the time required depends on the complexity of the application.
- The number of suppliers of nuclear-grade materials may be limited and the suppliers may experience delays in the delivery of materials.

As noted above, completing the full development of a new cask system in just a few years may be possible, but this usually occurs for simple systems with simple contents or when the new cask system is a variant of a system that has already received NRC approval for transportation. To illustrate the issue of extended development times (10 years or more) for SNF casks and related transportation equipment, recent experiences from the U.S. Navy, DOE, and the domestic and overseas nuclear industry are discussed below.

<u>U.S. Navy Experience.</u> *M-290 Transportation Cask* (also called a "shipping container" or a "package"). To accommodate longer SNF assemblies from decommissioned aircraft carriers, the U.S. Navy needed an SNF transportation cask that was longer than its existing M-140 cask. The Navy began making plans for the new, larger M-290 transportation cask in 2005 (Schwab 2016). The design, fabrication, and licensing of the cask proceeded in parallel with the development of a new, dedicated railcar to carry the M-290 cask (see below). In May 2013, the Navy submitted safety documentation for the M-290 cask to the NRC and requested an NRC review leading to certification of the cask for transportation (Miles 2013). The NRC completed its review and approved the M-290 CoC for transportation in December 2014 (NRC 2014c). In parallel, the Navy had the M-290 cask fabricated through one of its contracted suppliers. This experience shows that a focused effort by the U.S. Navy, backed by substantial resources and a national security mission, resulted in the development of a new transportation cask for SNF in approximately 10 years.

M-290 Cask Car. The U.S. Navy began its efforts to develop a new railcar to accommodate the M-290 transportation cask in 2005 (Schwab 2016). In 2007, the U.S. Navy contracted with Kasgro Rail Corporation to design, build, and test a new railcar for transporting naval SNF in a Navy M-290 transportation cask (Ketterman 2014). The Navy specified that the new railcar, designated the M-290 cask car, must meet the requirements of the Association of American Railroads (AAR) Manual of Standards and Recommended Practices, Standard S-2043, "Performance Specification for Trains Carrying High-Level Radioactive Material."

In September 2008, Kasgro delivered the first prototype of the M-290 cask car to the Transportation Technology Center, near Pueblo, Colorado, for testing. Following initial testing and modeling, a multiple railcar test with the M-290 cask car was conducted in 2014. In August 2015, AAR granted conditional approval to the Navy to use the M-290 cask car, subject to the requirements of Standard S-2043 (Schwab 2016). The development of the M-290 cask car, from conception to approval, required approximately 10 years.

<u>DOE Experience.</u> DOE is aware of the U.S. Navy's experience in developing the M-290 cask and cask car. Although DOE is not yet developing a transportation cask like the M-290 cask, it is developing a railcar—the Atlas railcar—that is based on the U.S. Navy's M-290 cask car for transporting SNF (Areva Federal Services 2016). Like the Navy, DOE plans to follow the requirements of AAR Standard S-2043 and conduct rail car testing at the Transportation Technology Center in Colorado.

DOE began procurement for its Atlas railcar project in early calendar year 2014 and its schedule forecasts the project, with a certified and operable railcar, will be completed in 2022 (Schwab 2016, 2019). This planned schedule of nine years is similar to that of the Navy's and appears to be realistic given DOE's use of the Navy's design as a starting point.

NAC International Experience. One of the newest commercial SNF storage and transportation designs offered by NAC International is the MAGNASTOR® system, consisting of the MAGNASTOR® Transportable Storage Canister, a storage overpack, a transfer cask, and the MAGNATRAN™ transportation cask. The storage components of the system (e.g., the MAGNASTOR® canisters and storage overpack) are approved for use by the NRC and have been installed and loaded at four commercial nuclear power plant sites (UxC 2019). There is no near-term plan for transporting commercial SNF away from nuclear power plant sites, and NAC International did not seek approval of the MAGNATRAN™ transportation cask on the same schedule as the associated storage components.

NAC International applied to the NRC for a transportation CoC for the MAGNATRAN™ cask in January 2011 (NAC 2011). Due to technical difficulties in the accident analysis supporting the application, the application was withdrawn and resubmitted in November 2012 (UxC 2017). Preparing an application for a transportation CoC and preparing the supporting documentation (e.g., a detailed Safety Analysis Report) is a lengthy process, taking as many as two to three years; so, NAC International began the process well before 2011. On April 5, 2019, the NRC approved the CoC for the MAGNATRAN™. This example shows that for a new transportation cask design, the NRC approval process alone can take more than six years to complete.

KKG Experience. Although the licensing process for SNF storage and transportation casks in Switzerland is not identical to that in the U.S., it is similar, and recent experience by KKG offers a good example of the time needed to develop a new SNF cask. During the Summer 2018 Board Meeting, the Board asked a KKG representative to explain the process needed to develop a new SNF cask (a new modification of the GNS CASTOR® geo series of dual-purpose casks). In response, the KKG representative provided a time breakdown of the entire process, from initial concept in 2013 to expected loading of the SNF in the new casks in 2027 (Whitwill 2018):

> "Year 1 – Feasibility studies for cask design / interface
>
> Year 3 – Issue Request for Proposals (RFP)
>
> Year 4 – Select supplier, negotiate contract, obtain board approval
>
> Year 5 – Start design and licensing work
>
> Year 7/8 – Submission of design to Swiss Federal Nuclear Safety Inspectorate (ENSI)
>
> Year 11 – Licensing completed, commence fabrication of first cask
>
> Year 15 – Delivery of first cask to KKG ready for loading"

Integration Issues: DOE will also have to coordinate closely with the NRC, with a sufficiently long lead time, to ensure that new transportation CoC applications and amendment requests are submitted by DOE (or cask vendors) and processed by the NRC on a schedule that supports DOE's overall transportation plan. This coordination effort may be large in scope, as illustrated by three examples below.

1. *Fabrication of casks and components*. Most NRC-approved SNF transportation casks have not yet been fabricated, and for those that have been fabricated, the vendor still needs to fabricate additional components, such as impact limiters. In the United States, 15 high-capacity commercial SNF transportation casks have been fabricated to date. Thirteen of these (six HI-STAR HB casks and seven HI-STAR 100 casks) are in storage service at ISFSIs. The remaining two (one MP187 and one MP197) have yet to be used for transportation. In the fabrication process, the cask manufacturers are likely to identify modifications or non-conformances that will require amendments or modification to the existing CoC for the SNF transportation casks.
2. *SNF or other contents that are out of specification*. In some cases, already known to DOE, amendments will be needed for existing NRC CoCs for SNF transportation casks. For example, Areva (2017a), which documents the condition of the SNF in dry storage at the Humboldt Bay shutdown site, notes that 44 SNF assemblies do not meet the CoC requirement for minimum initial enrichment of uranium-235. This condition will require an amendment to, or an exemption from, the applicable CoC.
3. *New-design SNF transportation cask systems*. New SNF transportation cask systems may need to be designed and approved by the NRC, depending on the nature of DOE's final overall waste management plan. For example, to improve overall efficiency, DOE may decide to develop a standardized cask system, to be implemented in 20 to 30 years, to transport commercial SNF that is not already packaged. DOE also may decide that existing SNF canisters that were not designed for transportation (e.g., the VSC-24 [see Technical Issue #12]) will need to be overpacked for transportation. In these cases, DOE would have to plan well in advance to ensure proper coordination with the NRC to receive timely NRC approval of the new systems.

As noted by an NRC representative at the Summer 2018 Board Meeting, the NRC would need a three- or four-year advance notice of a request for multiple new CoC applications and amendment requests. This time is needed to develop an NRC budget, on the prescribed timeline of the budget cycle, to request sufficient funding to hire and train the appropriate NRC staff in order to accommodate the needed review and approval actions.

Estimate of the Time It Will Take to Address the Technical Issue: During the Summer 2018 Board Meeting, DOE presented a "Summary Schedule for Transportation" (Boyle 2018). This summary schedule applies to the preparations needed before DOE could begin to transport commercial SNF and it includes a time estimate for selecting and procuring new transportation casks. However, Dr. Boyle noted that legal constraints apply to the plan he presented.[18] DOE's notional schedule for completing all preparations for transporting commercial SNF is seven years, subject to several assumptions noted below. Within the schedule, DOE allotted approximately four years to select and procure a transportation cask.

[18] Dr. Boyle included a legal caveat at the beginning of his presentation: "This is a technical presentation that does not take into account the contractual limitations under the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (Standard Contract) (10 CFR Part 961). Under the provisions of the Standard Contract, DOE does not consider spent nuclear fuel in multi-assembly canisters to be an acceptable waste form, absent a mutually agreed to contract amendment. To the extent discussions or recommendations in this presentation conflict with the provisions of the Standard Contract, the Standard Contract provisions prevail."

DOE's Summary Schedule for Transportation includes several prerequisites and assumptions:

- The seven-year period starts when DOE "stands up" a formal transportation program.
- A facility/destination for the SNF has already been chosen and is ready to receive SNF.
- DOE accepts commercial SNF, as packaged, in dual-purpose (storage and transportation) casks and canisters (see footnote 18).
- DOE will use existing transportation cask designs that have NRC-approved CoCs.
- CoC amendments will be needed in some cases.
- The amendment process (for all casks) will take two years total.
- Fabrication of transportation casks (and associated equipment) is identified as a critical path item that will take approximately three years to complete.
- The schedule includes other administrative steps, such as completing an Environmental Impact Statement for the SNF transportation system, which is identified as one of the longer "critical path" items.
- The schedule does not include a time allowance for dealing with contingencies, such as legal challenges.

As noted above, this DOE estimate includes the selection and procurement of transportation cask systems that are already approved by the NRC for transporting commercial SNF. This notional schedule does not apply directly to the development of a new cask design that DOE may need to use for some commercial SNF (that cannot be transported in existing transportation cask designs) or for DOE-managed SNF and HLW. Therefore, this time estimate of four years to complete procurement of a transportation cask is not indicative of the time needed to develop a new cask system. Given the experiences of the U.S. Navy and commercial nuclear cask vendors, a period of at least 10 years, as a basis for planning, should be allotted for the development of a new transportation cask system. The actual duration will be variable and will depend on the complexity of the design and range of contents envisioned to be shipped in the cask system.

Technical Issue #9. Identify and implement programs for designing, procuring, installing, and operating repackaging facilities and equipment at all sites, as necessary.

Assumptions, Conditions, Applicability:

a. If the Standard Contract is implemented as written (without amendment), this technical issue will apply to all sites that hold commercial SNF in dry-storage casks and canisters but that do not have an operational spent fuel pool or another means of moving SNF assemblies from dry-storage casks and canisters into a new DOE transportation cask.

b. Commercial SNF assemblies that remain in spent fuel pools at nuclear power plant sites can be loaded directly into a DOE-provided cask at the pool, and no new repackaging facility should be needed for those SNF assemblies. However, many nuclear power plant sites operate both a spent fuel pool and a dry-storage facility for SNF. For the SNF in dry storage at these sites, the nuclear utility will need to return the SNF canisters to the spent fuel pool to unload and repackage the SNF.

c. Although DOE has considered developing a pilot-scale or full-scale consolidated interim storage facility for SNF and locating an SNF repackaging facility there, this approach is inconsistent with the Standard Contract (as described at the beginning of this section), because commercial SNF would have to be transported from the nuclear power plant sites in its existing casks and canisters to the interim storage facility for repackaging.

Description: Under Scenario 1 (described above), DOE would deliver new SNF transportation casks to the nuclear power plant sites and the nuclear utilities would load commercial SNF assemblies into the DOE casks. For SNF assemblies stored wet in spent fuel pools, this process is expected to be straightforward, as it will be similar to cask loading operations that have been completed routinely. However, as of June 2019, more than 129,000 SNF assemblies are loaded into more than 3,000 dry-storage casks and canisters (UxC 2019). For these SNF assemblies to be loaded into the new DOE casks, one option, where no spent fuel pool is available, is to repackage them from their existing casks or canisters into the DOE casks using one or more new dry repackaging facilities. Alternatively, where an operational spent fuel pool still exists at the nuclear power plant site, the existing dry-storage casks and canisters could be moved into the spent fuel pool, and the SNF assemblies could be loaded wet into the new DOE casks or canisters. These two methods of repackaging SNF—dry and wet—are described in more detail below.

<u>Dry Repackaging.</u> In the dry repackaging process, the SNF dry-storage cask or canister would be moved from its storage location to a new facility where the SNF assemblies would be transferred dry into a new cask or canister. A spent fuel pool is not needed and the shielding against the radiation emitted by the SNF would be provided by robust shielding instead of deep water, as is found in a spent fuel pool. Ideally, the new repackaging facility would be constructed near the dry-storage location to minimize the distance the SNF has to be moved. The dry repackaging facility would make use of remote operations, where the site worker would operate the facility controls from a location outside a heavily shielded room or cell and remote-controlled equipment would handle the SNF assemblies inside the cell.

In 2012, DOE sponsored a study at the Idaho National Laboratory to evaluate options for the development of a dry repackaging facility (also called a "dry transfer system") for SNF. The study found that 13 dry transfer systems were in use or were planned both in the U.S. and in other countries. These 13 systems included systems that could handle bare SNF assemblies as well as those that could handle SNF canisters only (not bare SNF assemblies; Carlsen and BradyRaap 2012). The study found no significant technical issues that would preclude the development of a dry repackaging facility, but the study did observe that a dry repackaging facility designed "to accommodate a range of potential needs and canister designs, to be deployable at multiple sites, and/or to provide significant throughput capacity will be costly" (Carlsen and BradyRaap 2012).

Wet Repackaging. Wet repackaging involves removing the SNF cask or canister from its dry-storage location and moving it to the spent fuel pool where SNF handling equipment is already installed. The cask or canister would be submerged into the pool and flooded with water, and then the lid would be removed. The SNF assemblies would then be removed and placed temporarily into the spent fuel racks for future transfer into a new cask or canister. This wet repackaging operation would be done in an existing spent fuel pool if the SNF is located at a site where the spent fuel pool is still operational. For SNF stored at shutdown sites or sites without an operational spent fuel pool, the SNF repackaging would have to be done in a new dry repackaging facility as discussed above.

Designing and Building New Nuclear Facilities. Developing and starting up a new nuclear facility such as an SNF repackaging facility is a major undertaking that can cost hundreds of millions of dollars (or more) and take decades to complete. Within DOE, several DOE documents (DOE Directives) lay out the procedures for developing a new nuclear facility to ensure all safety, security, and legal requirements are met.[19] Given the extensive nature of the regulations that apply to nuclear facilities to ensure the protection of public health and safety, the overall process of developing a new nuclear facility is necessarily multi-faceted and detailed.

The U.S. GAO has reviewed, on several occasions, the DOE process for designing, building, and starting up new nuclear facilities. One of these GAO reviews (GAO 2007) examined major nuclear construction projects started by DOE in the late 1990s and early 2000s. The GAO review of 12 of these projects showed that the time elapsed from approving the project to the actual or estimated start-up date ranged from eight to 24 years, with an average of approximately 13 years.

Another GAO report documented examples of cost overruns and schedule delays associated with new DOE nuclear facilities:

> Cost increases ranged from $122 million for the Tritium Extraction Facility to $7.9 billion for the Waste Treatment and Immobilization Plant, and schedule delays ranged from almost 2 years for the Highly Enriched Uranium Materials Facility to over 11 years for the Pit Disassembly and Conversion Facility, with seven projects having schedule delays of 2 years or more. (GAO 2009)

Although some of the nuclear projects reviewed by GAO are much larger than a repackaging facility for commercial SNF, nearly all of the same federal regulations and DOE Directives apply. To develop a new repackaging facility for commercial SNF, DOE would have to follow these regulations and DOE Directives.

[19] DOE Order 413.3B, Change 3, *Program and Project Management for the Acquisition of Capital Assets*, and its associated DOE Guides.

Depending on the location and throughput of the proposed repackaging facility, the total cost to build and start the facility would range from $1 billion to $2 billion (Howard 2013). If the repackaging facility were to be located at an existing commercial nuclear power plant site, amendments to the site's 10 CFR Part 50 operating license and 10 CFR Part 72 storage license would likely be required.

Given the time and cost to develop a new nuclear facility, such as an SNF repackaging facility, significant advance planning will be necessary and the planning will have to begin in time to support the anticipated start of SNF transportation.

Technical Issue #10. Identify and mitigate (if needed) potential adverse effects of repackaging operations on SNF assemblies to ensure the SNF will meet transportation requirements.

Assumptions, Conditions, Applicability:

a. This issue applies to all SNF that must be repackaged from existing dry-storage casks or canisters into new casks or canisters. In Scenario 1, this includes all commercial SNF now stored in casks and canisters. For Scenario 2, see Technical Issues #11, #12, and #13 for reasons repackaging may be necessary.

b. Under the conditions of Scenario 1, the repackaging of SNF would have to occur where the SNF is stored rather than at an interim storage facility or a disposal site, because the latter two cases would require transporting SNF away from storage site in existing casks and canisters, contrary to the conditions of the Standard Contract.

Description: If repackaging of SNF becomes necessary, the repackaging operation can be done either wet or dry. See the descriptions of these two types of repackaging in Technical Issue #9. In either case, the SNF assemblies will be subjected to movement and handling that would not be necessary in a direct transportation scenario (i.e., without repackaging). For repackaging to occur, the SNF casks and canisters would have to be moved, subjecting the SNF assemblies to additional handling loads. The SNF assemblies would also have to be lifted, individually, from existing casks and canisters and moved to new casks or canisters. During the SNF lifting operation, human error or equipment failure could lead to the drop of or damage to SNF assemblies. However, the probability of such an event occurring is minimized by following NRC regulations for equipment design, equipment and personnel qualification, and training and procedures.

Wet repackaging of SNF presents other potential physical challenges to the SNF assemblies. Wet repackaging has been reviewed separately by the NWTRB, the NRC, and DOE, and some concerns have been raised. In 2010, the NWTRB observed the following:

> If dried rods are returned to the reactor pool and if they are still relatively hot, when they are lowered into the water, the rods will experience a rapid quench cool-down. This may induce high stresses in the cladding and possible fuel-rod failure. It also is unknown what effects rewetting may have on the fuel and its future degradation. (NWTRB 2010)

DOE also evaluated the need for future research and development (R&D) activities related to the storage and transportation of SNF. Regarding the rewetting of dried SNF during a wet transfer operation, this evaluation concluded the following:

> If the cask has to be reopened in a pool, the question of rewetting of the [structures, systems, and components] and the effect on material properties becomes paramount. One concern is that pools are typically around 30°C or less, and at those low temperatures additional hydrides will precipitate in the cladding and potentially alter the properties compared to what they were during storage. Another concern is that crud or oxide layers may spall, again affecting the analyses. (Stockman et al. 2014)

However, the NRC guidance suggests that SNF cask or canister unloading operations in a spent fuel pool be analyzed and then conducted in a manner that ensures the integrity of the SNF and cask components and the safety of site workers. NRC NUREG-1536, *Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility—Final Report*, contains guidance for NRC staff who are reviewing the applicant's analysis:

> For unloading operations, the thermal reviewer should ensure that the applicant evaluates temperature and pressure calculations. … To ensure that the cask does not overpressurize and that the fuel assemblies are not subjected to excess thermal stresses, the applicant's analysis should specify and justify the appropriate temperature and flow rate of the quench fluid, assuming maximum fuel cladding temperatures in the unloading configuration. This analysis should also be referenced in Chapter 12, "Accident Analyses Evaluation," of the SAR as having been considered in the development of thermal models for the unloading procedures, and be included, as appropriate, in the technical specifications. (NRC 2010, Section X.5.4.3.)

Because a dry repackaging process does not include rewetting the SNF assemblies, it will not subject the SNF assemblies to the same high thermal gradients. Therefore, there will be less stress in the SNF assemblies and rods, and less chance for damage to the fuel cladding.

Regardless of the repackaging capabilities developed for use, the impacts of repackaging on the SNF assemblies will have to be evaluated and factored into the future transportation, interim storage, and disposal of the SNF.

A2.2. Scenario 2—Technical Issues Affecting Commercial SNF (If DOE Accepts SNF Assemblies Already Packaged in Casks or Canisters)

As described in Scenario 1 above, the Standard Contract (10 CFR Part 961) between DOE and the nuclear utilities is based on the premise that DOE will accept unpackaged, bare SNF assemblies from the nuclear utilities. However, as of June 2019, approximately 90 percent of all SNF in dry storage at nuclear power plant sites is sealed inside welded stainless steel canisters (UxC 2019) and this SNF cannot easily be removed from these welded canisters (see the description of Scenario 1 in Section A2.1).

As an alternative, DOE could design and manage the nationwide waste management system to accommodate commercial SNF that is already packaged in SNF casks or canisters. For the purposes of this report, this alternative approach is called "Scenario 2," to which Technical Issues #11–15 apply.

Technical Issue #11. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to casks or canisters during dry storage that may affect the ability of the casks or canisters to meet transportation requirements.

Assumptions, Conditions, Applicability:

a. DOE will need to resolve this technical issue in the case that the nuclear industry has not already inspected and transported canisters of commercial SNF to a private, consolidated interim storage facility as has been proposed.

Description: Degradation mechanisms deemed to be credible in the steel wall of dry-storage casks or canisters for SNF include pitting corrosion, crevice corrosion, chloride-induced stress corrosion cracking, galvanic corrosion, and microbial-induced corrosion (NWTRB 2010; EPRI 2011). Some of these degradation mechanisms may be weather dependent and location dependent, so they are likely to vary among sites. Furthermore, scratches, scrapes, and dents on cask or canister walls that may occur during movement and placement in storage also can be initiation sites for corrosion or cracking. A crack, or corrosion that may lead to a crack, in the wall of an SNF canister can affect the plans for transporting the canister, particularly in the case in which the crack extends through the canister wall. The implications of a through-wall crack in an SNF canister are described by the NWTRB (2017a):

> During transportation, the SNF canister is loaded into a transportation cask (overpack). The transportation cask performs the functions of holding the canister securely for transport, preventing the release of radioactive materials during normal conditions and most transportation accidents, and providing radiation shielding. NRC regulations applicable to transporting SNF[20] do not require an SNF canister to remain leak-tight. However, if a canister were to leak radioactive material during transportation, the resulting radioactive contamination inside the transportation cask may possibly require cleanup and recovery actions after transportation. Furthermore, the affected SNF canister might not be accepted for storage at the destination storage site without remediation.

Degradation of the metallic seals or bolts in a bolted-lid dry-storage cask may delay transporting the cask until the affected metallic seals or bolts are replaced. In fact, some transportation CoCs require replacement of the lid seals and/or bolts irrespective of

[20] See 10 CFR Part 71.

actual degradation during storage. This issue should not prevent the cask from being transported, but significant planning and coordination will be needed because bolted-lid casks cannot be opened to replace the seals in situ at or near the ISFSI. They will need to be returned to the spent fuel pool for removal of the lid to allow replacement of the seals and/or bolts.

Research and Development. DOE, the NRC, and the nuclear industry (through the Electric Power Research Institute) have focused significant resources on identifying and understanding the potential degradation mechanism that could affect SNF casks and canisters during periods of extended storage and during transportation. The DOE Office of Nuclear Energy, through its Office of Spent Nuclear Fuel and Waste Science and Technology (formerly the Office of Used Nuclear Fuel Disposition R&D), funds research activities aimed at identifying and resolving technical issues that may adversely affect SNF storage and transportation. In 2017, DOE updated its "gap report," which assesses the technical information needs related to extended storage and transportation of SNF, and ranked the technical information needs in priority order to help focus research efforts (Alsaed and Hanson 2017). Many of the gaps, or technical information needs, pertain to degradation mechanisms in SNF casks and canisters.

Chloride-Induced Stress Corrosion Cracking (CISCC). To address specific technical issues related to CISCC in SNF canisters, the DOE Office of Spent Fuel and Waste Science and Technology sponsored research at SNL. This research examined, among other things, salt deposits that can lead to corrosion on the surface of SNF canisters (Bryan and Enos 2015) and weld residual stress that is a key component of CISCC in the walls of SNF canisters (Enos and Bryan 2016). The NRC also conducted research on the phenomenon of CISCC, focusing on the initiation of cracks and on crack growth rates (Caseres and Mintz 2010; He et al. 2014).

Through its Nuclear Energy University Program, DOE sponsored several research efforts to improve understanding of the basic science underlying the phenomenon of CISCC and to develop inspection techniques and equipment for conducting in situ examinations of SNF dry-storage canisters. A few examples include an Integrated Research Project (IRP) awarded in 2011 to a team led by Texas A&M University (McDeavitt 2016), an IRP awarded in 2014 to a team led by Pennsylvania State University (Lissenden et al. 2018), and an IRP awarded in 2015 to a team led by the Colorado School of Mines (final report not published as of June 2019).

DOE also participates in the EPRI-sponsored Extended Storage Collaboration Program (ESCP) that focuses on examining and resolving technical challenges to the extended storage and transportation of commercial SNF. Through the ESCP and related efforts, EPRI has identified research priorities to support the safe storage and transportation of commercial SNF. These research priorities include, among others, corrosion of metallic seals and bolts in bolted-lid casks and CISCC in welded canisters (EPRI 2011). The EPRI ESCP effort also includes a subcommittee on non-destructive examination that is actively developing and testing instrumentation and robotic delivery systems for inspecting SNF dry-storage canisters (EPRI 2016).

Technical Issue #12. Identify and remedy (if needed) types of dry-storage casks and canisters for SNF that are not approved for transportation as noted below:

- ***The cask or canister structural design or neutron absorber structural design does not meet transportation requirements.***
- ***The cask or canister is not yet approved by the NRC (although similar casks or canisters are approved).***

Assumptions, Conditions, Applicability:

a. This technical issue applies to some, but not all, dry-storage casks and canisters that hold commercial SNF. It is important to note that, at the 15 commercial nuclear sites considered to be shutdown sites as of April 2019, all dry-storage canister types in use are welded canister types that are approved by the NRC for both storage and transportation. Therefore, these canisters could be ready to be transported by DOE early when the national transportation campaign begins.

b. This technical issue does not address transportation restrictions that apply to the contents of the casks or canisters—that topic is covered in Technical Issue #13.

c. Because many of the dry-storage casks and canisters holding commercial SNF are currently approved for transportation, this technical issue, by itself, does not preclude DOE from beginning a transportation campaign—DOE can begin to transport the casks and canisters that are approved for transportation while it works to resolve this technical issue.

Description: Many of the existing dry-storage casks and canisters for commercial SNF have been designed and approved for both storage and transportation. However, as of April 2019, approximately 20 percent of all dry-storage casks and canisters loaded with commercial SNF are not approved by the NRC for transportation (UxC 2019; see Table A-2 in Technical Issue #6 for a listing of these casks and canisters). There are three broad reasons for this: (1) the cask or canister was not originally designed for transportation; (2) the cask or canister manufacturer has not yet applied for or not yet received NRC approval for transportation; or (3) the cask or canister (or its contents) has a characteristic that prevents it from meeting the NRC's transportation requirements.[21] The first two of these cases are described further below. The third case is described in Technical Issue #13.

- ***The cask or canister structural design or neutron absorber design does not meet transportation requirements.***

  This technical issue applies primarily to older canister designs that were intended for storage only. For these canisters, repackaging the SNF into a canister capable of transport may be necessary if transport approval cannot be obtained. This will depend on whether the NRC will allow compensatory measures to be utilized in the transport CoC (Leduc 2012). The following are the storage-only canister designs that are in use as of April 2019:

  - Orano TN (formerly Transnuclear, Inc.) NUHOMS® 07P, 24P, 24 PHB, 32P, 32PHB, and 52B canisters
  - EnergySolutions VSC-24 Multi-Assembly Sealed Basket (MSB) canisters

[21] See 10 CFR Part 71.

An example of the challenge in obtaining a CoC for transportation is provided by the EnergySolutions VSC-24 dry-storage system. The VSC-24 was originally approved for storage in 1993, when nuclear utilities still expected near-term removal of SNF from the nuclear power plant sites. As directed by the Nuclear Waste Policy Amendments Act of 1987, DOE was to provide a new cask for SNF, remove SNF assemblies from nuclear power plant sites, and begin disposing of SNF on January 31, 1998. So, at the time the VSC-24 system was deployed, cask vendors and nuclear utilities did not believe they also needed to design dry-storage canisters for transportation.

In SNF dry-storage systems, a nuclear criticality accident[22] caused by water flooding into the welded canister is not considered a credible accident scenario. Therefore, the VSC-24 MSB was designed and built with no neutron absorber material (also called "neutron poison") that would otherwise be needed prevent a nuclear criticality accident if the canister became flooded with water (EnergySolutions 2006). However, the transportation requirements contained in 10 CFR Part 71 stipulate that the licensee must assume that the SNF transportation package becomes flooded with water in a hypothetical accident, regardless of the credibility (i.e., probability) of the accident. Because of this requirement, most SNF casks and canisters in the U.S. were designed and built with neutron absorber materials inside as a control to prevent nuclear criticality.

In 2006, EnergySolutions applied to the NRC for an amendment to the transportation CoC for the EnergySolutions TS125 transportation cask to include the VSC-24 MSB. EnergySolutions tried to make the case that it did not need to include a neutron absorber in the MSB for criticality control because the neutron source from the loaded SNF was too low to support a criticality accident. However, the NRC had many questions about this proposed approach to criticality safety, and the VSC-24 system has not yet been approved by the NRC for transportation.

Similarly, the Orano TN (formerly Transnuclear) NUHOMS® 24P SNF storage canister was designed and built without neutron absorbers. The Safety Analysis Report for storage of the NUHOMS® System (Transnuclear 2004, p. 1.1-1) states, "Unlike the NUHOMS®-07P design, no borated neutron absorbing material is used in the internal basket design of the NUHOMS®-24P [dry-storage canister] for criticality safety." Although the 24P canister is approved by the NRC for storage, it is not approved for transportation.

- ***The cask or canister is not yet approved by the NRC (although similar casks or canisters are approved).***

  Several bolted-lid cask designs and welded canister designs for commercial SNF that were intended to be used for both storage and transportation are approved by the NRC for storage only. In some cases, the manufacturer simply has not applied

[22] A criticality accident can occur under certain physical and radiological conditions. In the case of SNF storage, the necessary conditions for criticality include a sufficiently strong source of neutrons, which can be supplied by the fissile material (e.g., uranium-235 and plutonium-239) inside the SNF; a close-packed geometry of the neutron sources, which can be found in SNF storage casks and canisters; and a sufficient means of neutron moderation (slowing of the neutrons to an optimum energy range to support a critical chain reaction), which would be provided if the SNF cask or canister were flooded with water (water is a good neutron moderator). The NRC enforces, and nuclear utilities implement, strict controls designed to prevent a criticality accident from occurring.

to the NRC for transportation approval. In other cases, the manufacturer has applied for approval, but the NRC review and approval process has not yet been completed. The following casks and canisters fall into these categories:

- Orano TN NUHOMS® 32PTH1-2W canister;
  TN-32 and TN-40HT bolted-lid casks
- Holtec International HI-STORM MPC-68M canister
- NAC International I28 bolted-lid casks
- GNS (Gesellschaft für Nuklear-Service mbH) CASTOR® V/21 and X/33 bolted-lid casks
- Westinghouse MC-10 bolted-lid cask

For the systems listed above, DOE expects that NRC approval of transportation CoCs will be possible to obtain because these systems, or similar systems, have been approved for transportation either in the U.S. or in other countries (Leduc 2012).

Technical Issue #13. Identify and correct (if needed) individual dry-storage casks and canisters with contents or physical conditions that do not meet the requirements specified in the NRC-approved transportation Certificate of Compliance.

Assumptions, Conditions, Applicability:

a. This technical issue applies to some, but not all, dry-storage casks and canisters holding commercial SNF.

b. Because many of the dry-storage casks and canisters holding commercial SNF meet the CoC transportation requirements, this technical issue, by itself, does not preclude DOE from beginning a transportation campaign—DOE can begin to transport the casks and canisters that meet the CoC requirements while it works to address this technical issue.

Description: In the NRC process for approving an SNF cask or canister for transportation, the NRC ensures that the cask or canister meets the requirements of 10 CFR Part 71. Notably, 10 CFR Part 71 specifies limits on the maximum temperature for each transportation cask and limits on the maximum dose rate at the surface (or near the surface) of the cask in both normal and accident conditions. The NRC also issues a CoC applicable to a specific transportation cask (or transportation overpack and canister combination) that provides additional detailed specifications about the types and quantities of SNF that can be transported. These specifications vary for each type of cask or canister approved and can include limits on any or all of the following parameters:

- Type of SNF (PWR or BWR, or even just one specific fuel design)
- Fuel pellet geometry
- Assembly geometry
- Cladding material
- Cladding thickness
- Total mass
- Maximum initial uranium-235 content
- Maximum initial uranium-235 enrichment
- Minimum initial uranium-235 enrichment
- Maximum burnup
- Minimum burnup
- Minimum cooling time
- Assembly decay heat
- Whole container decay heat
- Number of damaged fuel assemblies or number of damaged fuel cans
- Number or mass of individual fuel rods (or pieces of fuel rods)

Although a given cask or canister *design* may be approved for transportation, if the contents of a specific loaded cask or canister are outside the limits of the CoC, then that cask or canister will not be allowed to be transported. The condition or conditions that do not meet the transportation limits will have to be resolved before the affected cask or canister can be transported. Some illustrative examples are provided below.

SNF Decay Heat. A simple (and expected) example of a condition outside the limits of the CoC is a case in which the SNF in the cask or canister has not been cooled for the minimum time required by the CoC. In this case, the licensee will allow more time for the SNF to cool before attempting to transport the cask or canister holding the SNF. However, this approach will lead to delays in the removal of SNF from some nuclear power plant sites, as discussed below.

DOE has examined the trend in SNF dry storage at nuclear power plant sites (Williams 2013). On average, during 2004–2013, the nuclear utilities discharged SNF that has higher burnups (approximately 45 GWd/MTU) than previously discharged SNF and, therefore, is thermally hotter and more radioactive. In addition, the nuclear utilities are loading SNF into larger dry-storage casks and canisters to improve operational efficiency and reduce cost. The largest of these canisters now holds as many as 37 PWR assemblies or 89 BWR assemblies. As a result, these larger casks and canisters are hotter than earlier dry-storage casks and canisters; therefore, they will take longer to cool sufficiently to meet transportation requirements.

DOE estimated that if SNF was repackaged from large casks and canisters into smaller standardized canisters (and using standard assumptions about the operating lifetime of the U.S. fleet of nuclear reactors), DOE could remove SNF from all nuclear power plant sites by approximately 2070. However, if no repackaging occurs, some of the largest SNF canisters storing the hottest SNF would not be cool enough to meet the transportation requirements until approximately 2100 (Williams 2013).

SNF Minimum Burnup Versus Initial Enrichment (Loading Curve). Many transportation CoCs approved by the NRC for casks and canisters used to transport PWR SNF include a requirement that SNF assemblies must have a minimum amount of burnup for a given initial enrichment of uranium (when plotted on a graph, the values of burnup versus initial enrichment create a curve called the "loading curve"). This requirement is established to help preclude a criticality accident during transportation: the higher burnup level in an SNF assembly ensures that more of the fissile uranium-235 has been consumed during reactor operation and, therefore, is not available to fission in a hypothetical accident condition such as a criticality caused by flooding during a transportation mishap. However, many PWR SNF assemblies that have been discharged from commercial nuclear reactors, including some that have been loaded into casks or canisters for storage, do not meet the loading curve requirements applicable to many of the NRC-approved transportation casks.

One of the primary means used by applicants to mitigate this issue is to take credit for certain actinides and fission products that absorb neutrons and that are produced in the nuclear fuel during reactor operations. Because these actinides and fission products absorb neutrons, they lower the reactivity of the fuel (which must be compensated for during reactor operation) and lower the probability of a criticality accident later in the fuel cycle (e.g., during SNF transportation). As nuclear fuel burnup increases, the concentrations of actinides and fission products in the fuel also increase, providing more neutron absorption. Accounting for the neutron-absorbing properties of actinides and fission products in the SNF when performing criticality analyses is called using "burnup credit." The NRC has discussed the loading curve issue and the use of burnup credit for PWR SNF in its Division of Spent Fuel Storage and Transportation, Interim Staff Guidance

(ISG) document, ISG-8, Rev. 3, *Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transportation and Storage Casks* (NRC 2012).

The issues of burnup versus initial enrichment and the use of burnup credit are concerns primarily for PWR SNF and less so for BWR SNF. However, for newer, larger-capacity SNF dry-storage casks and canisters loaded with BWR SNF, this issue will have to be addressed. As noted by the NRC, in ISG-8, Rev. 3:

> [BWR] burnup credit has not typically been sought by dry storage and transportation applicants due to the complexity of the fuel and irradiation parameters, the lack of code validation data to support burnup credit, and a general lack of need for such credit in existing designs. Although the ISG does not provide explicit guidance on BWR burnup credit, criticality analyses which include such credit should be reviewed on a case-by-case basis. (NRC 2012)

Analysts at ORNL have been studying the issue of loading curve restrictions and the use of burnup credit for transporting PWR SNF. They have applied the analysis tools and database included in the UNF-ST&DARDS tool (see Technical Issue #7 for a description of UNF-ST&DARDS) to analyze alternative approaches to the use of burnup credit for PWR SNF (Clarity et al. 2017).

To illustrate the issue, the ORNL analysts plotted the burnup and initial enrichment of PWR SNF assemblies that were loaded into approximately 100 Holtec MPC-32 canisters for storage at eight U.S. nuclear power plant sites (ORNL obtained the data from the DOE GC-859 database, circa 2013). The analysts then added a curve to the plot showing the loading curve requirements for the Holtec MPC-32 canister from the applicable Safety Analysis Report. This loading curve requirement is also reflected in the NRC-approved CoC for the Holtec HI-STAR 100 transportation cask, which is approved to carry the MPC-32 canister. Figure A-1 (adapted from Clarity et al. 2017) shows the results and indicates that approximately half of the PWR SNF assemblies analyzed do not meet the transportation requirements in the HI-STAR 100 without taking some other corrective action. Possible actions that could be taken to mitigate this issue and allow some or all of the SNF to be transported include applying additional burnup credit that accounts for the actinides and fission products in the fuel or presenting a technical justification to the NRC that water cannot enter the welded SNF canister (the moderator exclusion approach). Both approaches would require an amendment to the CoC for the HI-STAR 100 transportation cask.

The full extent of this issue is unclear due to the lack of publicly available information. The ORNL analysts (Clarity et al. 2017) performed criticality analyses for approximately 100 MPC-32 canisters being stored at eight nuclear power plant sites in 2013. As of June 2019, 457 MPC-32 canisters were loaded for storage at 12 sites (UxC 2019) and more MPC-32 canisters continue to be loaded. For the broader population of commercial SNF, the ORNL analysts have noted that, as of May 2018, they had access to sufficiently detailed canister loading data (e.g., canister loading maps showing the exact locations of SNF assemblies) to enable criti-cality analyses for only 556 of more than 2,700 dry-storage casks and canisters.

Note that Figure A-1 shows just one example loading curve: for the Holtec MPC-32 canister to be transported in the HI-STAR 100 transportation cask. Similar loading curves exist for other cask systems that are approved for transporting PWR SNF. DOE or the affected licensees will have to assess the extent of this issue, determine the number and distribution of PWR SNF assemblies that do not meet the CoC's transportation requirements, and implement corrective actions to resolve the issue.

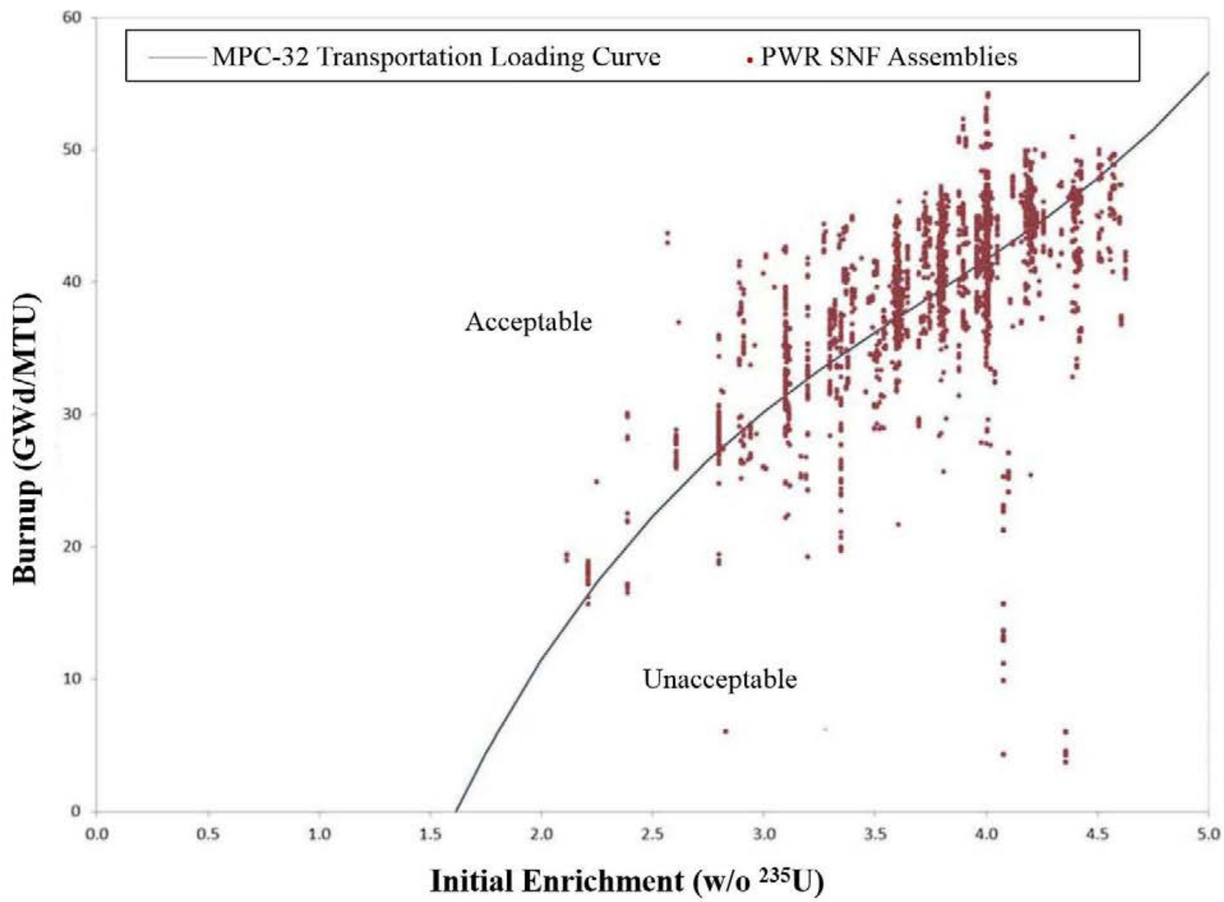

Figure A-1. PWR SNF assembly burnup versus enrichment overlaid on the MPC-32 transportation loading curve.

The data points represent PWR SNF assemblies loaded into Holtec MPC-32 canisters for storage at eight U.S. nuclear power plant sites. Points below the MPC-32 loading curve represent PWR SNF assemblies that are not acceptable for transportation as stored. (Adapted from Clarity et al. 2017)

As illustrated by the preceding examples, the storage conditions of SNF casks and canisters must be verified to ensure that the limits of the corresponding transportation CoCs are met prior to transporting the casks or canisters. DOE has begun to examine the CoC requirements and has completed detailed assessments at six of the 15 nuclear power plant sites shut down as of April 2019. According to a statement by a DOE-NE representative at the Summer 2018 Board Meeting, DOE plans to continue these detailed assessments for all shutdown sites, starting with two more sites in the 2018–2019 timeframe.[23]

If conditions are found that do not meet the requirements of the transportation CoC, DOE (or the CoC holder) will have to address and correct those issues before the affected SNF can be transported.

[23] See the statement of Dr. Erica Bickford, recorded in the transcript of the Summer 2018 Board Meeting (p. 286), http://www.nwtrb.gov/docs/default-source/meetings/2018/june/june-2018-meeting-transcript.pdf?sfvrsn=4, (accessed September 7, 2018).

Technical Issue #14. Identify inspection requirements, procedures, and equipment needed to verify the condition of all casks and canisters before transportation; perform inspections; and rectify identified problems, if needed.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all SNF casks and canisters (under the assumptions of Scenario 2) and must be addressed before the casks or canisters can be transported.

b. This technical issue may have considerable variability associated with it because the inspection requirements imposed by the NRC prior to transporting a cask or canister holding commercial SNF can be different depending on the cask or canister to be transported.

Description: The NRC regulation, 10 CFR Part 71, specifies the requirements for transporting radioactive materials, including SNF. 10 CFR Part 71 includes requirements that apply specifically to the condition of the SNF casks and canisters. To ensure that the SNF casks and canisters meet the requirements of 10 CFR Part 71, DOE will have to check the applicable CoCs and supporting documents (Safety Analysis Reports and Operating Procedures) to verify the requirements and then determine what inspections will be needed.

No casks or canisters of commercial SNF now in dry storage have received full-surface inspections since they were placed in dry storage. Furthermore, there is no equipment fully developed to conduct inspections of 100 percent of the surface of SNF canisters in storage. Prior to receiving approval to transport SNF, DOE will have to identify and develop the necessary inspection equipment and procedures and then conduct inspections of the SNF casks and canisters to be transported. If DOE finds a non-conforming condition that indicates the cask or canister does not meet the CoC requirements, that condition will have to be addressed through means such as repair, replacement, or a request for NRC approval of an amendment to the CoC for transportation that allows the non-conforming condition.

As of April 2019, approximately 40 types of SNF casks and canisters (and variants) were in use that were approved for both storage and transportation (Carter 2016a, 2016b). In addition, approximately 20 types of storage-only casks and canisters (and variants) were in use that may be approved for transportation in the future. Although some of these 60 types of casks and canisters are similar in size and shape, most of them have different lengths, diameters, and weights. For example, lengths range from 2.9 to 5.0 m (115 to 197 in); diameters range from 0.9 to 2.8 m (37 to 110 in); and loaded weights range from 10.0 to 109.8 MT (22,000 to 242,000 lb) (Carter 2016a, 2016b). This large range of physical parameters will have to be accounted for as DOE develops the procedures and equipment necessary to inspect all SNF casks and canisters before transportation.

In anticipation of the need to inspect SNF dry-storage casks and canisters, the nuclear industry has begun to develop inspection equipment. In one broad-based effort to develop such an inspection capability, EPRI, through its Extended Storage Collaboration Program, established a Nondestructive Examination (NDE) Subcommittee to coordinate the research and development work of nuclear industry participants. This EPRI NDE team has been developing inspection procedures, inspection instruments, and robotic delivery systems to be applied to the inspection of SNF dry-storage canisters. A recent summary of these efforts is provided in the EPRI report *Extended Storage Collaboration Program (ESCP): Nondestructive Evaluation (NDE) Subcommittee—Industry Progress Report* (EPRI 2017).

Individual cask vendors, such as Orano TN, Holtec International, and NAC International, have also started to develop inspection equipment. For example, Orano TN has been designing an integrated inspection device that could be used to inspect the full outside surface of an SNF dry-storage canister as it is removed from its dry-storage module. Orano TN proposes that this system would be used as a nuclear utility in transferring SNF canisters from the storage modules into transportation casks in preparation for shipment off site (Donahue 2016). However, this system supports inspections of the surface of SNF canisters only as they are being removed from the dry-storage modules and cannot be used to inspect the canisters while they are inside the modules.

Technical Issue #15. Complete the design, licensing, fabrication, and testing of all needed transportation casks and associated components.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all commercial SNF (under the assumptions of Scenario 2) and must be addressed before the SNF can be transported.

b. The development of a railcar needed to transport SNF casks and canisters is not included in this issue but is covered by Technical Issue #18.

Description: For all commercial SNF in dry-storage casks and canisters, some essential initial steps in preparing for transportation are procuring, fabricating, and assembling at the storage site all necessary transportation equipment. As of June 2019, there is no transportation cask system design for commercial SNF in the U.S. for which all the necessary equipment to support a transportation campaign is available (UxC 2019). In all cases—all transportation system designs approved by the NRC—some or all transportation equipment still needs to be fabricated and delivered to the storage site for use. Depending on the transportation system to be used, major components still to be provided include one or more of the following:

- Transportation cask (sometimes called an "overpack")
- Spacers to be used between the SNF canister and the transportation cask
- Impact limiters that fit on the ends of the transportation cask
- Lifting fixtures for the transportation cask
- Cask-specific cradle that fits on an SNF railcar to hold the transportation cask

DOE has recognized this need and has been evaluating and identifying detailed prerequisites, including equipment needs for transporting commercial SNF (see, for example, Leduc 2012; Maheras et al. 2017; Areva 2017a). As part of the Atlas railcar design (see Technical Issue #18), DOE included the capability to transport all NRC-approved and planned commercial SNF transportation casks. DOE also completed preliminary designs for cask-specific cradles that will be mounted to the Atlas railcar to hold the casks during rail transport.

DOE will have to continue to work with nuclear utilities and cask vendors to ensure that all necessary transportation components and equipment are available and compatible with the Atlas railcar that it is developing to transport SNF. In addition, DOE will have to coordinate closely with the NRC, as described in Technical Issue #8, to ensure the NRC has sufficient advance notice of planned applications or amendments for SNF transportation casks.

A2.3. Technical Issues Affecting Commercial SNF (Regardless of SNF Packaging)

Whether DOE uses the approach of Scenario 1 or Scenario 2, described above, or a combination of the two, DOE will have to address some technical issues common to both scenarios before commercial SNF can be transported to an interim storage facility or a waste repository. Technical Issues #16–18 describe the issues to be addressed.

Technical Issue #16. Identify and mitigate (if needed) degradation mechanisms in commercial SNF occurring over extended periods of dry storage that may affect the ability of SNF to meet transportation requirements.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all commercial SNF in dry storage.

b. This issue must be addressed before commercial SNF can be transported. However, this issue will not preclude the transportation of HLW.

c. This issue must be addressed for both normal conditions of transport and accident conditions during transport, and for transport by rail, truck, and barge.

Description: The Nuclear Waste Policy Act (as amended) directed DOE to remove SNF from commercial nuclear power plant sites and dispose of the SNF at the Yucca Mountain waste repository in Nevada starting in 1998. However, DOE was unable to begin removing SNF from the sites in 1998, and development of the Yucca Mountain project was halted by the Obama Administration in 2010. One consequence of this series of events is that commercial SNF will continue to be stored at nuclear power plant sites much longer than originally anticipated.

Because the commercial nuclear utilities originally expected SNF to be removed by DOE starting in 1998, they did not originally plan for storage capacity beyond that provided by the spent fuel pools. Dry storage of SNF was not expected, nor was extended dry storage of SNF. However, many of the spent fuel pools at nuclear power plant sites began to reach capacity, so the nuclear utilities designed and built dry-storage facilities (called “Independent Spent Fuel Storage Installations”), into which older SNF could be moved to make room in the spent fuel pools for newly discharged SNF.

However, even dry storage of SNF was expected to be a relatively short-term situation, needed only until DOE removed the SNF for disposal. For example, the nuclear utilities did not install monitoring equipment in the dry cask storage systems to measure temperatures or radiation levels. Nor did they incorporate into welded canister designs the capability to monitor the condition of the SNF inside the canisters.

When it became apparent that the SNF would remain in storage for many years longer than originally expected, several organizations evaluated the potential consequences of extended storage. In June 2009, the NWTRB convened a panel of experts to discuss the possible impacts of extended storage of SNF and to identify gaps in knowledge about extended storage. Following the panel discussion, the NWTRB noted in a letter to the Secretary of Energy that “the technical basis for designing and operating dry-storage systems for a very long term warrants improvement” (NWTRB 2009). Several related assessments of SNF extended storage were conducted, including those by the NWTRB (2010), EPRI (2011), and DOE (Hanson et al. 2012). The NRC also modified its regulations to accommodate longer periods of “continued storage” of SNF (NRC 2014b).

The various assessments produced similar results; most identified that the potential SNF degradation mechanisms in need of further evaluation included, among others, the following:

- Corrosion mechanisms in SNF cladding
- Stress-induced SNF cladding creep
- Hydrogen effects in the SNF cladding:
    - Zirconium-hydride reorientation and zirconium-hydride embrittlement of the SNF cladding
    - Delayed hydride cracking in SNF cladding

The nuclear industry has conducted some studies of the condition and behavior of SNF in dry storage. For example, starting in 1984, a monitored dry-storage demonstration program was sponsored by the NRC and EPRI at the Idaho National Environmental and Engineering Laboratory (now the Idaho National Laboratory). This study included monitoring of SNF in dry-storage casks and examination of PWR SNF fuel rods at the end of the demonstration period. The results showed little excess pressurization of the SNF rods and little cladding creep (McKinnon and DeLoach 1993; EPRI 2002). However, this demonstration included only low burnup SNF (maximum burnup of 35 GWd/MTU), and the demonstration spanned only 15 years.

Some uncertainty remains about which SNF degradation mechanisms may be most significant when storing high burnup SNF, or when storing any SNF for extended periods, much longer than 15 years. In the worst cases, the degradation mechanisms noted above could alter the physical condition of the fuel or SNF cladding such that the SNF may not be sufficiently robust to be transported, unless it is overpacked or other compensatory measures are implemented. Therefore, DOE continues to conduct research to gain a better understanding of the effects of storing high burnup SNF and storing any SNF for extended periods.

In 2017, DOE updated its listing of technical information needs applicable to the extended storage and transportation of SNF (Alsaed and Hanson 2017). The updated top research priorities related to the condition of the SNF and SNF cladding were the following:

- Achieving a better understanding of thermal profiles in SNF assemblies
- Achieving a better understanding of stress profiles in SNF assemblies
- Achieving a better understanding of SNF drying processes
- Continuing research into hydrogen effects in SNF cladding, particularly zirconium-hydride reorientation and embrittlement

To address the thermal, stress, and hydrogen effects in high burnup SNF during storage, DOE and EPRI sponsored the High Burnup Dry Storage Cask Research and Development Project (EPRI 2014). However, this dry-storage test began in late 2017 and will last for 10 years, so data about the condition of the SNF after storage will not be available until 2027, at the earliest.

To address questions about the effectiveness of the standard commercial SNF drying process, DOE awarded a grant, through its Nuclear Energy University Program, for the University of South Carolina to lead an Integrated Research Project (Knight 2019). The university team began its research in 2016 and partnered with Areva (now Orano TN) to obtain a prototypical (non-radioactive) Atrium™ 10A BWR SNF assembly to use in a series of drying tests. The tests included measurements of both the temperatures during the industry-standard drying process and the quantity of water remaining after drying. The tests were conducted both with a fuel assembly containing all intact fuel rods and with an assembly containing intact fuel rods and one “failed” fuel rod, which had a small hole drilled into the fuel cladding.

The results showed that, for drying tests that used intact fuel rods, “[a]ll assembly and chamber features were dried during normal industry procedures” (Knight 2019). In tests that included a failed fuel rod, “the failed rod was dried in almost all tests” (Knight 2019). However, the failed fuel rod was not completely dried in some tests, and several questions remain regarding the dryness test used by industry and the amount of water that may remain in an SNF canister after the drying process. Therefore, DOE has been considering additional research on SNF drying to improve its understanding of the process.

As part of its mission to provide oversight of DOE, the Board is evaluating DOE research on the characteristics and behavior of high burnup SNF during extended storage and transportation. As of April 2019, the Board was working on a draft report of its evaluation.

In parallel with DOE’s efforts, the NRC also sponsored research on high burnup SNF to better understand its characteristics and its behavior in storage and transportation. For example, the NRC sponsored testing at ORNL to examine the bending behavior and bending fatigue life of high burnup SNF cladding. The results of these studies have been documented and published (Wang and Wang 2017). The NRC staff is working to interpret the results of this ORNL testing and has published a draft report for comment (NRC 2018). However, the NRC staff’s preliminary conclusions are based on test results from just one type of SNF.[24] The NRC staff noted that testing on other fuel and cladding types would be needed to validate their preliminary conclusions and that DOE is conducting much of this testing as part of its High Burnup Dry Storage Cask Research and Development Project. Furthermore, during the public comment period, the NRC received many comments on its draft report, and a final version of the report is not expected until 2020.

As of April 2019, the results of research sponsored by DOE, the NRC, and the nuclear industry do not indicate that known degradation mechanisms would be severe enough to preclude SNF, including high burnup SNF, from receiving NRC approval for transportation. However, not all fuel types and cladding types have been fully tested, and DOE is continuing related research as discussed above.

Currently approved CoCs for transportation include a requirement that the certificate holder must complete package preparation steps (typically documented in the supporting Safety Analysis Report, Chapter 7, “Package Operations”) prior to shipment of SNF. These preparation steps typically include radiation surveys and temperature surveys of the SNF canister to ensure the SNF inside the canister has not moved or reconfigured during storage, providing assurance that no significant degradation has occurred.

[24] The ORNL testing was performed on pressurized water reactor, high burnup SNF with Zircaloy-4 cladding.

Technical Issue #17. Determine what burnup credit can be taken for all SNF types other than pressurized water reactor SNF (for which burnup credit is allowed by the NRC in its Interim Staff Guidance-8, Rev. 3).

Assumptions, Conditions, Applicability:

a. This technical issue applies to certain commercial SNF, determined on a case-by-case basis.

b. This issue must be addressed before DOE (or a transportation licensee) can use burnup credit in criticality safety analyses to support transportation of many types of commercial SNF. However, this issue will not preclude the transportation of DOE-managed SNF, or HLW.

c. In specific cases, in which moderator exclusion is used to provide criticality safety during transportation, this issue may not apply.

Description: The NRC Division of Spent Fuel Storage and Transportation, ISG-8, Rev. 3, *Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transportation and Storage Casks* (NRC 2012), provides the background and explanation for the concept of burnup credit:

> Title 10 of the Code of Federal Regulations (10 CFR) Part 71, Packaging and Transportation of Radioactive Material, and 10 CFR Part 72, Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste, require that spent nuclear fuel (SNF) remain subcritical in transportation and storage, respectively. Unirradiated reactor fuel has a well-specified nuclide composition that provides a straightforward and bounding approach to the criticality safety analysis of transportation and storage systems. As the fuel is irradiated in the reactor, the nuclide composition changes and, ignoring the presence of burnable poisons, this composition change will cause the reactivity of the fuel to decrease. Allowance in the criticality safety analysis for the decrease in fuel reactivity resulting from irradiation is termed burnup credit. Extensive investigations have been performed both within the United States and by other countries in an effort to understand and document the technical issues related to the use of burnup credit.

To ensure that SNF shipments meet the NRC requirements for preventing criticality during transportation (10 CFR Part 71), the licensee must prove that the shipment remains subcritical under all conditions. This includes the fully flooded condition specified in 10 CFR 71.55(b). One way of demonstrating that an SNF cask meets the requirements for subcriticality is to perform a detailed criticality safety analysis, using proven computer software codes. Among the inputs to the criticality safety analysis is the burnup credit discussed above.

In some cases, the NRC may allow a licensee to take an approach to criticality safety for transportation that demonstrates the transportation package is sufficiently sealed and water-tight so that a fully flooded condition is not a credible scenario, even in an accident. This "moderator exclusion" approach to criticality safety eases the burden of showing that the SNF remains subcritical and burnup credit may not be needed when assuming moderator exclusion. In ISG-8, the NRC addressed burnup credit for PWR SNF. For BWR SNF, ISG-8 states the following:

> The recommendations of this ISG were developed with PWR fuel as the basis. [BWR] burnup credit has not typically been sought by dry storage and transportation applicants due to the complexity of the fuel and irradiation parameters, the lack of code validation data to support burnup credit, and a general lack of need for such credit in existing designs. Although the ISG does not provide explicit guidance on BWR burnup credit, criticality analyses which include such credit should be reviewed on a case-by-case basis" (NRC 2012).

If DOE plans to use burnup credit in the criticality analysis to support the transportation of BWR SNF, then DOE will have to develop a strong technical basis for this approach. Further detail and some specific examples are discussed in Technical Issue #13.

Technical Issue #18.Complete the design, licensing, fabrication, and testing of a commercial SNF railcar (e.g., the DOE Atlas railcar).

Assumptions, Conditions, Applicability:

a. This issue applies to all SNF under all scenarios.

Description: DOE has stated that rail transportation is the preferred mode of transportation for shipments of commercial SNF from nuclear power plant sites to a waste repository (DOE 2004). By extension, it can be expected that the same preference applies to transporting SNF to a consolidated interim storage facility, if one were to be developed. In a few cases, a heavy-haul truck or a barge may be used to move the SNF from the storage site to a trans-loading station where the SNF cask can be loaded onto a railcar for shipment to its destination. Given the reasonably certain need for rail transportation of SNF, DOE began a project in 2014 to design, test, build, and gain approval for an SNF railcar—the Atlas railcar (Schwab 2016).

Both the NRC and the DOT regulate the transportation of hazardous materials, including SNF. The NRC approves SNF transportation packages (casks or overpacks) per the requirements of 10 CFR Part 71. The DOT sets other requirements for transporting hazardous materials in 49 CFR Parts 171–177. Further guidance applicable to railcars carrying SNF is published by the AAR in Standard S-2043, *Performance Specification for Trains Used to Carry High-Level Radioactive Material*. In Standard S-2043, "high-level radioactive material" includes SNF and HLW.

In 2016, DOE completed the preliminary design of the Atlas railcar that will be used to transport commercial SNF (Areva 2016). The Atlas railcar is being designed to transport each of the 17 commercial SNF transportation cask designs that are already NRC-approved or planned to be developed by cask vendors. To accommodate all 17 designs, the Atlas railcar includes four families of cask cradles (sometimes called "skids"). The cradles attach to the railcar, and cask-specific attachment equipment allows each of the 17 transportation cask designs to be securely mounted onto the corresponding cradle (Schwab et al. 2017). Development of the Atlas railcar continues, and DOE estimates that the first Atlas railcar will be ready for use by 2022 (Schwab 2019).

Estimate of the Time It Will Take to Address the Technical Issue: As noted above, DOE plans to complete the Atlas railcar project in 2022.

A3. Technical Issues Affecting DOE-Managed SNF (naval SNF excluded)

Technical Issue #19. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to dry-storage casks and canisters for DOE-managed SNF that may affect the ability of the casks or canisters to meet transportation requirements.

Assumptions, Conditions, Applicability:

a. This technical issue applies to existing dry-storage casks and canisters holding DOE-managed SNF and will have to be addressed unless DOE decides to repackage the SNF into new casks or canisters prior to transport.

Description: This technical issue is the same as Technical Issue #11, which applies to commercial SNF. The technical issue—remediating damage or potential damage to SNF canisters—is the same whether the canister holds DOE-managed SNF or commercial SNF. In all cases, the potential for general corrosion, pitting corrosion, stress corrosion cracking, and other physical damage is present and will have to be addressed.

Most of the DOE-managed SNF stored at the Hanford Site is packaged in storage containers similar to those used for commercial SNF. At Hanford, the MCOs and Shippingport Spent Fuel Canisters (modified MCOs) are made of Type 304L stainless steel (Garvin 2002b), which is the same as or similar to the stainless steel used for commercial SNF canisters. Another similarity is that the top and bottom closures are welded shut. These features (304L stainless steel and closure welds) can make the canister susceptible to chloride-induced stress corrosion cracking.

At the Fort St. Vrain site in Colorado, DOE stores SNF that was used in the Fort St. Vrain commercial nuclear power reactor. The Fort St. Vrain SNF is stored dry in canisters made of carbon steel (NRC 2014a). The carbon steel canisters are susceptible to general corrosion, pitting corrosion, crevice corrosion, and physical damage, but not chloride-induced stress corrosion cracking.

Other DOE-managed SNF at Hanford, the Idaho National Laboratory, and the Savannah River Site is stored as bare fuel assemblies, in temporary containers, or in bolted-lid casks. If this SNF is not processed (e.g., treated at the H-Canyon Facility at the Savannah River Site [SRS] or at the Fuel Conditioning Facility at INL), then it will have to be packaged for transportation and disposal. Therefore, the issue of canister corrosion does not apply to this SNF.

For more details about this issue, see Technical Issue #11.

Technical Issue #20. Complete existing designs, or develop new designs, for multi-purpose SNF canisters and complete the licensing, fabrication, and testing to accommodate all DOE-managed SNF that will not be processed at the Hanford Site, the Idaho National Laboratory, or the Savannah River Site.

Assumptions, Conditions, Applicability:

a. This technical issue applies to non-naval DOE-managed SNF, including the following:
    - SNF at Hanford that is not already packaged in MCOs or Shippingport Spent Fuel Canisters (modified MCOs)
    - SNF at INL that will not be processed at the Fuel Conditioning Facility
    - SNF at SRS that will not be processed at the H-Canyon Facility

b. This issue must be addressed before DOE-managed SNF can be transported off site. However, this issue will not preclude shipping commercial SNF or HLW.

Description:

DOE Standardized Canister (also known as the "standardized DOE SNF canister"). For several years, DOE has been sponsoring research and design work on a standardized, multi-purpose (storage, transportation, and disposal), SNF canister called the "DOE standardized canister." This canister is intended to accommodate many types of non-naval, DOE-managed SNF for storage, transportation, and disposal. DOE has yet to finish research and development activities for the DOE standardized canister that will be needed to support the design of any packaging facility DOE develops. DOE still 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 for canisters containing SNF with high fissile isotope concentrations (NWTRB 2017f). DOE may decide that the DOE standardized canister will be used for non-naval, DOE-managed SNF that is not already packaged. If not, the SNF types discussed below will need to be considered when developing and licensing a new SNF canister.

Hanford Site. DOE stores approximately 2,135 metric tons of heavy metal (MTHM)[25] of SNF at the Hanford Site in Washington State. This represents the largest inventory (by mass) of DOE-managed SNF in the nation. Approximately 2,105 MTHM of this SNF is defense-origin SNF, mostly from the N-Reactor at Hanford. This SNF has been packaged, dried, and stored in welded stainless steel containers called "MCOs." DOE also stores approximately 16 MTHM of Shippingport Core 2 blanket fuel in Shippingport Spent Fuel Canisters (modified MCOs). The MCOs and Shippingport Spent Fuel Canisters are designed for storage, transportation, and disposal. DOE can finish preparing these canisters for transportation by completing the licensing process and identifying a transportation cask (see Technical Issue #22).

The remainder of the 2,130 MTHM of SNF at Hanford—approximately 14 MTHM—is SNF from various commercial, test, and research reactors (Garvin 2002a). DOE stores this SNF in a variety of dry-storage casks and canisters placed in shielded overpacks on

[25] 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 masses of other constituents of the fuel, such as cladding, alloy materials, and structural materials, are not included. A metric ton is 1,000 kilograms, which is equal to about 2,200 lb.

a concrete pad called the "200 Area Interim Storage Area." Specifically, approximately 10 MTHM of SNF from the Fast Flux Test Facility are stored in steel containers called "Core Component Containers," approximately 2 MTHM of commercial power reactor SNF (both PWR and BWR SNF) stored in NAC-1[26] casks, less than 1 MTHM of Los Alamos Molten Plutonium Reactor Experiment SNF are stored in an EBR-II shielded cask, and less than 1 MTHM of TRIGA® [27] reactor SNF from the Neutron Radiography Facility at Hanford and the TRIGA® reactor at Oregon State University are stored in DOT-6M[28] containers and TRIGA® casks (Garvin 2002a).

Some of these casks and canisters were, or still are, approved for transportation. However, these casks and canisters are not designed for disposal and they hold small quantities of SNF, typically no more than two SNF assemblies. To transport all non-MCO-packaged SNF off site for interim dry storage or disposal, the SNF must be retrieved from storage, repackaged, and dried.

Idaho National Laboratory. DOE manages and stores approximately 325 MTHM of SNF in 10 facilities under both wet and dry conditions at three INL locations: the Idaho Nuclear Technology and Engineering Center, the Materials and Fuels Complex, and the Naval Reactors Facility. In addition, small quantities of SNF are managed at the Advanced Test Reactor fuel canal at the Reactor Technologies Complex. The 325 MTHM of SNF at INL includes approximately 28 MTHM of naval SNF and approximately 297 MTHM of non-naval SNF (NWTRB 2017f). DOE also stores approximately 15 MTHM of commercial SNF at the decommissioned Fort St. Vrain nuclear power plant site, and this fuel will eventually be transported to INL for final packaging and transportation to an interim storage site or a waste repository (NWTRB 2017f).

One type of SNF at INL that will not need to be packaged for transportation is sodium-bonded SNF. Sodium-bonded SNF contains elemental sodium between the fuel cladding and the fuel material. The sodium-bonded SNF at INL came from three sources: the Fermi-1 Breeder Reactor in Michigan; the Experimental Breeder Reactor-II at INL; and the Fast Flux Test Facility at the Hanford Site in Washington State (DOE 2006). The sodium-bonded SNF will be processed using an electrometallurgical treatment process at the Fuel Conditioning Facility at INL (DOE 2006). See Technical Issue #28 for details about the waste streams produced by this treatment process.

None of the non-naval SNF at INL is packaged and approved in a manner that is ready for transportation to an interim storage facility or a disposal facility. A few types of non-naval SNF at INL are packaged in containers that were previously approved for transportation or were designed for transportation but have not yet received NRC approval for transportation. These fuel types and corresponding containers include the following:

- Three Mile Island Core-2 debris in 29 Transnuclear NUHOMS® 12T storage and transportation canisters
- SNF from the R.E. Ginna commercial nuclear power plant that is stored in a TN-REG transportation cask on a railcar

[26] NAC was called the "Nuclear Assurance Corporation" and is now NAC International.
[27] Training, Research, Isotopes, General Atomics (reactor).
[28] DOT is the Department of Transportation, and the DOT-6M container meets the requirements of the DOT regulations: 49 CFR Parts 171-177.

- SNF from the Big Rock Point commercial nuclear power plant that is stored in a TN-BRP transportation cask on a railcar

For these SNF types, DOE will need to complete the approval process by applying to the NRC for new or renewed transportation CoCs.

For all other non-naval SNF to be transported off site for interim dry storage or disposal, the SNF must be retrieved from storage, packaged, and dried. If not using the DOE standardized canister or an existing commercial SNF cask or canister design, DOE will have to design, fabricate, test, and gain NRC approval of a new cask or canister design.

Savannah River Site. DOE stores approximately 30 MTHM of SNF at the 105-L Basin facility (L Basin) at SRS in South Carolina. Except for some small quantities of SNF in dry storage, all SNF is stored in a water-filled pool at the L Basin. The SNF inventory at SRS includes more than 30 varieties of fuel types, including aluminum-clad SNF as well as zirconium alloy-clad and stainless steel-clad SNF. Most SNF comes from domestic research and test reactors and foreign research reactors (Sindelar and Deible 2011). DOE continues to receive research and test reactor SNF at the L Basin for storage.

As of May 2018, storage for test reactor SNF in the L Basin was approximately 80 percent full, with approximately 3,000 of 3,650 storage spots filled (Maxted 2018). Another area of the L Basin is designed to store SNF cores from the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory. The HFIR SNF storage area is filled to 90 percent capacity (108 of 120 positions filled) as of May 2018 (Maxted 2018).

To make room in the L Basin facility so that DOE can continue to receive research and test reactor SNF, DOE issued an amended Record of Decision for the Environmental Impact Statement regarding SNF management at SRS (DOE 2013b). The amended Record of Decision states that DOE will remove from the L Basin as much as 3.3 MTHM of the projected inventory of 22 MTHM of aluminum-clad SNF and process the SNF at the site's H-Canyon Facility (DOE 2013b). The 3.3 MTHM includes as many as 200 HFIR SNF cores and approximately 1,000 bundles of aluminum-clad SNF.

None of the SNF at SRS is currently packaged in a manner that will support off-site transportation. To be transported off site for interim dry storage or disposal, aluminum-based SNF that is not processed at H-Canyon as mentioned above and all non-aluminum-based SNF must be retrieved from the L Basin, packaged, and dried. If not using the DOE standardized canister or an existing commercial SNF cask or canister design, DOE will have to design, fabricate, test, and gain NRC approval of a new cask or canister design.

This technical issue is nearly identical to Technical Issue #8.

Technical Issue #21. Complete a new analysis to validate the structural integrity of the Hanford multi-canister overpack (MCO) design to support NRC approval of the MCO for transportation.

Assumptions, Conditions, Applicability:

a. This technical issue applies to SNF at Hanford that is packaged in MCOs or Shippingport Spent Fuel Canisters (modified MCOs).

b. This issue must be addressed before the MCO-packaged SNF at Hanford can be transported off site. However, this issue will not preclude transporting SNF or HLW from other locations.

Description: DOE stores approximately 2,105 MTHM of defense-related SNF in 394 MCOs and 16 MTHM of SNF from the Shippingport reactor in 18 Shippingport Spent Fuel Canisters (modified MCOs) at the Hanford Site. The NWTRB (2017f) describes DOE's efforts to analyze these containers in preparation for transportation and disposal:

> DOE designed these containers for on-site storage, off-site transportation, and disposal at the Yucca Mountain repository. DOE has not completed repository facility design details, probabilistic event sequence categorization analyses, and criticality analyses that are necessary to demonstrate compliance with 10 Code of Federal Regulations Part 63 for event sequences involving a low probability drop and breach of these containers at the repository (DOE 2009). DOE was developing the necessary information to demonstrate that the MCOs would not breach during a drop at the repository when the project was put on hold (Carlsen 2014). The NRC's safety evaluation of DOE's repository license application (NRC 2015) stated that DOE may not, without prior NRC review and approval, accept DOE SNF in these containers at the Yucca Mountain repository. In addition, the NRC (2015) noted that DOE will need to provide information "that confirms that the current pre-closure safety assessment bounds the intended performance of the waste packages and canisters at the geologic repository operations area." Alternatively, DOE will need to provide information "that demonstrates, through the pre-closure safety assessment, that these waste packages and canisters can be safely received and handled at the repository during the pre-closure period" (NRC 2015) [in-text citations are from source].

The remaining work to be done by DOE is also described by the NWTRB (2017f):

> The remaining developmental work for the MCOs is focused on survivability from off-angle drops during handling operations at a repository (i.e., pre-closure safety) and off-site transportability (McCormack 2014; Carlsen 2014). The National Spent Nuclear Fuel Program identified several key findings and recommendations for dealing with off-angle drops during the pre-closure period (e.g., an MCO-specific fragility curve should be developed). However, the program was put on hold prior to any actions on the recommendations (Carlsen 2014). The National Spent Nuclear Fuel Program also completed scoping analyses for transporting the MCOs offsite. These analyses included structural analyses for transporting the MCO and steady state thermal analyses for a hypothetical MCO transportation cask [in-text citations are from source].

Technical Issue #22. Define the transportation cask(s) to be used for DOE-managed SNF.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all non-naval DOE-managed SNF.

b. This issue must be addressed before non-naval DOE-managed SNF can be transported. However, this issue will not preclude transporting commercial SNF or HLW.

Description: For many years, DOE has been shipping small quantities of SNF, both domestically and from other countries, using relatively small transportation casks (e.g., NAC-LWT, which normally holds no more than one SNF assembly). The SNF that DOE transports includes domestic and foreign research reactor SNF and various, small quantities of SNF intended for post-irradiation examination at DOE laboratories. DOE has not developed a large-capacity transportation cask that can efficiently support a nationwide campaign for shipping DOE-managed SNF.

When it was preparing to transport non-naval SNF to a waste repository in the 1990s and 2000s, DOE developed a design for a "DOE standard canister" that would have been a welded, thin-walled, multi-purpose canister, intended to be used with an overpack for storage and a different overpack (cask) for transportation (DOE 2009). Eventually, the canister would have been disposed of without having to remove the SNF from the canister. Although DOE advanced the design of the DOE standard canister sufficiently to support its license application for the Yucca Mountain project, no canisters were built. Furthermore, DOE did not develop a corresponding transportation overpack (cask) beyond a basic, pre-conceptual design.

For transporting naval SNF, the U.S. Navy has developed and is using a new transportation cask (called the "M-290 cask"). The Navy intends to use the M-290 cask for future transportation needs, including shipping naval SNF to a waste repository, when one is available (Miles 2016).

DOE will have to decide what transportation cask design it will use to most efficiently and effectively support its nationwide campaign for transporting DOE-managed SNF. The issue of designing, fabricating, and licensing a new-design transportation cask is captured by Technical Issue #23.

Technical Issue #23. If not using an existing transportation cask, then design, license, fabricate, and test a new transportation cask for DOE-managed SNF.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all non-naval DOE-managed SNF.

b. This issue must be addressed before non-naval DOE-managed SNF can be transported. However, this issue will not preclude transporting commercial SNF or HLW (unless DOE will use the same transportation cask for these wastes).

Description: This issue is identical to Technical Issue #8 for commercial SNF because all the steps necessary to develop a cask for DOE-managed SNF will be the same as the steps necessary to develop a cask for commercial SNF. For details about designing, fabricating, testing, and licensing a new SNF transportation cask, see Technical Issue #8.

To transport naval SNF, the U.S. Navy has developed and is using a new transportation cask (called the "M-290 cask"). The Navy intends to use the M-290 cask for future transportation needs, including shipping naval SNF to a waste repository, when one is available (Miles 2016).

A4. Technical Issues Affecting DOE-Managed HLW

Technical Issue #24. Identify and correct (if needed) damage, or mitigate degradation mechanisms leading to damage, to dry-storage canisters for DOE-managed HLW that may affect the canisters' ability to meet transportation requirements.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all current canisters holding DOE HLW.

b. This issue must be addressed before DOE HLW can be transported. However, this issue will not preclude transporting SNF.

Description: DOE manages HLW in liquid form, solid form, or both, at four DOE sites: the Hanford Site in Washington, INL in Idaho, SRS in South Carolina, and the West Valley Demonstration Project (West Valley) in New York. Three of these sites—INL, SRS, and West Valley—store HLW that has been treated and solidified, and of these, only West Valley and SRS have packaged the solidified HLW in welded stainless steel canisters that are designed for storage, transportation, and disposal.

At West Valley, liquid HLW was incorporated into a molten borosilicate glass that was poured, while hot, into stainless steel canisters (this process is called "vitrification"). After the glass cooled and solidified, steel covers were welded onto the top of the canisters. DOE processed and packaged HLW at West Valley from 1996 to 2002 and produced 275 HLW canisters. The West Valley HLW canisters are made of 304 stainless steel, are 61 cm (24 in) in outside diameter, and are 300 cm (118 in) tall (Eisenstatt 1986).

At SRS, DOE began vitrifying HLW at the Defense Waste Processing Facility (DWPF) in 1996. This process is the same as the process used at West Valley. DOE expects to continue to vitrify HLW at DWPF until 2038 (Chew and Hamm 2016). The DWPF HLW canisters are made of 304L stainless steel, are 61 cm (24 in) in outside diameter, and are 300 cm (118 in) tall (Baxter 1988). As of November 2018, DWPF has produced 4,173 HLW canisters (Cantrell 2018).

At the Hanford Site, DOE has not yet started to process HLW and package it into canisters for storage, transportation, and disposal. However, DOE plans to vitrify liquid HLW in a process similar to that used at West Valley and SRS and package the HLW glass into stainless steel canisters that will be 61 cm (24 in) in outside diameter and 457 cm (180 in) tall (Jantzen 2013). Early planning by DOE indicates that the Hanford HLW Vitrification Facility, which is under construction, will produce approximately 10,500 canisters through the end of tank waste processing in 2047 (ORP 2014).

At INL, DOE plans to process liquid tank waste, called "sodium-bearing waste," using a fluidized bed steam reforming process (a process known as "calcining"). DOE plans to package the resulting solid waste product in stainless steel canisters that will be welded shut. Preliminary plans by DOE's contractor at INL assume this waste will be classified as remote-handled transuranic waste, which will be disposed of at the DOE Waste Isolation Pilot Plant. However, DOE has not made a final decision regarding the classification of the sodium-bearing waste, and it is possible the waste may be classified as HLW.

Finally, also at INL, DOE manages another stream of HLW, called “calcine waste,” that was produced following SNF processing at the Idaho Chemical Processing Plant (now the Idaho Nuclear Technology and Engineering Center). The calcine HLW is stored in six sets of stainless steel silos (called “bin-sets”; see Technical Issue #26). DOE plans to retrieve and repackage the calcine waste into new canisters suitable for transportation and disposal off site. DOE has not yet determined the design of the canister to be used for the calcine waste, but based on all other HLW canister designs, it will likely be made of welded stainless steel.

For the HLW canisters at West Valley and SRS, this technical issue is the same as Technical Issues #11 and #19, which apply to commercial SNF and DOE-managed SNF, respectively. The technical issue—remediating damage or potential damage to canisters—is the same whether the canister holds commercial SNF, DOE-managed SNF, or DOE HLW. In all cases, the potential for general corrosion, pitting corrosion, stress corrosion cracking, and other physical damage is present and must be addressed.

For Hanford and INL, no HLW canisters have been produced, but some may be produced before DOE begins a nationwide campaign to transport SNF and HLW (e.g., DOE plans to process and package sodium-bearing waste at INL as soon as the associated processing facility is ready—DOE has not provided a start-up date, but the Board estimates that processing could start by 2020 or 2021). For the HLW canisters to be produced at Hanford and INL, DOE has the opportunity to take action to preclude damage and degradation to the canisters, or, in some cases, to choose a canister design that is more resistant to certain degradation mechanisms.

Technical Issue #25. Finalize the decision on whether the sodium-bearing waste at the Idaho National Laboratory is remote-handled transuranic waste or HLW.

Assumptions, Conditions, Applicability:

a. This technical issue applies only to the sodium-bearing waste at INL.

b. This issue should be addressed before DOE begins processing and packaging the sodium-bearing waste. The issue must be addressed before the waste is transported to a disposal site, because the classification of the waste directly affects its disposal location.

c. This issue will not preclude transporting SNF or HLW at other locations.

Description: DOE manages approximately 3,400 m^3 (900,000 gal) of liquid radioactive waste in three underground tanks at INL. This waste is a byproduct of INL SNF reprocessing, which ended in 1992 (Wagner 1999). Although this waste was previously managed as HLW, its processing history and relatively low radionuclide content have led DOE to consider the possibility that the waste can be managed as remote-handled transuranic (TRU) waste rather than HLW (Case 2012a). Because the waste may not be classified as HLW, and because it contains a relatively high concentration of sodium, DOE calls the waste "sodium-bearing waste."

DOE's planned approach for the disposition of the sodium-bearing waste is to treat the waste using a fluidized bed steam reforming process (DOE 2005). The resulting waste form will be a dry, granulated powder that DOE plans to package in welded stainless steel canisters. According to DOE's Record of Decision for the *Idaho High-Level Waste and Facilities Disposition Final Environmental Impact Statement* (DOE/EIS-0287):

> The Department's preferred disposal path for this waste is disposal as TRU waste at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico. Until such time as the regulatory approvals are obtained and a determination that the waste is TRU is made, the Department will manage the waste to allow disposal at WIPP or at a geologic repository for spent nuclear fuel (SNF) and HLW. (DOE 2005)

DOE's process for classifying the waste as TRU waste includes several steps, which could be completed concurrently. First, DOE must complete a "waste determination" process per the requirements of DOE Order 435.1, *Radioactive Waste Management*. In this process, DOE can classify the sodium-bearing waste as "other than HLW" (i.e., classify it as low-level radioactive waste or TRU waste), if the waste meets certain conditions. Because of the relatively high concentration of transuranic elements in the sodium-bearing waste, it cannot meet the requirement for the definition of low-level waste and would be classified as TRU waste in this process.

Second, DOE would need to ensure the final waste form meets the WIPP Waste Acceptance Criteria. For example, the waste must be shown to have been generated by "atomic energy defense activities" and meet the definition of TRU waste, which is waste that contains more than 100 nanocuries per gram of waste of alpha-emitting TRU isotopes with half-lives greater than 20 years (DOE 2016).

Other restrictions apply. Most notably, the WIPP Land Withdrawal Act, P.L. 102-579, as amended by P.L. 104-201, restricts waste disposal at WIPP as follows: "The Secretary shall not transport high-level radioactive waste or spent nuclear fuel to WIPP or emplace or dispose of such waste or fuel at WIPP."

The restriction against the disposal of SNF and HLW is also codified in the WIPP Hazardous Waste Facility Permit granted by the State of New Mexico. The State of New Mexico's authority to regulate the hazardous waste at WIPP is established in the New Mexico Hazardous Waste Act and the Resource Conservation and Recovery Act. Allowing waste that had been managed as tank waste would likely require a high-level permit modification (called a "Class 3 Permit Mod").

Although the need for a decision about the classification of the sodium-bearing waste has been known since 2005, DOE has yet to complete the associated administrative process and finalize the decision. Since 2005, several outside organizations have highlighted the importance and urgency for DOE to finalize this decision. For example, the NWTRB noted the following in a December 11, 2012, letter to DOE (NWTRB 2012):

> The Board believes that it would be prudent to formalize the classification of [sodium-bearing waste] prior to processing to ensure that it meets the applicable final disposal requirements. The Board notes, however, that should the management decision change, it may become necessary to modify the [sodium-bearing waste] form so that it can be accepted at a geologic repository for HLW and SNF. In this case, a more detailed knowledge of the properties of the waste form may be required.

More recently, in September 2017, the Energy Communities Alliance (an organization composed of representatives from communities adjacent to DOE waste management sites), published a report entitled *Waste Disposition: A New Approach to DOE's Waste Management Must Be Pursued* (ECA 2017). The report describes the perceived obstacles to waste cleanup at the DOE sites and prioritizes several actions DOE should take to expedite the cleanup. Among the recommendations offered, one states the following:

> A number of pilot projects and near-term term waste management initiatives should be given priority and pursued as soon as possible in order to better understand alternative approaches and inform future policy decisions. These include:
>
> …
>
> o A waste determination for Idaho Sodium-Bearing Waste
>
> …

DOE's final decision regarding the classification of the sodium-bearing waste will directly affect the waste form requirements, the packaging requirements, and the location of final disposal. These considerations make it important for DOE to finalize the classification decision as soon as possible to allow time for adequate planning before the waste can be transported.

Technical Issue #26. Complete the development and deployment of any required treatment process for calcined HLW at the Idaho National Laboratory.

Assumptions, Conditions, Applicability:

a. This issue applies only to the calcined HLW stored at INL.

b. This issue must be addressed before the calcined waste can be transported, but the issue will not preclude beginning shipments of SNF or other types of HLW.

Description: HLW generated at INL was stabilized by calcining (i.e., converted from a liquid to granular solids). The HLW was the waste product of reprocessing SNF to recover uranium-235, krypton-85, and other fission products (Todd et al. 1993). The SNF was reprocessed from 1952 to 1991 and the resulting liquid HLW was calcined from 1963 to 2000. Calcined HLW is a dry, granular material with particle diameters typically in the range 0.3–0.7 mm (0.01–0.03 in) (Staiger and Swenson 2011), a size range like that of coarse sand. Approximately 4,400 m^3 (160,000 ft^3) of calcined waste are stored in six sets of stainless steel silos (called "bin-sets"). The Idaho Settlement Agreement requires that the calcined waste be ready for disposal outside the State of Idaho by December 31, 2035 (Idaho et al. 1995). More details on the calcined HLW at INL can be found in the Board's Fact Sheet, *Calcined High-Level Radioactive Waste* (NWTRB 2017b).

Prior to shipment off site, the calcined waste must be removed from the six bin-sets, treated, and packaged for transportation. In December 2009, DOE selected a hot isostatic pressing process as the preferred alternative for treating the calcined waste (DOE 2010). In hot isostatic pressing, the waste material is placed in a sealed container and pressed at high temperature (1,050–1,200°C) and high pressure (7,200–15,000 psi), creating a glass-ceramic waste form. During pressing, the volume of the waste form is reduced by 40–60 percent (Case 2012b). DOE has begun designing a process for removing calcined waste from the binsets and expects to begin removing calcined HLW from Bin Set 1 in fiscal year 2020 (Shaw 2017).

In parallel with these efforts, DOE will have to design, fabricate, and test a package for the INL calcined HLW. The package will also have to be approved by the NRC for transportation. Although DOE has not yet identified a design for a package for the calcined HLW, the designs used or planned for HLW at the West Valley Demonstration Project, the Savannah River Site, and the Hanford Site all consist of stainless steel cylinders with welded top and bottom closures.

Technical Issue #27. Complete the design, licensing, fabrication, and testing of packaging for the Hanford cesium and strontium capsules.

Assumptions, Conditions, Applicability:

a. This issue applies only to the cesium and strontium capsules stored at Hanford.

b. This issue must be addressed before the cesium and strontium capsules can be transported off site, but the issue will not preclude beginning shipments of SNF or other types of HLW.

Description: Cesium (mostly as the isotope cesium-137, along with minor amounts of the much longer-lived isotope cesium-135) and strontium (as the isotope strontium-90) were separated from HLW at the Hanford Site and solidified from 1967 to 1985. These materials were processed and encapsulated at the Hanford Waste Encapsulation and Storage Facility (an annex of the Hanford B-Plant). The cesium and strontium materials are sealed within double-walled, metal alloy capsules and stored in a water-filled basin at the Waste Encapsulation and Storage Facility. The capsules are approximately 7 cm (3 in) in outside diameter and 53 cm (21 in) long. There are 1,335 cesium capsules and 601 strontium capsules. More details about the cesium and strontium capsules at Hanford can be found in the Board's Fact Sheet, *Cesium and Strontium Capsules* (NWTRB 2017c).

The aging structures and systems at the Waste Encapsulation and Storage Facility led to concerns about the continued safe storage of the cesium and strontium capsules, so DOE initiated a new project (the Management of the Cesium and Strontium Capsules Project) to transfer the capsules out of the water-filled basin. DOE plans to move the capsules into overpack containers, and then move the overpacks to a new dry-storage facility at the Hanford Site. DOE approved the "mission need" (called "critical decision-0" in DOE's project management parlance) for this effort on November 5, 2015 (DOE 2017). On November 2, 2016, DOE awarded a contract to NAC International to design and fabricate 16 dry cask storage systems, building on the experience gained while moving HLW canisters into dry storage at the West Valley Demonstration Project in New York State (CH2M 2016; Reddick 2018).

Information presented by DOE (Reddick 2018) indicates that the project will make use of equipment that was used at West Valley to load HLW canisters into the NAC International-MPC (Multi-Purpose Canister) dry cask storage system. For example, DOE plans to reuse the canister welding equipment and the onsite cask transporter that were used at West Valley. The NAC-MPC system includes a stainless steel canister, called the "Transportable Storage Canister" (TSC), which is fitted with an internal basket specially designed to hold the radioactive material to be stored (e.g., SNF at commercial nuclear power plants or HLW at the West Valley Demonstration Project). After loading and drying, the TSC is welded shut and placed into a dry-storage overpack, called the "Vertical Concrete Cask" (VCC), which is then moved, using the onsite cask transporter, to a concrete storage pad. The VCC is constructed with 62 cm (24 in)-thick reinforced concrete walls and a 13 to 15 cm (5 to 6 in)-thick steel shield plug for shielding against radiation (Green, Medford, and Macy 2013). For commercial SNF applications, and for HLW at West Valley, NAC International applied for and received NRC approval of a CoC to transport the loaded TSCs in the NAC International STC Transport Cask (NRC 2016).

Because DOE is using a version of the NAC-MPC system to store the cesium and strontium capsules at Hanford, little new design work should be required other than designing a new waste basket that fits inside the TSC. Furthermore, the use of this NAC design will accommodate future transportation campaigns to ship the cesium and strontium capsules from the Hanford Site to an interim storage facility or a waste repository. In this case, DOE would have to submit a request to the NRC to amend the CoC for the NAC-STC to allow its contents to include the cesium and strontium capsules. However, if DOE decides to use a different transport cask design, then DOE will have to complete all the necessary steps to design (if needed) and obtain NRC approval of the alternative transport cask.

Technical Issue #28. Complete the design, licensing, fabrication, and testing of packaging for the ceramic and metallic HLW forms from the Idaho Fuel Conditioning Facility.

Assumptions, Conditions, Applicability:

a. This issue applies only to the ceramic and metallic HLW forms from the Idaho Fuel Conditioning Facility.

b. This issue must be addressed before the ceramic and metallic HLW forms can be transported off site, but the issue will not preclude beginning shipments of SNF or other types of HLW.

Description: At INL, DOE manages a certain type of SNF (among other types of SNF) called "sodium-bonded SNF." Sodium-bonded SNF contains elemental sodium between the fuel cladding and the fuel material. The sodium-bonded SNF at INL came from three sources: the Fermi-1 Breeder Reactor in Michigan; the Experimental Breeder Reactor-II at INL; and the Fast Flux Test Facility at the Hanford Site in Washington State (DOE 2006).

To stabilize the sodium-bonded SNF, DOE opted for electrometallurgical treatment at the Fuel Conditioning Facility at INL (DOE 2006). The electrometallurgical treatment process results in two waste streams that are considered HLW—a ceramic HLW form and a metallic HLW form. The treatment uses an electrorefiner with a molten salt electrolyte to dissolve the SNF (Hill and Fillmore 2005). The electrorefiner separates the cladding from the fuel by dissolving the sodium and fission products (radionuclides) into the molten salt. DOE indicated that once the molten salt reaches its capacity to accumulate radionuclides, the salt and accumulated radionuclides in the salt will be converted to a ceramic HLW form. The cladding and other metals remain intact during the treatment process and are removed from the electrorefiner and converted to a metallic HLW form. After the electrometallurgical treatment of the sodium-bonded SNF, the ceramic and metallic HLW forms will be stored at the Radioactive Scrap and Waste Facility at INL awaiting geological disposal (Hill and Fillmore 2005).

DOE will need to design, fabricate, test, and obtain NRC approval of new waste packages for both the ceramic HLW form and the metallic HLW form resulting from the treatment of sodium-bonded SNF at INL. As of April 2019, DOE had not identified packages for these HLW forms.

Technical Issue #29. Define the transportation cask(s) to be used for DOE-managed HLW.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all DOE-managed HLW that has been treated and packaged into welded stainless steel canisters. There is one exception: DOE has already identified the NAC International NAC-STC to be used to transport West Valley HLW canisters.

b. This issue must be addressed before canisters of DOE-managed HLW can be transported. However, this issue will not preclude transporting commercial SNF or DOE-managed SNF (unless DOE will use the same transportation cask for these wastes).

Description: For an introduction to DOE-managed HLW, including the various HLW forms and packaging for each waste form, see Section 1.3 in the main body of this report or the Board's Fact Sheets on DOE-managed HLW (NWTRB 2017b, 2017c, 2017d, 2017e). In summary, DOE manages several HLW forms at four sites: the Hanford Site in Washington State, the Idaho National Laboratory in Idaho, the Savannah River Site in South Carolina, and the West Valley Site in New York State. At the first three sites listed above, DOE has progressed through various stages of treating liquid HLW, solidifying the waste, and packaging the waste into welded canisters for on-site storage. However, at these three sites, little work has been done to develop a transportation cask for the HLW. The West Valley Site is the one exception, and DOE's efforts there are described below.

From 1996 to 2002, DOE produced 275 HLW canisters at the West Valley Site in New York State, and DOE continues to produce HLW canisters at the Savannah River Site in South Carolina. DOE also plans to process other, various forms of HLW at the Hanford Site in Washington State and at INL and package these wastes in stainless steel canisters.

Although DOE has handled HLW canisters and transported HLW canisters short distances within DOE site boundaries using specially designed transport equipment, none of these loaded HLW canisters has been transported off site. For any HLW canister to be transported off site, DOE will first have to identify a transportation cask to carry the canisters. Generally, DOE has two options for selecting a transportation cask design: one, select an existing transportation cask design that can be modified to accommodate the HLW canisters; or two, select a new canister design that DOE will fabricate, test, and gain NRC approval for use.

For the West Valley HLW canisters, DOE has completed this process. As part of the West Valley HLW canister relocation project, where the HLW canisters were moved from in-facility storage to an outdoor dry-storage pad, DOE included licensing of a transportation cask for eventual off-site shipping of the canisters (Zadins 2011). DOE selected NAC International as the contractor for the project, and the HLW canisters were transferred in groups of five into NAC International MPCs, which are made of stainless steel and have welded closure lids. The MPCs were placed inside NAC International shielded vertical concrete casks and moved to the outdoor storage pad. Early in the project, NAC International also submitted to the NRC Revision 14 the transportation CoC for the NAC-STC to allow the it to carry the West Valley HLW canisters in the NAC MPCs. In February 2016, the NRC approved the new CoC (NRC 2016).

The NAC-STC is also approved to transport commercial SNF, including directly loaded PWR SNF assemblies, Connecticut Yankee PWR SNF in welded canisters, and LaCrosse BWR SNF in welded canisters (NRC 2016). Although two NAC-STCs have been fabricated, approved, and put into operation overseas, none have been used for transportation in the U.S. (Greene et al. 2013).

An additional complication to this technical issue is that different HLW forms have been, or are planned to be, packaged into different-sized canisters. Table A-4 provides an overview of the DOE-managed HLW, the sizes of existing and planned canisters for that waste, and, for HLW that is packaged, the number of canisters.

At one extreme, the cesium and strontium capsules at the Hanford Site are only 0.07 m (2.6 in) in diameter and 0.53 m (21 in) long. At the other extreme, the HLW canisters to be produced at Hanford's Waste Immobilization and Treatment Plant will be 0.61 m (24 in) in diameter and 4.5 m (14 ft, 8 in) long. These different canister sizes will have to be considered as DOE decides whether to use a new or existing transportation cask system for shipping DOE-managed HLW.

The issue of designing, fabricating, and licensing a new-design transportation cask for HLW is captured by Technical Issue #30.

Table A-4. Characteristics of DOE HLW Canisters

Waste Form	DOE Site	Canister Diameter (m)	Canister Length (m)	Date First HLW Canister Produced	Number of Canisters Produced
Vitrified HLW	West Valley Demonstration Project	0.61[a]	3.0	1996	278
Vitrified HLW	Savannah River Site	0.61	3.0	1996	4,173[b]
Vitrified HLW	Hanford	0.61	4.5	2036 (est.)[c]	(not started)
Cesium/Strontium capsules	Hanford	0.07	0.53	1974	1,936
Sodium-bearing waste[d]	Idaho National Laboratory	0.66	3.0	TBD	650 (est.)[e]
Calcine HLW	Idaho National Laboratory	TBD	TBD	TBD	TBD
Ceramic HLW from processing sodium-bonded SNF[f]	Idaho National Laboratory	TBD	TBD	TBD	TBD
Metal HLW from processing sodium-bonded SNF[f]	Idaho National Laboratory	TBD	TBD	TBD	TBD

[a] West Valley HLW canister dimensions as reported in Vance et al. (1997).

[b] Number of DWPF HLW glass canisters poured as of November 2018 (Cantrell 2018).

[c] Date for full, hot (radioactive) operations of the Waste Treatment and Immobilization Plant, set by Amended Consent Decree in U.S. District Court.

[d] DOE has not finalized its decision on the waste classification of sodium-bearing waste at INL; the waste may be classified as remote-handled transuranic waste or as HLW.

[e] See Hagers (2009).

[f] One of two HLW forms produced during the electrochemical processing of sodium-bonded SNF at the Fuel Conditioning Facility at INL (Hill and Fillmore 2005).

Technical Issue #30. If not using an existing transportation cask, then design, license, fabricate, and test a new transportation cask for DOE-managed HLW.

Assumptions, Conditions, Applicability:

a. This technical issue applies to all DOE-managed HLW. There is one exception: DOE has already identified the NAC-STC to be used to transport West Valley HLW canisters.

b. This issue must be addressed before canisters of DOE-managed HLW can be transported. However, this issue will not preclude transporting commercial SNF or DOE-managed SNF (unless DOE will use the same transportation cask for these wastes).

c. This technical issue will be significantly reduced in scope if DOE selects an existing transportation cask design for shipping HLW; only the licensing step, and, in some cases, the fabrication step, will have to be completed.

Description: This issue is identical to Technical Issue #8 for commercial SNF because all the steps necessary to develop a transportation cask for DOE-managed HLW will be the same as the steps necessary to develop a cask for commercial SNF. For details about designing, fabricating, testing, and licensing a new SNF transportation cask, see Technical Issue #8.

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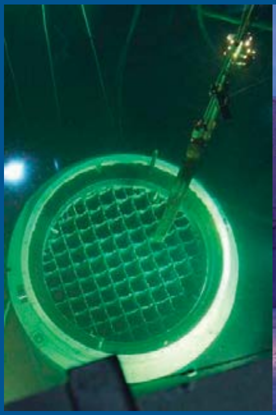

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