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## **Preliminary Evaluation of Removing Used Nuclear Fuel from Shutdown Sites**

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### **Abstract**

An updated preliminary evaluation of removing used or spent nuclear fuel (SNF) from 13 shutdown nuclear power reactor sites was conducted. At these shutdown sites the nuclear power reactors have been permanently shut down and the sites have been decommissioned or are undergoing decommissioning. The shutdown sites included here are Maine Yankee, Yankee Rowe, Connecticut Yankee, Humboldt Bay, Big Rock Point, Rancho Seco, Trojan, La Crosse, Zion, Crystal River, Kewaunee, San Onofre, and Vermont Yankee. The evaluation was divided into four components: (1) characterization of the SNF and greater-than-Class C low-level radioactive waste (GTCC waste) inventory, (2) a description of the on-site infrastructure at the shutdown sites, (3) an evaluation of the near-site transportation infrastructure and transportation experience, including identification of gaps in information, and (4) an evaluation of the actions necessary to prepare for and remove SNF and GTCC waste. Every site was found to have at least one transportation mode option for removing its SNF and GTCC waste; some have multiple options. Experience removing large components during reactor decommissioning provided an important source of information used to identify the transportation mode options for the sites. Especially important in conducting the evaluation were site visits, through which information was obtained that would not have been available otherwise. Extensive photographs taken during the site visits proved to be particularly useful in documenting the current conditions at or near the sites. As additional sites such as Fort Calhoun, Clinton, Quad Cities, Pilgrim, Oyster Creek, and Diablo Canyon shut down, these sites will be included in updates to the evaluation.

## Introduction

In January 2013, the U.S. Department of Energy (DOE) issued the Administration's Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste [1]. Among the elements contained in this strategy is an initial focus on accepting spent nuclear fuel (SNF) from shutdown reactor sites. This focus is consistent with the recommendations of the Blue Ribbon Commission on America's Nuclear Future, which identified removal of stranded SNF at shutdown sites as a priority so that these sites may be completely decommissioned and put to other beneficial uses [2].

In order to prepare for the transportation of SNF with an initial focus on removing SNF from the shutdown sites, a preliminary evaluation of removing SNF from 13 shutdown sites was conducted. The shutdown sites included here are Maine Yankee, Yankee Rowe, Connecticut Yankee, Humboldt Bay, Big Rock Point, Rancho Seco, Trojan, La Crosse, Zion, Crystal River, Kewaunee, San Onofre, and Vermont Yankee (see Figure 1). These sites have no other operating nuclear power reactors at their sites and have also notified the U.S. Nuclear Regulatory Commission (NRC) that their reactors have permanently ceased power operations and that nuclear fuel has been permanently removed from their reactor vessels. Shutdown reactors at sites having other operating reactors were not included in this evaluation.

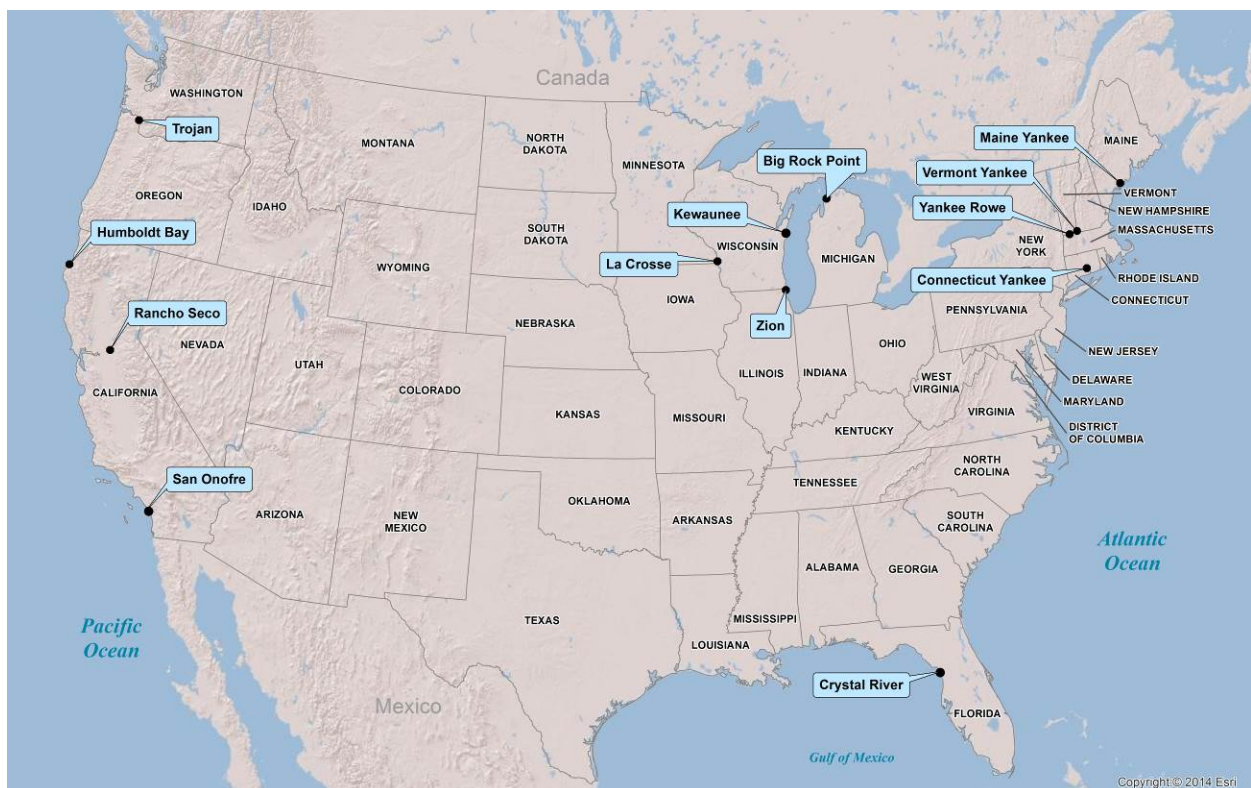


Figure 1 Locations of shutdown sites

## Evaluation of the Shutdown Sites

The evaluation was divided into four components:

- Characterization of the SNF and greater-than-Class C low-level radioactive waste (GTCC waste) inventory
- A description of the on-site infrastructure at the shutdown sites
- An evaluation of the near-site transportation infrastructure and transportation experience at the shutdown sites
- An evaluation of the actions necessary to prepare for and remove SNF and GTCC waste.

Maheras et al. [3] summarizes the wide variety of sources that were used to complete the components of the evaluations listed above. The primary sources for the inventory of SNF are the U.S. Department of Energy (DOE) GC-859 and RW-859 spent nuclear fuel inventory databases. The primary sources for information on the conditions of on-site and near-site transportation infrastructure and experience included observations and information collected during site visits to the thirteen shutdown sites, information provided by managers and staff at the shutdown sites, and Google Earth imagery. Tribal, State, State Regional Group, and Federal Railroad Administration representatives have participated in ten of these shutdown site visits.

## Results

Figure 2 illustrates the number of canisters containing SNF and GTCC waste that are stored or are anticipated to be stored at each of the shutdown sites.<sup>1</sup> The number of canisters stored at Maine Yankee, Yankee Rowe, Connecticut Yankee, Humboldt Bay, Big Rock Point, Rancho Seco, Trojan, La Crosse, and Zion represent actual canisters in storage. The number of SNF canisters at Crystal River, Kewaunee, San Onofre, and Vermont Yankee represents an estimate of the number of canisters that will be stored at the conclusion of canister loading and the number of canisters at Crystal River, Kewaunee, San Onofre, and Vermont Yankee containing GTCC waste represents an estimate of the number of canisters generated during decommissioning. There are predicted to be a total of 541 to 547 canisters in storage at the 13 sites (actual plus estimated). The number of canisters ranges from 5 at La Crosse to 134-140 at San Onofre.

Figure 3 illustrates the number of SNF assemblies stored at each site. There are a total of 17,963 SNF assemblies present at the shutdown sites. These assemblies are composed of 12,919 pressurized water reactor assemblies and 5044 boiling water reactor assemblies. The number of assemblies ranges from 333 at La Crosse to 3880 at Vermont Yankee. The majority (16,301) of the SNF assemblies are zirconium alloy-clad; but Yankee Rowe, Connecticut Yankee, La Crosse, and San Onofre-1 have a combined total of 1662 stainless steel-clad SNF assemblies in storage.

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<sup>1</sup> To the extent the discussions or recommendations in this paper conflict with the provisions of the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste, 10 CFR § 961.11, the Standard Contract provisions prevail.

Figure 4 illustrates the metric tons of heavy metal stored at each site. A total of 6227.6 metric tons heavy metal (MTHM) of SNF at the shutdown sites consists of 5399.3 MTHM of pressurized water reactor SNF and 828.2 MTHM of boiling water reactor SNF.

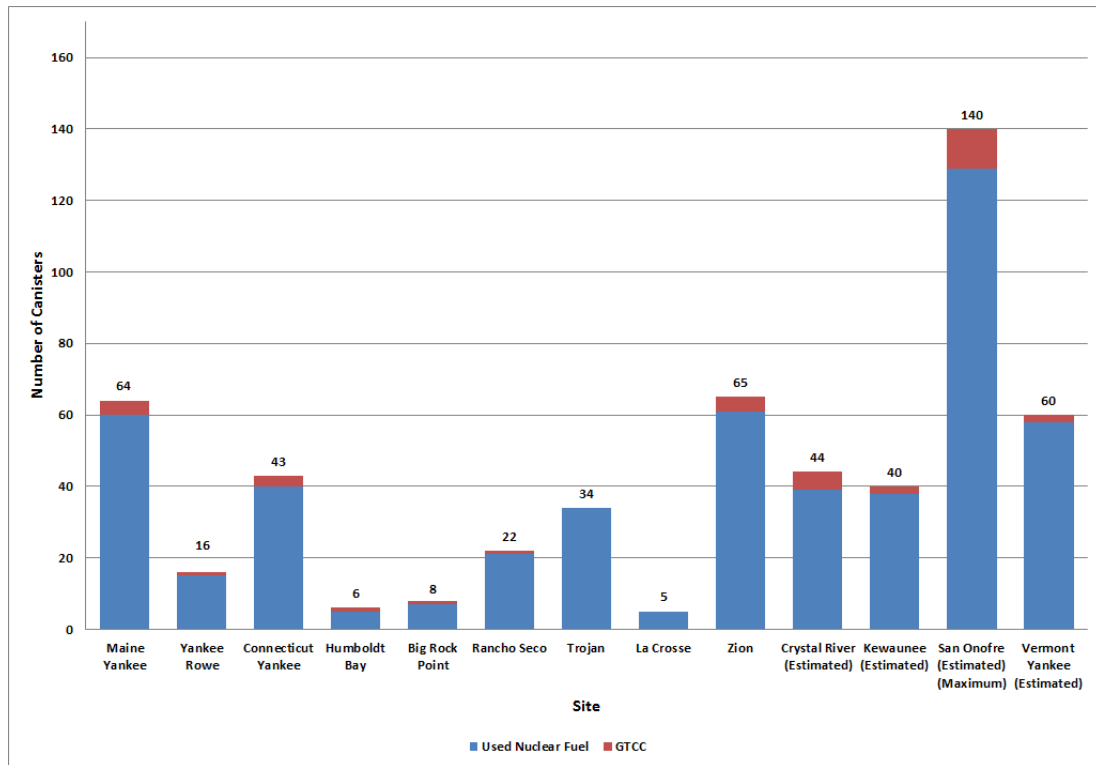


Figure 2 Number of canisters at shutdown sites

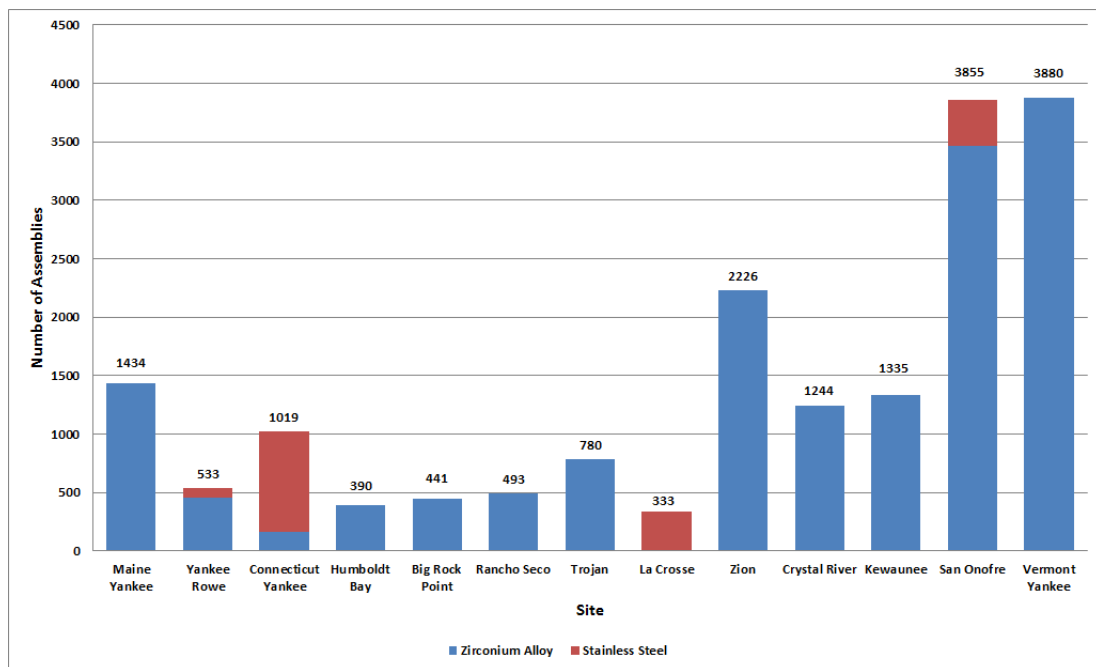
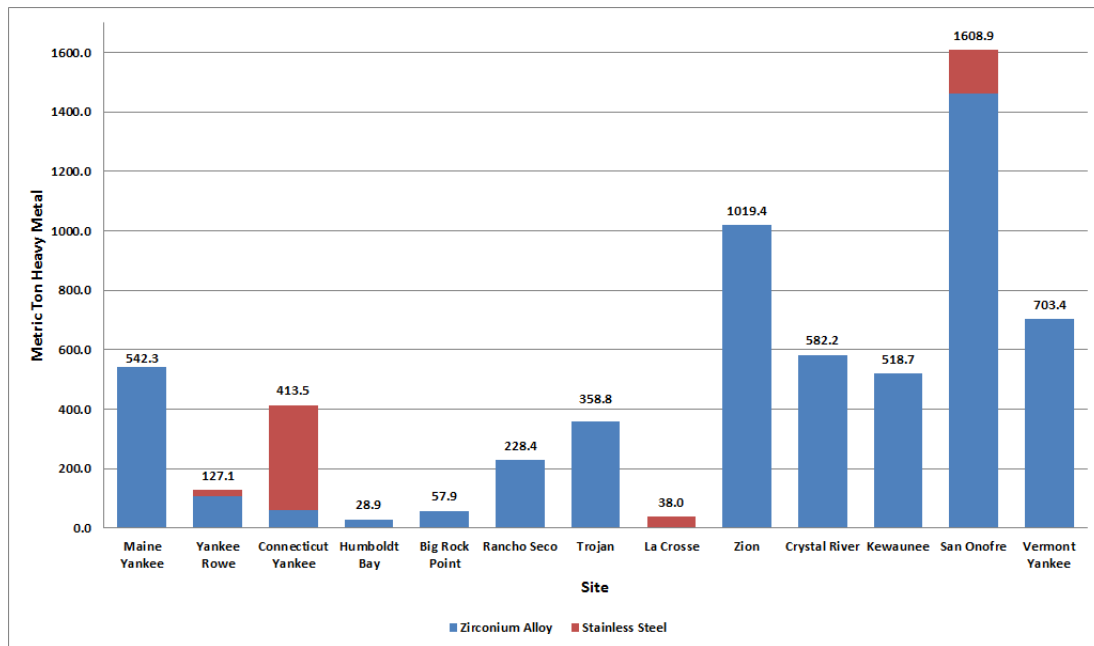


Figure 3 Number of assemblies at shutdown sites



**Figure 4 Metric tons heavy metal at shutdown sites**

Table 1 lists the storage systems used at the shutdown sites and the corresponding transportation casks that are certified to ship the storage canisters containing SNF and GTCC waste at each of the sites. The 13 shutdown sites use designs from 4 different suppliers, including 11 different (horizontal and vertical) storage systems that would require 9 different transportation cask designs. Out of the nine transportation cask designs listed in Table 1, only three types have been fabricated for use in the U.S.: the HI-STAR HB, the MP187, and the HI-STAR 100. Impact limiters have not been fabricated for any of the transportation casks. The HI-STAR HB transportation casks can only be used to ship SNF from the Humboldt Bay site. The MP187 transportation cask can be used to ship SNF from the Rancho Seco and San Onofre sites. The HI-STAR 100 casks that have been fabricated are being used as storage casks at the Dresden and Hatch commercial nuclear power reactor sites. If these HI-STAR 100s were to be re-used to ship compatible SNF canisters from the Trojan or Vermont Yankee sites, they would need to be unloaded, their contents placed in other storage overpacks, and the casks transported to the Trojan or Vermont Yankee sites. It would also be necessary to procure impact limiters and spacers for the HI-STAR 100 casks. Two NAC-STC transportation casks have been fabricated for use in China, but not for use in the United States. In addition, an MP197HB transportation cask is being fabricated in Japan. However, fabrication is on hold.

Several issues were identified during the characterization of the SNF and GTCC waste inventory at the shutdown sites. The most important of the issues was at the Rancho Seco site, where six damaged fuel assemblies were loaded into five fuel-with-control-component dry shielded canisters (FC-DSCs) instead of into failed fuel dry shielded canisters (FF-DSCs). Further evaluation would be needed to determine if the canisters containing this damaged fuel can be shipped in the MP187 transportation

**Table 1 Storage systems and transportation casks at shutdown sites**

<b>Reactor Site</b>	<b>ISFSI Load Dates</b>	<b>Storage System/Canisters</b>	<b>Transportation Cask Status</b>	<b>Canisters SNF/GTCC</b>
Maine Yankee (PWR)	08/2002-03/2004	NAC-UMS Transportable Storage Canister	NAC-UMS UTC (Docket No. 71-9270) Certificate expires 10/31/2017. None fabricated	60/4
Yankee Rowe (PWR)	06/2002-06/2003	NAC-MPC/Yankee-MPC transportable storage canister	NAC-STC (Docket No. 71-9235) Certificate expires 05/31/2019. Foreign use versions fabricated.	15/1
Connecticut Yankee (PWR)	05/2004-03/2005	NAC-MPC/CY-MPC transportable storage canister	NAC-STC (Docket No. 71-9235) Certificate expires 05/31/2019. Foreign use versions fabricated.	40/3
Humboldt Bay (BWR)	08/2008-12/2008	Holtec HI-STARHB/MPC-HB canister	HI-STAR HB (Docket No. 71-9261) Certificate expires 04/30/2019. Fuel in canisters in fabricated casks. No impact limiters.	5/1
Big Rock Point (BWR)	12/2002-03/2003	Fuel Solutions W150 Storage Overpack/W74 canister	TS125 (Docket No. 71-9276) Certificate expires 10/31/2017. None fabricated.	7/1
Rancho Seco (PWR)	04/2001-08/2002	TN NUHOMS/FO-DSC, FC-DSC, and FF-DSC canisters	MP187 (Docket No. 71-9255) Certificate expires 11/30/2018. One cask fabricated. No impact limiters.	21/1
Trojan (PWR)	12/2002-09/2003	TranStor Storage Overpack/Holtec MPC-24E and MPC-24EF canisters	HI-STAR 100 (Docket No. 71-9261) Certificate expires 04/30/2019. Units fabricated but dedicated to storage at other sites. No impact limiters or spacers.	34/0
La Crosse (BWR)	07/2012-09/2012	NAC MPC-LACBWR/MPC-LACBWR transportable storage canister	NAC-STC (Docket No. 71-9235) Certificate expires 05/31/2019. Foreign use versions fabricated.	5/0
Zion 1 and 2 (PWR)	12/2013-03/2015	NAC MAGNASTOR/TSC-37 canister	MAGNATRAN (Docket No. 71-9356) Application for certificate of compliance under review. None fabricated.	61/4 <sup>b</sup>
Crystal River (PWR)	Planned 01/2018-08/2019	TN Standardized NUHOMS/32PTH1 canister	MP197HB (Docket No. 71-9302) Certificate expires 08/31/2017.	39/5 <sup>b,c</sup>
Kewaunee (PWR)	08/2009-08/2014	TN Standardized NUHOMS/32PT canister	MP197HB (Docket No. 71-9302) Certificate expires 08/31/2017.	14
Kewaunee (PWR)	Planned 2016	NAC MAGNASTOR/TSC-37 canister	MAGNATRAN (Docket No. 71-9356) Application for certificate of compliance under review. None fabricated.	24/2 <sup>b,c</sup>
Kewaunee Total				38/2

**Table 1 Storage systems and transportation casks at shutdown sites (continued)**

Reactor Site	ISFSI Load Dates	Storage System/Canisters	Transportation Cask Status	Canisters SNF/GTCC
San Onofre-1 (PWR)	09/2003-06/2005	TN Standardized Advanced NUHOMS/24PT1 canisters	MP187(Docket No. 71-9255) Certificate expires 11/30/2018. One cask fabricated. No impact limiters.	17/1
San Onofre-2 and -3 (PWR)	03/2007-07/2012	TN Standardized Advanced NUHOMS/24PT4 canisters	MP197HB (Docket No. 71-9302) Certificate expires 08/31/2017.	33
San Onofre-2 and -3 (PWR)	Not Announced	TN Standardized Advanced NUHOMS/24PT4 canisters	MP197HB (Docket No. 71-9302) Certificate expires 08/31/2017.	0-12/0-12 <sup>b,c</sup>
San Onofre-2 and -3 (PWR)	Not Announced	TN Standardized Advanced NUHOMS/24PT4 and 32PTH2 <sup>d</sup> canisters	MP197HB (Docket No. 71-9302) Certificate expires 08/31/2017.	0-6/0-6 <sup>b,c</sup>
San Onofre-2 and -3 (PWR)	Not Announced	Holtec HI-STORM UMAX/MPC-37 canisters	HI-STAR 190 (Docket No. 71-9373) Application for certificate of compliance submitted in 2015.	≤73/0 <sup>b</sup>
San Onofre Total				123-129/11
Vermont Yankee (BWR)	05/2008-06/2012	Holtec HI-STORM 100S/MPC-68 canisters	HI-STAR 100 (Docket No. 71-9261) Certificate expires 04/30/2019. Units fabricated but dedicated to storage at other sites. No impact limiters or spacers.	13/0
Vermont Yankee (BWR)	Not Announced	Holtec HI-STORM 100S/MPC-68 canisters	HI-STAR 100 (Docket No. 71-9261) Certificate expires 04/30/2019. Units fabricated but dedicated to storage at other sites. No impact limiters or spacers.	45/2 <sup>b,c</sup>
Vermont Yankee Total				58/2
Total				506-512/35

a. Dates represent the dates that the SNF was transferred to the ISFSI.

b. Estimated.

c. Additional canisters of GTCC waste could be generated during decommissioning.

d. The list of approved contents in the certificate of compliance for the MP197HB transportation cask would have to be modified to include the 32PTH2 canister.

BWR= boiling water reactor

GTCC= greater-than-Class C

ISFSI= independent spent fuel storage installation

PWR= pressurized water reactor

SNF= spent nuclear fuel

cask without repackaging. In addition, the transportation certificate of compliance for the HI-STAR HB transportation cask would also need to be revised to allow transport of 44 SNF assemblies at Humboldt Bay with initial enrichments of 2.08 weight percent, which is less than the minimum initial enrichment authorized by the NRC transportation certificate of compliance.

The lists of approved contents in the certificates of compliance for the TS125, HI-STAR HB, and MP187 transportation casks do not include GTCC waste. For GTCC waste to be shipped from the Humboldt Bay, Rancho Seco, and San Onofre sites in these transportation casks, the certificates of compliance would need to be revised. Also, the certificates of compliance for the TS125 and MP187 transportation casks would need to be updated from a -85 to a -96 designation before the casks or impact limiters could be fabricated. In addition, the SNF or GTCC waste that may be stored in 32PTH2 canisters at San Onofre would not be transportable without changes to the list of approved contents in the certificate of compliance for the MP197HB transportation cask.

Six of the sites, Maine Yankee, Zion, Crystal River, Kewaunee, San Onofre, and Vermont Yankee, have high burnup SNF in storage. The 90 high burnup SNF assemblies at Maine Yankee are packaged in Maine Yankee Fuel Cans (i.e., damaged fuel cans). This option for transporting high burnup SNF is allowed by the certificate of compliance for the NAC-UMS UTC transportation cask, and eliminates the concern over its transportability. For the Zion site, all high burnup fuel was packaged in damaged fuel cans. This also eliminates the concern over transportability of the 36 high burnup SNF assemblies at Zion. High burnup SNF stored in 32PTH1 canisters at Crystal River and 24PT4 canisters at San Onofre would be transportable in the MP197HB transportation cask; high burnup SNF that will be stored in MPC-68 canisters at Vermont Yankee would not be transportable without changes to the list of approved contents in the certificate of compliance for the HI-STAR 100 transportation cask. An application for a certificate of compliance for the HI-STAR 190 transportation cask has been submitted to the NRC; high burnup SNF that will be stored in MPC-37 canisters at San Onofre would be transportable if it is included in the list of approved contents in the certificate of compliance for the HI-STAR 190 transportation cask.

All sites were found to have at least one transportation mode option for removing their SNF and GTCC waste, and most sites have multiple options. Table 2 provides a summary of these transportation mode options for the shutdown sites. Experience with large component removals during reactor decommissioning provided an important source of information in developing Table 2.

As part of the evaluation, the current condition of the transportation infrastructure at the shutdown sites was observed. In some cases, transportation infrastructure was removed during decommissioning or was not being actively maintained (see Figures 5 and 6). In other cases, transportation infrastructure appeared to be in good condition or was being maintained as part of decommissioning activities (see Figures 7 through 9). At some sites, the transportation infrastructure was in active use (see Figure 10). Other sites would require transloading onto railcars or barges off-site (see Figure 11).



**Table 2 Summary of transportation mode options at shutdown sites**

Site	Transportation Mode Options		Comments
Maine Yankee	Direct rail	Barge to rail	The on-site rail spur is not being maintained. The condition of the Central Maine and Quebec Railway would need to be verified. It is uncertain whether the barge slip is deep enough to accommodate barges without dredging.
Yankee Rowe	Heavy haul truck to rail	–	Potential transload location at the east portal of the Hoosac Tunnel (12 km from site).
Connecticut Yankee	Barge to rail	Heavy haul truck to rail	The on-site barge slip has not been used since decommissioning but remains intact. It is uncertain whether the cooling water discharge canal is deep enough to accommodate barges without dredging. The shortest heavy haul would be about 20 km to the end of the Portland rail spur. The rail infrastructure at the end of the Portland rail spur would need to be evaluated.
Humboldt Bay	Heavy haul truck to rail	Heavy haul truck to barge to rail	The heavy haul distance to a rail siding or spur would be in the range of 260 to 450 km. The Fields Landing Terminal located 3.2 km from the Humboldt Bay site is in use but the condition would need to be verified for barge transport.
Big Rock Point	Heavy haul truck to rail	Barge to rail	Potential transload locations in Gaylord, Michigan (84 km from site) and Petoskey, Michigan (21 km from site). The rail infrastructure at these locations would need to be evaluated.
Rancho Seco	Direct rail	–	The on-site rail spur is not being maintained. Weight restrictions on the lone Industrial Lead would require route clearance by the railroad or a track upgrade.
Trojan	Direct rail	Barge to rail	The on-site rail spur was removed. It is uncertain whether the onsite barge slip would require dredging and leveling.
La Crosse	Direct rail	Barge to rail	An on-site rail spur was used to ship the reactor pressure vessel. It is uncertain whether the onsite barge facility could accommodate SNF transportation casks.
Zion	Direct rail	Barge to rail	The on-site rail spur was recently refurbished to support reactor decommissioning waste shipments. The Zion barge facility was abandoned and the land on which it was located was donated to the Illinois Beach State Park. However, the barge pilings remain.
Crystal River	Direct rail	Barge to rail	Extensive on-site rail system serves co-located fossil fuel plants. Large components have also been received by barge, at an area adjacent to the coal barge unloading area.
Kewaunee	Heavy haul truck to rail	Heavy haul truck to barge to rail	Potential rail transload locations in Bellevue, Luxemburg, Denmark, and Manitowoc. Potential barge transload location in city of Kewaunee.
San Onofre	Direct rail	Heavy haul truck to barge to rail	The on-site rail spur was refurbished to support decommissioning of San Onofre-1. The Del Mar Boat Basin was recently used for barge transport of steam generators.
Vermont Yankee	Direct rail	–	The on-site rail spur will be reactivated to support decommissioning.



**Figure 5 Condition of onsite rail system at Maine Yankee (2012)**



**Figure 6 Rail spur approaching Vermont Yankee site entrance (2016)**



**Figure 7 Onsite rail spur at La Crosse (2013)**



**Figure 8 Junction of onsite rail spur and Union Pacific Railroad at Zion (2013)**



**Figure 9 Junction of on-site rail spur and mainline at San Onofre (2015)**



**Figure 10 On-site rail spur at Crystal River (2015)**



**Figure 11 Potential off-site transload location near Kewaunee (2014)**

## **Conclusions**

An updated preliminary evaluation of removing SNF and GTCC waste from 13 shutdown sites was conducted. The evaluation included characterization of the sites' inventories of SNF and GTCC waste, on-site conditions, and near-site transportation infrastructure and experience. Especially important in conducting the evaluation were site visits, through which information was obtained that would not otherwise have been available. Extensive photographs taken during the site visits proved to be particularly useful in documenting the current conditions at or near the sites. Additional conclusions from this evaluation include:

- The 13 sites use designs from 4 different suppliers involving 11 different (horizontal and vertical) dry storage systems that would require the use of 9 different transportation cask designs to remove the SNF and GTCC waste from the shutdown sites.
- Each site has unique features and/or conditions.
- Although some changes to transportation certificates of compliance will be required, the SNF at the initial 9 shutdown sites (Maine Yankee, Yankee Rowe, Connecticut Yankee, Humboldt Bay, Big Rock Point, Rancho Seco, Trojan, La Crosse, and Zion) is in dual-purpose dry storage canisters that can be transported, including a small amount of high-burnup fuel.
- Most sites indicated that 2-3 years of advance time would be required for its preparations before shipments could begin. Some sites could be ready in less time.

- Most sites have more than one transportation option, e.g., rail, barge, or heavy haul truck, as well as constraints and preferences.

As additional sites such as Fort Calhoun, Clinton, Quad Cities, Pilgrim, Oyster Creek, and Diablo Canyon shut down, they will be added to the evaluation.

### **Acknowledgments**

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