Proceedings of the 19th International Symposium on the Packaging and Transportation of Radioactive Materials PATRAM 2019

August 4-9, 2019, New Orleans, LA, USA

Paper No. 1346

AT-REACTOR CONDITIONS AFFECTING TRANSPORTATION OF SNF FROM US COMMERCIAL NUCLEAR SITES[1]

Robby Joseph

Oak Ridge National Laboratory

Mark Nutt

Pacific Northwest National Laboratory

Abstract

The US Department of Energy (DOE) is developing solutions for long-term sustainable management of the nation's spent nuclear fuel (SNF) and high-level radioactive waste (HLW). An important aspect of a potential future nuclear waste management system is the transportation of SNF from the fleet of commercial nuclear reactors to interim storage and/or disposal facilities.

This paper summarizes a preliminary evaluation of the SNF transportation infrastructure at nuclear power plant sites and explores the constraints in preparing SNF shipments imposed by refueling operations and associated spent fuel pool (SFP) activities at reactor sites. Additionally, approaches for how this information could be implemented into Integrated Waste Management (IWM) system analyses are discussed. This paper also explores providing estimates of the times required for loading transportation casks from an SFP or from an independent spent fuel storage installation (ISFSI), including an estimate of rail transportation preparation processing times for removing SNF from a reactor site. This estimate considers each step that would occur from the time when a rail consist containing one or more empty SNF transportation casks would arrive at either a reactor site or an intermodal transfer location and when the loaded rail consist would leave. Having estimates of unit processing times over this entire process is necessary since the casks and rolling stock are unavailable when in use, thus affecting the estimates of cask and rolling stock fleet size.

This is a technical paper 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)

---

[1] This manuscript has been authored by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the US Department of Energy (DOE).

(10 CFR Part 961). For example, 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, and DOE is not responsible for maintenance, refurbishment, or upgrades of a site's transportation infrastructure. To the extent discussions or recommendations in this paper conflict with the provisions of the Standard Contract, the Standard Contract provisions prevail.

Introduction

The US Department of Energy (DOE) is developing solutions for the long-term, sustainable management of the nation's spent nuclear fuel (SNF) and high-level radioactive waste (HLW). One aspect of a potential future nuclear waste management system is transportation of SNF from the fleet of commercial nuclear reactors to interim storage and/or disposal facilities.

As of mid-2018 there were 74 commercial nuclear power reactor sites in the United States, 60 of which were operating and 14 of which were permanently shutdown. Each of the 74 sites contains SNF that is being stored in spent fuel pools (SFPs) and/or independent spent fuel storage installations (ISFSIs). *Shutdown sites* are defined as those commercial nuclear power reactor sites where all of the nuclear power reactors on site have been shut down and the site has been decommissioned or is undergoing decommissioning. *Operating sites* are defined as those commercial nuclear power reactor sites where at least one nuclear power reactor is generating electricity.

This paper provides a preliminary evaluation of the SNF transportation infrastructure at operating nuclear power plant sites. This evaluation identifies potential modes and sub-modes that could be used for transporting SNF from the commercial reactor sites (both operating and shutdown). The paper then explores the constraints in preparing SNF shipments that are imposed by refueling operations and associated SFP activities at reactor sites. The next section provides estimates of the times required for loading transportation casks from an SFP or from an ISFSI. The final section presents approaches for how this information could be implemented into IWM system analyses.

Discussion

Evaluation of SNF Transportation Infrastructure at Operating Nuclear Power Plant Sites

A preliminary evaluation of the SNF transportation infrastructure at commercial nuclear power plant sites was completed to support both IWM system architecture analyses and future planning efforts [1]. The evaluation presented herein updates reactor site surveys performed by DOE in the 1990s and early 2000s describing the transportation infrastructure at commercial reactor sites at that time. Geographical information systems (GISs) and available open-source information about the reactor sites were used to identify changes in the transportation infrastructure at the operating commercial nuclear power plant sites. The data and schematics contained within the previous surveys were comparatively analyzed alongside the GIS tools Google Earth, Google Maps [2], and DOE's Stakeholder Tool for Assessing Radioactive Transportation (START) Version 3.0 [3,4] to determine potential transportation modes and to identify improvements to the transportation infrastructure that may be needed at each of the sites [1].

There are three modes that could be used to transport SNF from the 60 operating commercial nuclear sites: rail, barge, and heavy-haul truck (HHT). Each operating reactor site was first assessed to determine if it currently has or once had the capability for rail and barge transportation. Once the potential transportation modes at each site were identified, the onsite and near-site infrastructure for utilizing that mode was assessed [1].

Each of the 60 operating commercial nuclear power plant sites was evaluated. All the sites appear to be capable of transporting SNF off-site using HHTs. The following observations were reported regarding the 60 sites:

- *SNF can be removed from all operating reactor sites via one or more modes of transportation;*
- *HHT transport is viable for all sites, and intermodal transfer locations exist where SNF could be transloaded from HHT to rail. Twenty-two sites appear to currently have or have had only direct rail as another potential transportation mode;*
- *15 sites appear to currently have or have had only barge as another potential transportation mode;*
- *18 sites appear to have or have had both direct rail and barge as other potential transportation modes; and*
- *5 sites appear to have HHT as the only transportation mode* [1].

Selection of the transportation mode that would be used at each reactor site will depend on several factors with one being the condition of the onsite and near-site transportation infrastructure and the amount of refurbishment/reinstallation that would be necessary. The preliminary evaluation indicated that the amount of refurbishment/reinstallation that would be necessary varies. It must be recognized that this evaluation is preliminary, and the results are subjective. Fully assessing the actual onsite and near-site infrastructure can only be accomplished through physical examination and discussions with reactor site staff, the railroads, the US Coast Guard, road authorities, etc. This was the approach used in prior assessments of operating commercial nuclear reactor sites and recently completed assessments of the shutdown reactor sites [1].

Transportation Modes and Sub-Modes from Commercial Nuclear Power Plant Sites

The preliminary evaluation of operating reactor sites discussed above, the initial site-specific de-inventory reports [5, 6, 7, 8, 9, 10], and preliminary evaluation of removing SNF from 14 shutdown sites [11] were used to identify potential modes and sub-modes that could be used for transporting SNF from operating and shutdown commercial reactor sites. The transportation modes are the primary way that SNF will be transported away from the reactor sites. *Sub-modes* are transfers that may need to occur between where the SNF is located (SFP or ISFSI) and the transportation asset that will be used to ultimately ship the SNF away from a reactor site (rail car or barge). Such transfers may be made to locations inside the protected area, on owner-controlled property (on site) outside the protected area, or for a short distance off of owner-controlled property (off site). The modes and sub-modes are:

- Rail: direct load
- Rail: protected area or onsite transfer
- Rail: off-site HHT
- Barge: onsite transfer
- Barge: off-site HHT
- HHT

The transportation mode and sub-modes for the operating reactor sites that would potentially be used were identified from the current conditions at each site, and a subjective estimate was made of realistic upgrades that could be undertaken to improve the transportation infrastructure. In addition, the following attributes were considered:

- Rail length in the protected area and on site;
- Rail accessing SFP or adjacent to the ISFSI;
- Cask receipt area capability to accommodate the Atlas railcar;
- Whether the ISFSI is inside the overall plant protected area;
- Distance between the SFP and the rail track or barge slip/dock;
- Distance between the ISFSI and the rail track or barge slip/dock; and
- Distance to an off-site HHT transfer location.

For the reactor sites, these attributes are summarized in Figure 1 for shipments directly from SFPs and in Figure 2 for shipments from ISFSIs. Figures 1 and 2 shows the number of reactor sites that are assumed to use each transportation mode and sub-mode.

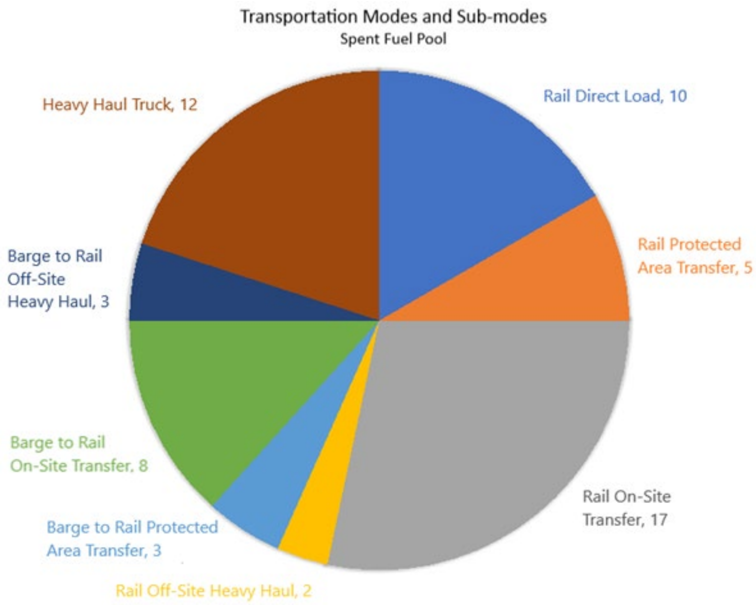

Figure 1. Transportation modes and sub-modes for shipments from an SFP.

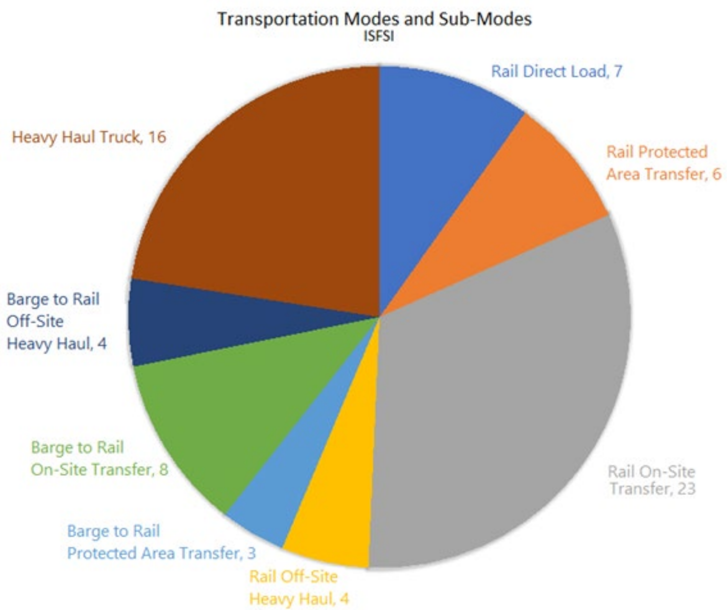

Figure 2. Transportation modes and sub-modes for shipments from an ISFSI.

Classification of Commercial Nuclear Reactor Sites and the Subsequent Impacts on Preparing Spent Nuclear Fuel for Shipment

The extent to which ongoing operations at reactor sites might restrict the reactor sites' availability to prepare SNF for shipment has been explored previously [12]. In an effort to better understand the constraints affecting when SNF could be loaded or shipped at reactor sites, the sites were categorized into 14 families based on the following criteria:

- ***Number of operating reactors on site.*** *Commercial reactor sites in the United States have between 1 and 3 reactors operating on site at a time. Sites on which all on-site reactors have been permanently shut down are simply termed* shutdown sites.
- ***Operating reactor type.*** *The reactors at commercial sites are either pressurized water reactors (PWRs) or boiling water reactors (BWRs).*
- ***Length of refueling cycle.*** *This refers to the amount of time between refueling outages of a reactor. The duration of these cycles is either 18 or 24 months for reactors at commercial reactor sites in the United States.*
- ***Number of SFPs.*** *Sites have between 1 and 4 SFPs on site.*
- ***Configuration of spent fuel pools.*** *At some sites, multiple reactors discharge SNF into the same SFP (i.e., a shared SFP). At other sites, each reactor unit has a dedicated SFP* [12].

The work by Moses et al. resulted in both conservative and aggressive estimates for reactor activities, resulting in a wide range in the number of weeks of availability for all reactor site families [12]. These results inform system analysis, specifically the maximum number of shipments or loadings that should be assumed at various reactor sites in a year.

At-reactor SNF Transportation Process Steps and Durations

The time that it takes to transport SNF from the reactor sites affects several important IWM system attributes, including:

- The number of transportation casks that could be loaded directly from a SFP annually—either in re-useable bolted lid bare-fuel transportation casks or in dual-purpose canisters and their associated transportation casks—both for operating and shutdown reactor sites;
- The number of dual-purpose welded canisters and bolted casks that could be loaded and/or transported from both operating and shutdown reactor sites; and
- The size of the cask and rolling asset (cask, buffer, and escort cars) that would be needed to accept SNF from the reactor sites.

While there is operating experience information available regarding the time required for loading dual-purpose dry storage systems in the United States, there is no operating experience information available regarding the time required to load large transportation casks directly from an SFP or to load welded canisters or bolted casks from an ISFSI and ship them from a reactor site.

This estimate of SNF at-reactor transportation processing times considered steps between when a rail consist containing one or more empty SNF transportation casks arrives at either a reactor site or an intermodal transfer location and when the rail consist leaves. Having estimates of unit processing times over this entire process is necessary since the casks and rolling stock are unavailable during these times, thus affecting estimates of cask and rolling stock fleet size.

First, high-level steps between when a consist arrives empty and when it leaves full, either from a reactor site or an intermodal location, were developed. The duration of each lower level process step, or combination of process steps, was estimated from information contained in "Operational Requirements for Standardized Dry Fuel Canister Systems" [13], a re-useable bare fuel transportation cask design study [14], and the site-specific de-inventory reports [5, 6, 7, 8, 9, 10]. The process steps and their estimated durations were developed for each of the potential transportation modes and sub-modes.

The process steps and duration estimates can be used to estimate the overall time required between when a consist arrives with empty casks at a reactor site or intermodal transfer location and when it departs with full casks. Figure 3 shows this cycle time assuming a 5-car train consist for each transportation mode and sub-mode.

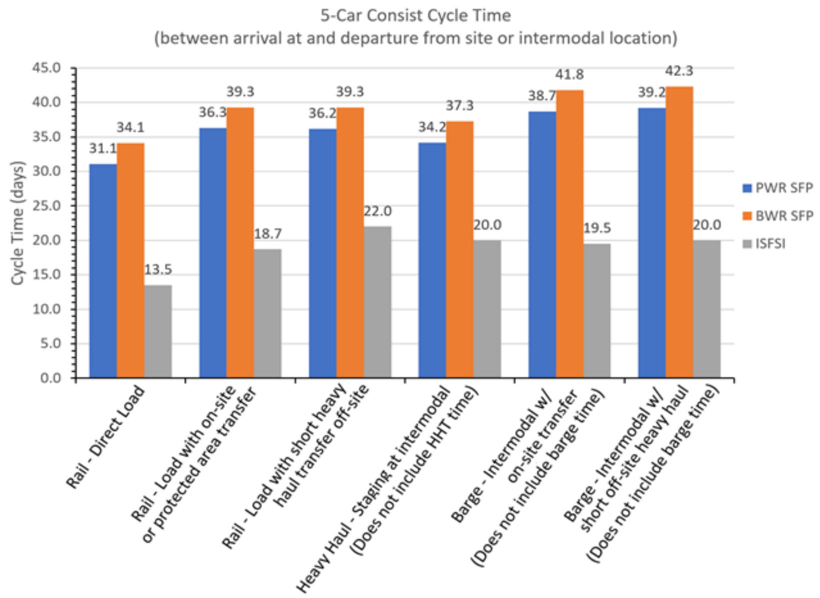

Figure 3. Estimated Duration for Cycling a 5-Car Train Consist for Different Transportation Modes and Sub-Modes.

It can be seen that the cycle times for SNF being transported from an SFP would be significantly longer than the cycle times for SNF that would be transported from an ISFSI. This is due to having to load individual fuel assemblies and to dry and close the canister/cask. The cycle times for a given transportation mode also increase for sub-modes that require the transfer of casks from the SFP or the ISFSI to either the rail consist located at a site or to the site's barge slip/dock. Sub-modes that require a short off-site HHT transfer have cycle times that are longer than onsite transfer.

Next Generation System Analysis Model (NGSAM) Implementation

Approaches for implementing at-reactor transportation information presented herein into IWM system analyses, and specifically the NGSAM model, are planned to be implemented in the future. In general, both a simple and a more complicated path forward have been proposed for each instance. In some cases, the simple path forward has already been implemented or is in the process of being implemented.

To provide one example of how this information could be used in system analysis, two approaches are recommended for reactor site availability:

- Set a maximum number of casks that could be shipped from the SFP and ISFSI each year.
- Explicitly model reactor site availability in NGSAM.

Ideally, explicitly modeling reactor site availability within NGSAM, and having the simulation tool determine the number of casks that could be shipped annually based on the cask processing times for the site-specific transportation modes and sub-modes, would be preferred. However, the logic and algorithms required to implement this approach may be complex. The simpler approach of setting the maximum number of casks that could be shipped annually is adequate for IWM system analyses at this time, and therefore has already been implemented. The more complex method is planned to be implemented in the future. Recommendations on how to best implement other information discussed in this report in system analysis have been developed as well.

References

[1] WILLIAM M. NUTT and N. HICKS, Preliminary Evaluation of SNF Transportation Infrastructure at Operating Commercial Nuclear Power Plant Sites, Proceedings of the WM2018 Conference, March 18–22, 2018, Phoenix, Arizona, USA (2018).

[2] GOOGLE, INC. 2017. Google Maps; map data ©2017 Google. Available at www.google.com/maps.

[3] M. ABKOWITZ and E. BICKFORD, Development and Application of the Stakeholder Tool for Assessing Radioactive Transportation (START), Proceedings of the WM2016 Conference, March 6–10, 2016, Phoenix, Arizona, USA (2016).

[4] NORTH WIND SERVICES, Stakeholder Tool for Assessing Radioactive Transportation (START): Version 1.2.1 User Manual, Report No. FCRD-NFST-2014-000092, Rev. 2 (2015).

[5] AREVA FEDERAL SERVICES LLC, Maine Yankee De-Inventory Study, RPT-3016127-000 (2016).

[6] AREVA FEDERAL SERVICES LLC, Initial Site-Specific De-Inventory Report for Big Rock Point, RPT–3014537-002 (2017).

[7] AREVA FEDERAL SERVICES LLC, Initial Site-Specific De-Inventory Report for Connecticut Yankee, RPT – 3014538-002 (2017).

[8] AREVA FEDERAL SERVICES LLC, Initial Site-Specific De-Inventory Report for Humboldt Bay, RPT–3015142-004 (2017).

[9] AREVA FEDERAL SERVICES LLC, Initial Site-Specific De-Inventory Report for Kewaunee RPT-3019262-000 (2017).

[10] AREVA FEDERAL SERVICES LLC, Initial Site-Specific De-Inventory Report for Trojan, RPT-3016128-002 (2017).

[11] S. J. MAHERAS, R. E. BEST, S. B. ROSS, K. A. BUXTON, J. L. ENGLAND, P. E. MCCONNELL, L. M. MASSARO, and P. J. JENSEN. Preliminary Evaluation of Removing Used Nuclear Fuel from Shutdown Sites, Report No. SFWD-IWM-2017-000061, US Department of Energy, Washington, DC (2017).

[12] P. MOSES, C. TRAIL, and W. NUTT, A Classification of Commercial Nuclear Reactor Sites and the Subsequent Impacts on Preparing Spent Nuclear Fuel for Shipment, WM2017 Conference, March 5–9, 2017, Phoenix, Arizona, USA (2017).

[13] ENERGYSOLUTIONS, NAC INTERNATIONAL, EXELON NUCLEAR PARTNERS, BOOZ ALLEN HAMILTON, DOE Advisory and Assistance Services Contract, Task Order 21: Operational Requirements for Standardized Dry Fuel Canister Systems, Updated Final Report (2015).

[14] AREVA FEDERAL SERVICES LLC, Task Order 17 – Cask Design Study Final Report, Report No. RPT-3011681-000, March 25 (2015).