Proceedings of the 18th International Symposium on the
Packaging and Transportation of Radioactive Materials
PATRAM 2016
September 18-23, 2016, Kobe, Japan

Paper No. 5046

Analysis of Transportation Options for Commercial Spent Fuel in the U.S.

Elena A. Kalinina
Sandia National Laboratories

Ingrid K. Busch
Oak Ridge National Laboratory

Abstract

The U.S. Department of Energy (DOE) is laying the groundwork for implementing interim storage and associated transportation of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) consistent with the Administration's Strategy for the Management and Disposal of Used Nuclear Fuel. This includes preparing for large-scale transportation of commercial SNF from reactor sites to a consolidated interim storage facility (ISF) and/or repository. Transportation system analysis is being conducted to help inform these efforts and this paper describes some initial high-level analysis results.

The U.S. commercial SNF inventory is projected to be approximately 140,000 MTU by 2055. The transportation of this SNF would require a large-scale shipping campaign spread over at least a few decades. Developing and operating such a transportation system successfully necessitates advance planning to address various technical and programmatic challenges. This task is further complicated by the uncertainties involving the waste management system including future SNF management practices, and locations of potential interim storage facilities and a repository for commercial SNF.

The purpose of this study was to provide an initial high-level evaluation of what it would take to transport all of the SNF from shutdown and currently operating U.S. commercial reactor sites while accounting for the uncertainties in the waste management system and using timing assumptions from the Administration's Strategy. This evaluation was not meant to provide specific details or suggest specific options. Rather, it was designed to identify the issues that might be important for planning transportation campaigns in the future.

The logistics analysis results provided information regarding the potential size of the transportation fleet; the number of trips; and the number of loaded consist miles. The results of the cost analysis provided the Rough Order of Magnitude (ROM) capital, operational, and maintenance costs of the transportation system. This study produced system-level data and offered useful insights for a large-scale commercial SNF transportation capability and its role as an integral part of the broader waste management system.

Introduction

The U.S. Department of Energy is laying the groundwork for implementing interim storage and associated transportation of spent nuclear fuel and high-level radioactive waste consistent with the Administration’s Strategy for the Management and Disposal of Used Nuclear Fuel [Ref. 1]. This includes preparing for large-scale transportation of commercial SNF from reactor sites to a consolidated interim storage facility and/or repository. Transportation system analysis is being conducted to help inform these efforts.

The U.S. commercial SNF inventory is projected to be approximately 140,000 MTU by 2055 [Ref. 2]. The transportation of this SNF would require a large-scale shipping campaign spread over at least a few decades. Developing and operating such a transportation system successfully necessitates advance planning to address various technical and programmatic challenges. This task is further complicated by the uncertainties involving the waste management system including future SNF management practices, and locations of potential ISF(s) and a repository for commercial SNF.

The purpose of this study was to provide an initial high-level evaluation of several options of transporting all of the SNF from shutdown and currently operating U.S. commercial reactor sites using timing assumptions from the Administration’s Strategy. Two groups of scenarios were considered: with and without an ISF. This evaluation was not meant to provide specific details or suggest specific options. Rather, it was designed to identify the issues that might be important for planning transportation campaigns in the future.

This analysis is a continuation of the work presented in Kalinina and Busch [Ref. 3] with the emphasis on the impacts of ISF on the total transportation cost and distance traveled with loaded rail consists. The impacts considered in Ref. 3 included the different at-reactor practices (type of canisters loaded), time required for loading and unloading SNF for transportation, and train speed on the mainline rail. The other transportation studies [Ref. 4-9] were more detailed, but focused only on the unloading shutdown reactor sites.

The transportation costs were evaluated as a part of the waste management system analysis presented in Ref. 10 and 11. Compared to the other costs (repository, at-reactor, ISF, and repackaging), the transportation costs are small. They constitute 4% to 6% of the total waste management system cost [Ref. 11]. Note that the total cost in this evaluation did not include taxpayer costs associated with Judgment Fund payments to utilities as the result of partial breach of contract litigation between utilities and DOE.

This analysis focuses on transportation. It does not compare the transportation costs to the other waste management costs.

Transportation Analysis Setup

The analysis was done with the Transportation Operations Model (TOM) [Ref. 12]. TOM calculates the resources (transportation casks and vehicles) required for meeting the specified pickup schedule, the timing of each trip (its transportation cycle), and all associated capital, operational, and maintenance costs. TOM assumes that a rail consist arrives with empty transportation casks into which the canisters will be loaded[11], unless the transportation casks exist at the site. TOM attempts to use maximum consist size defined by the user. TOM builds as many of the largest-sized consists permitted at the pickup site as possible and then adds another less-than-maximum-sized consist to move the remaining casks. The consist size refers to the number of cask cars. One escort car and two buffer cars are added to each consist.

The majority of the input parameters used in TOM calculations are defined in the TOM database. These include the locations of all the reactor sites, the transportation routes and options (rail, barge, and heavy haul as applicable), the empty and loaded weight of the casks, the processing times (cask loading and unloading, fleet and cask maintenance, and inspections), the cask and rolling stock costs, and other data required for simulations. The transportation is by rail only if the reactor sites have direct rail access to rail. If no direct rail access is available, either heavy-haul or heavy-haul and barge transportation to the nearest rail node are used.

The pickup schedule is the major input into the TOM calculations. The pickup schedules are generated with CALVIN [Ref. 13] and are based on different allocation strategies and at-reactor practices. CALVIN selects SNF from among the appropriate reactor sites from at-reactor pools and dry storage that meet site-specific transportation thermal limits. The resulting pickup schedule indicates how many casks and what types of casks need to be picked up from each site during each year of the transportation campaign.

Two groups of scenarios were considered: with and without an ISF (Figure 1). The pickup schedules for these scenarios were generated using the same allocation strategy - oldest-fuel-first between the reactor sites; priority allocation for the existing shutdown reactors sites; and fuel from a dry storage-only allocation strategy[2]. Different at-reactor practices were used as described below. It was also assumed that the ISF and repository acceptance rate is 3,000 MTU/year, an ISF is located in the southeastern U.S. and is available in 2021, and a repository is located in southwestern U.S. and is available in 2048.

---

[1] 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.

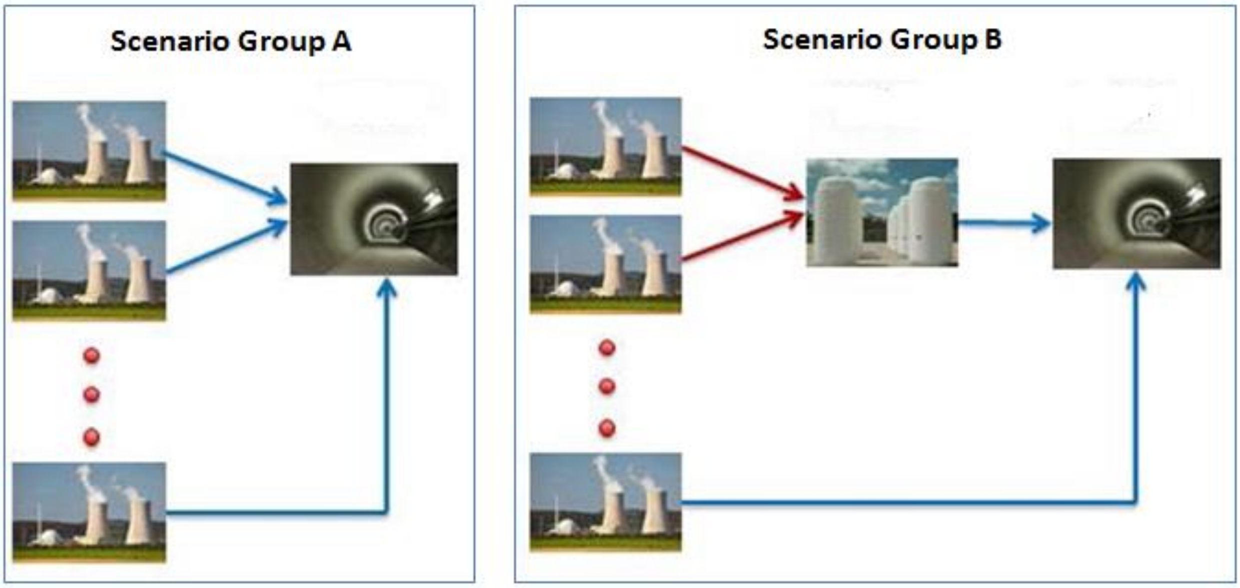

Figure 1. Two Transportation Schemes Considered in the Transportation Analysis

The group A scenarios assume that the SNF will be transported from the reactor sites directly to a repository. The group B scenarios assume that the SNF will be transported from the reactors sites to the ISF from 2021 to 2048. Starting in 2048 the SNF will be transported from the reactor sites and from the ISF directly to a repository.

Two general cases of “at-reactor practices” were considered. In the first case, it was assumed that the existing dual-purpose storage canisters (DPCs) will be loaded at reactor sites until all SNF is transported off site. In the second case, it was assumed that in the future the power plants that still have non-canistered SNF will switch to loading smaller, multi-purpose canisters (MPCs), whereMPCs are defined here the same as that used internationally: a sealed canister intended and designed for storage, transport, and disposal. The following dates of switching to MPCs were considered in this study: 2025, 2030, and 2036. The MPC capacity was assumed to be 12 assemblies for PWR SNF and 32 assemblies for BWR SNF. It was further assumed that a transportation overpack will be designed to transport one MPC. The smaller MPC capacity (4PWR/9BWR) was not considered because a few (presumably 4) of these MPCs can be placed in one transportation overpack. As a result, the potential impacts on the transportation should be smaller in the latter case.

Transportation Analysis Results

Table 1 presents the results of the transportation analysis of the scenarios with and without the ISF in terms of the ranges of the total cost, hardware acquisitions, and distance traveled by loaded consists. In these scenarios the maximum consist size was 3 SNF cask cars. Scenarios with the ISF cost $0.7B to $2.2B more than scenarios without ISF. However, the largest impact on the total cost ($2.2B to $4.4B), either with or without and ISF is due to the at-reactor (canister loading) practice. This is because the total transportation cost is driven by the operational costs, which compose about 80% of the total. Switching to the smaller canisters (MPCs) leads to more trips and results in higher total cost.

The annual total costs are similar in the corresponding scenarios with and without the ISF during 2048-2095. The additional total costs in the scenarios with the ISF are due to the costs incurred during the 2021 to 2048-time period when the transportation from the reactor sites to the ISF takes place.

The scenarios without the ISF have very similar hardware acquisitions. This is because the assumed switch to MPCs occurs before the transportation begins. The scenarios with the ISF have some variations in hardware acquisitions. This is because in the scenarios with MPCs, the additional large acquisitions occur in the year of the switch to MPCs and in the few years following the switch.

The scenarios with the ISF results in 0.6 to 4.3-million miles greater distances traveled with the loaded consists. However, the largest impact on the distance traveled (8.9 to 12.6-million miles) is due to the at-reactor canister loading practice. This is because switching to MPCs leads to more trips and more miles traveled.

Table 1. Summary of Transportation Analysis Results

Category	**Scenarios A (No ISF)**		**Scenarios B (ISF)**	
	Low	**High**	**Low**	**High**
Total Cost ($B)	**3.8**	**6.7**	**4.5**	**8.9**
Loaded consist miles (million)	**12.3**	**21.2**	**12.9**	**25.5**
Campaign duration (years)	**47**		**74**	
Acquisition Summary				
Cask railcars	**50**	**63**	**65**	**83**
Buffer railcars	**36**	**56**	**48**	**60**
Escort railcars	**18**	**28**	**24**	**30**
Total number of vehicles	**104**	**147**	**137**	**173**
Transportation overpacks	**183**	**193**	**283**	**361**

Note that in all scenarios about 10% of the total cost is the heavy-haul operational cost. There are 25 reactor sites requiring heavy-haul transportation to the nearest rail node. Figure 2 shows the total highway miles for each of these reactor sites.

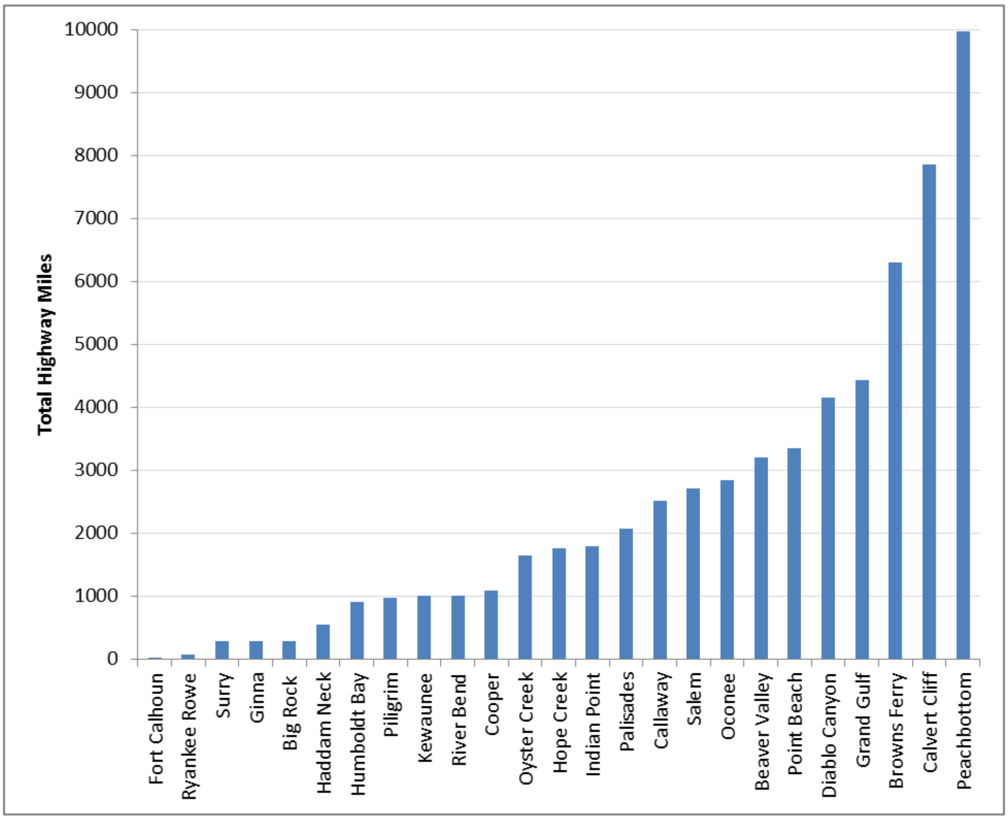

Figure 1. Total Highway Miles for the Reactor Sites without Direct rail Access.

As it was previously noted, the maximum consist size considered in the analysis was 3-cask cars. It was expected that using larger consists may result in the lower total costs and shorter total distance traveled. The scenarios without the ISF were re-calculated using maximum consist size of 2-, 4-, and 5-cask cars. The total transportation cost as a function of the maximum consist size is shown for one of the scenarios in Figure 3. The total transportation cost decreases with the increase in the maximum consist size. However, the difference between the scenarios with the different consist sizes are small.

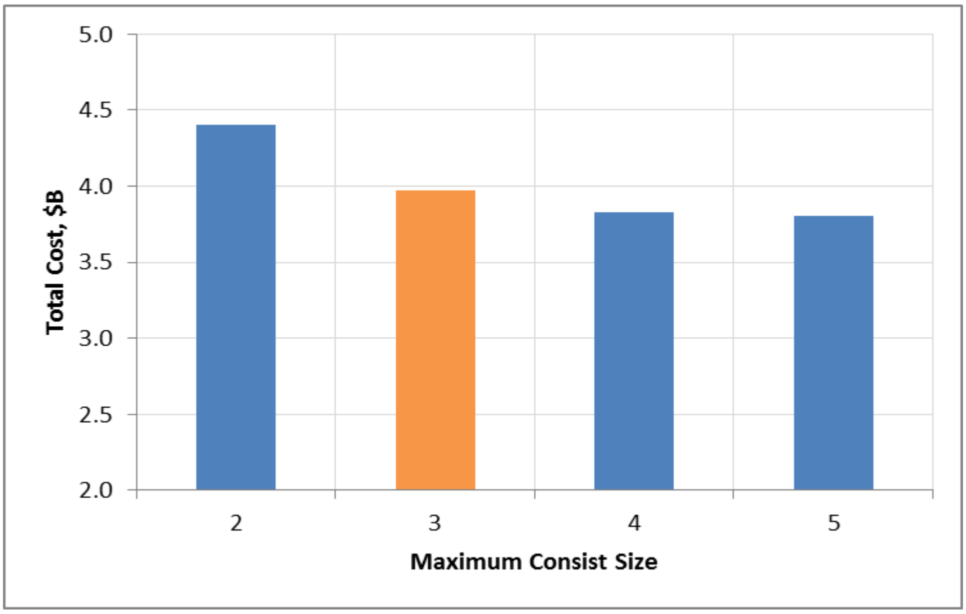

Figure 3. Total Cost as a Function of Maximum Consist Size in Scenario without ISF

Figure 4 explains why the variations in the total costs are small. This figure shows the number of trips with the different number of cask cars for each simulated maximum consist size. Because of the complexity of the pickup schedules, the maximum consist size is achievable in only 74% of the trips for the scenarios with the maximum consist size of 2, 50% of trips for the scenarios with the maximum consist size of 3, 31% of the trips for the scenarios with the maximum consist size of 4, and 20% of the trips for the scenarios with the maximum consist size of 5. As a result, the total cost and the distance traveled do not decrease significantly from the case with the maximum consist size of 2 casks to the case with the maximum consist size of 5 casks.

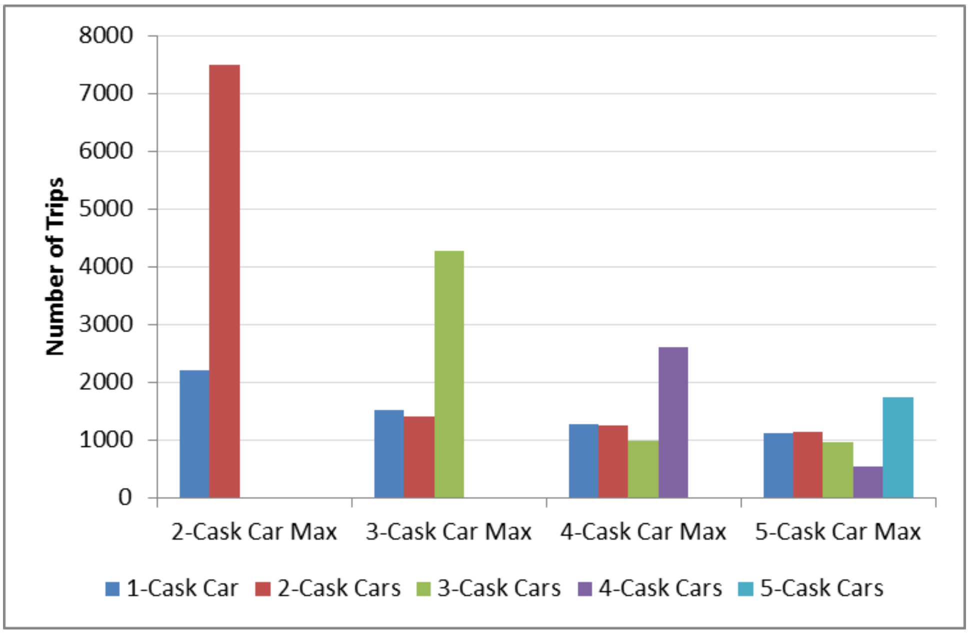

Figure 4. Distribution of the Trips with Different Number of Cask Cars in a Scenario without ISF as a Function of Maximum Rail Consist Size

Based on the results discussed above, it can be concluded that using larger rail consist sizes to unload reactor sites may not offer significant advantages with regard to transportation costs and travel distances. This is mainly due to the restrictions posed by the timing of pickups, their multiple locations, and availability of SNF. Transporting SNF from the ISF to the repository should not have these restrictions. The ISF should have an infrastructure designed to effectively manage all operations related to transportation. The availability of SNF should not be a problem because a significant inventory of SNF should be stored at the ISF by the time transportation from the ISF to the repository will take place. Finally, all shipments will originate at the same location (i.e., the ISF). It was hypothesized that using large maximum consist sizes for the SNF shipments between the ISF and repository may noticeable decrease the total costs and the total travel distances.

The scenarios with the ISF were re-calculated using different maximum consist sizes (5, 6, and 7-cask cars) from the ISF to the repository. The results of these calculations are shown for one of the scenarios with the ISF and are compared to the corresponding scenario without an ISF in Figures 5 and 6. Using a larger maximum consist size results in noticeably lower total costs and travel distances compared to the base case with the 3-cask car maximum consist size. For the case with the 7-cask car maximum consist size, the total cost in the scenario with the ISF is only $260M (4%) higher than in the scenario without the ISF. The total travel distance in the cases with 5, 6, and 7-cask car maximum consist sizes is smaller than in the scenario without the ISF. The larger maximum consist size (if feasible) would offer even greater benefits.

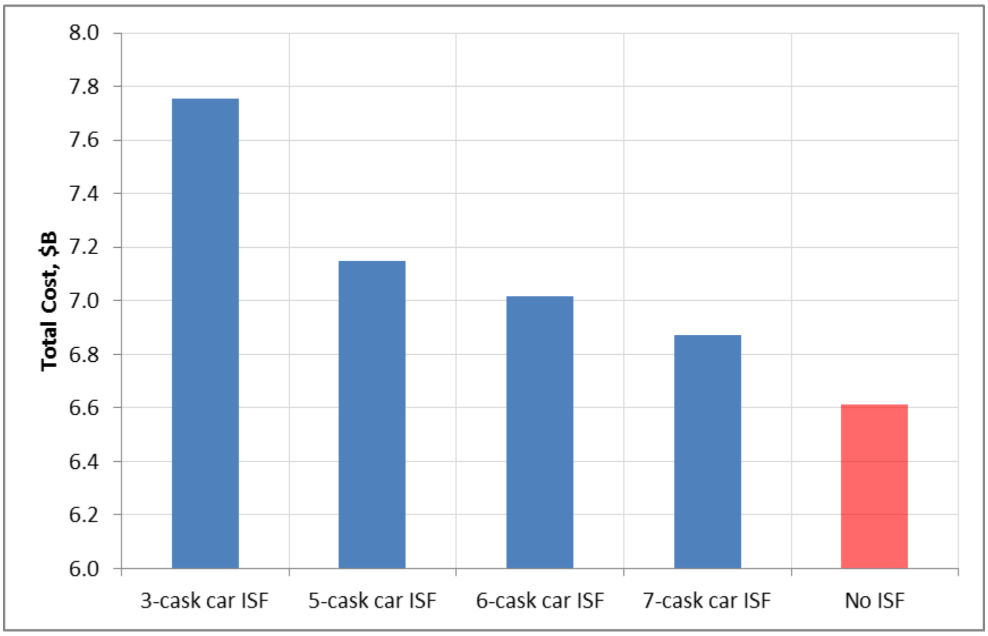

Figure 5. Total Cost as a Function of ISF-to-Repository Maximum Rail Consist Size

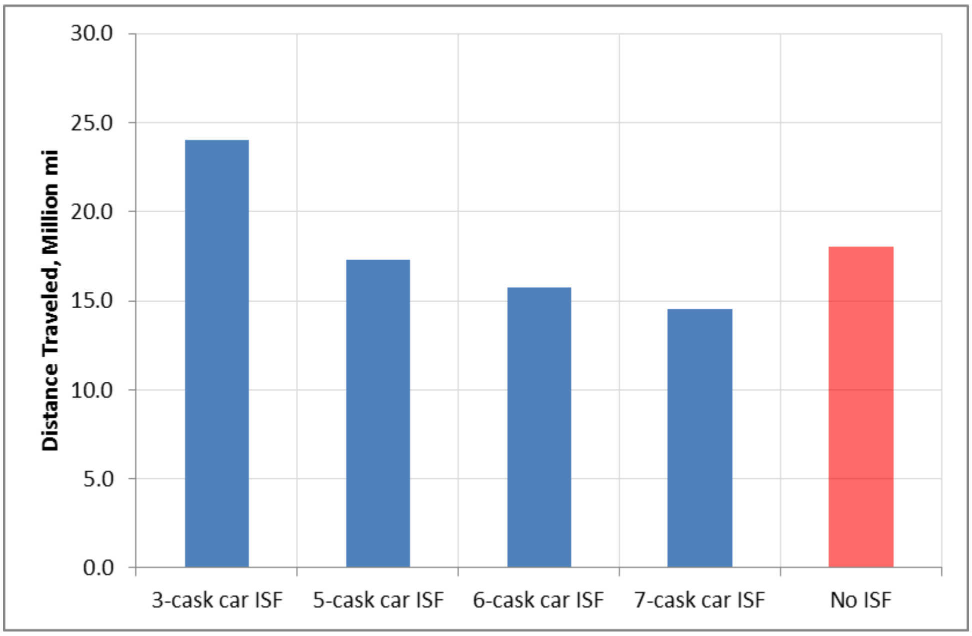

Figure 6. Total Loaded Rail Consist Travel Distance as a Function of ISF-to-Repository Maximum Consist Size

Figure 7 shows the annual travel distance for the same scenarios as the ones in Figures 5 and 6. The distance traveled from the reactor sites to the ISF in the scenario with an ISF during 2021-2048 (no shipments in the scenario without ISF) is "compensated" by a smaller distance traveled during 2048-2094 compared to the scenario without an ISF.

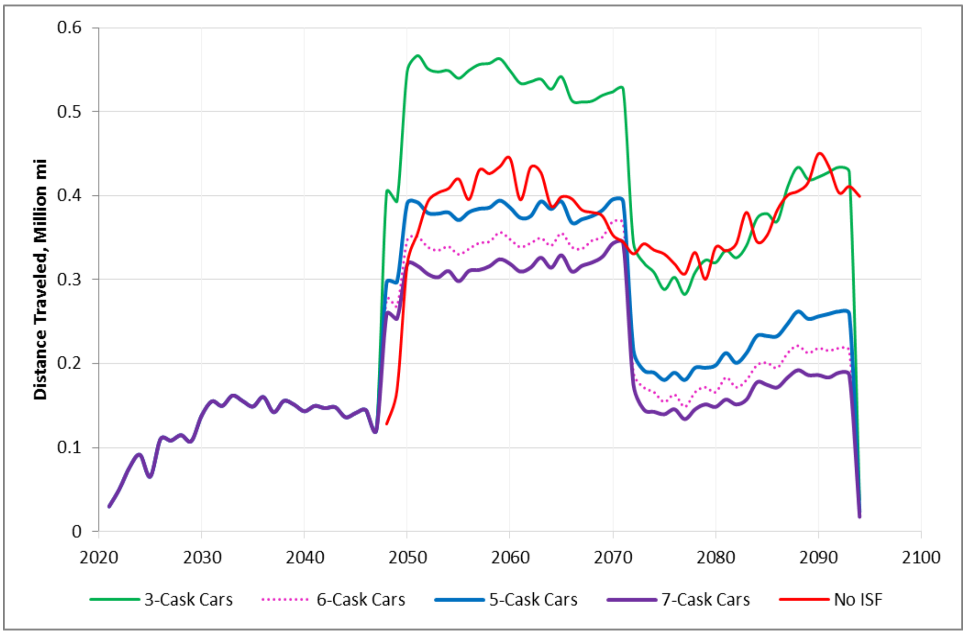

Figure 7. Annual Loaded Rail Consist Travel Distance as a Function of ISF-to-Repository Maximum Consist Size

The transportation campaign will require acquiring large number of transportation overpacks (Table 1). This is due to the large variety of the SNF canisters used at the reactor sites. Different types of canisters will require different overpacks. One way to minimize the cask acquisition is to use a universal transportation cask that can accommodate any type of dry canister and fuel. This analysis considered a hypothetical scenario in which an imaginary universal transportation cask was used for all shipments.

Using the universal transportation cask allows for a significantly smaller fleet of transportation casks. Only 31 universal casks were needed in the hypothetical scenarios to conduct the transportation campaign. However, the impact on the total cost and travel distances are small. Using the universal cask resulted in a 6.5% lower total transportation cost and 1.9% smaller travel distance. This is because the capital costs of transportation cask purchases are less than 20% of the total cost.

Conclusions

The purpose of this study was to provide an initial high-level evaluation of several options of transporting all of the SNF from shutdown and currently operating U.S. commercial reactor sites.

This evaluation was designed to identify the issues that might be important for planning transportation campaigns in the future.

Two groups of scenarios were considered: with and without an ISF. The total transportation cost in these scenarios ranged from $4B to $9B. The transportation fleet that would be required for the transportation campaign included 104 to 173 cars (cask railcars, escort railcars, and buffer railcars) and 183 to 361 transportation overpacks. The duration of the campaign was 47 years in the scenarios without an ISF and 74 years in the scenarios with an ISF. The total loaded rail consist miles ranged from 12.3 to 25.5 million miles.

The presence of an ISF in the waste management system raises questions related to the additional transportation costs and, especially, additional trips. This analysis demonstrated that the transportation campaign in scenarios withan ISF can be organized in such a way that the transportation costs would be comparable and the number of trips would be less than in the scenarios without an ISF.

The scenarios without an ISF were considered with different (2 to 5-cask car) maximum consist sizes. It was concluded that using larger consist sizes to unload the reactor sites may not offer significant advantages with regard to transportation costs and travel distances. This is mainly due to the restrictions posed by the timing of pickups, their multiple locations, and availability of SNF. As a result the greater the maximum consist size, the more trips that are done with smaller than the maximum consist size.

The scenarios with an ISF were considered with different maximum consist sizes (5, 6, and 7-cask cars) from the ISF to the repository. Using larger maximum consist size results in a comparable total cost and smaller distance traveled compared to the scenarios without an ISF. For the case with the 7-cask car maximum consist size, the total cost in the scenario with the ISF is 4% higher than in the scenario without the ISF. The total travel distance in the cases with 5, 6, and 7-cask car maximum consist size is smaller than in the scenario without the ISF. The larger maximum consist size (if feasible) would offer even greater benefits.

A hypothetical scenario in which an imaginary universal transportation cask was used for all the shipments was evaluated. Using the universal transportation casks allows for a significantly smaller transportation fleet (31 universal casks). However, the impacts on the total cost and travel distances are small: 6.5% lower total transportation cost; and 1.9% smaller travel distance. This is because the major benefit from the universal cask is in smaller capital costs and the capital costs are less than 20% of the total cost.

Acknowledgments

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

References

1. DOE 2013, *Strategy for the Management and Disposal of UNF and High Level Radioactive Waste*, January 2013.
2. Nutt, W.M., Puig, F., Morris, E., Park Y.S., Joseph, R., Peterson, G., Giuliano, D., and Howard, R., 2013. *Used Fuel Management System Architecture Evaluation, FY2013*. FCRD-NFST-2013- 000377, Draft REV 01.
3. Kalinina, E.A. and Busch, I.K., 2015. *Transportation of Spent Nuclear Fuel from Reactor Sites in the US – What Will It Take?* Proceedings, International Radioactive Waste Management Conference, Charleston, South Carolina, April 12-16, 2015.
4. Kalinina, E.A., Busch, I.K., McConnell, P.E., and Maheras, S.J., 2013. *Logistics Case Study for Shipping Used Nuclear Fuel from Shutdown Reactor Sites.* Proceedings, International Radioactive Waste Management Conference, Albuquerque, New Mexico, April 28-May 2, 2013.
5. Kalinina, E., Busch, I., McConnell, P., and Maheras, S., 2013. *Logistics Case Study for Shipping Used Nuclear Fuel from Shutdown Reactor Sites.* Radwaste Solutions, September-October Issue, 2013
6. Kalinina, E., McConnell, P., Busch, I., Maheras, S., and Best, R., 2013. *Transportation Operations Model Analysis for the Removal of Stranded Fuel from Shutdown Reactors*, 17th International Symposium on Packaging and Transportation of Radioactive Materials (PATRAM), August 18-23, 2013, San Francisco.
7. Maheras, S., Best, R., Ross, S., Buxton, K., England, J., McConnell, P., Massaro, L., and Jensen, P., 2014. *Preliminary Evaluation of Removing Used Nuclear Fuel from Shutdown Sites*, FCRD-NFST-2014- 000372, July 1, 2014.
8. Maheras, S., Best, R., McConnell, P., and Kalinina, E., 2014. *Optimizing Shutdown Sites Shipping Campaigns*, FCRD-NFST-2014-000369, PNNL- 23242, March 2014.
9. Maheras, S. J., Best, R. E., Ross, S. B., Buxton, K. A., England, J. L., and McConnell, P., 2013. *Preliminary Evaluation of Removing Used Nuclear Fuel from Shutdown Sites, Rev. 1*, FCRD-NFST- 2013-000238, September 30, 2013.
10. Jarrell, J.J., Joseph III, R.A., Fortner, J.A., Hale, R.E., Howard, R.L., Kalinina, E.A., Petersen, G.M., Wilkerson, R.B., 2015. *Initial Evaluation of Standardized Canisters in the Waste Management System*, International High Level Radioactive Waste Management Conference, 2015.
11. Jarrell, J.J., Joseph III, R.A., Cumberland, R., Petersen, G., Fortner, J., Kalinina, E.A., and

Severynse, T., 2016. *An Evaluation of Standardized Canisters in the Waste Management System*, Proceedings, Waste Management Symposium, Phoenix, AZ, March 2016.

12. Busch, I. K. and Howard, R., 2012. *Transportation Operations Model (TOM) Technical Manual*, FCRD- NFST-2012-000425, October 2012.
13. Nutt, M., Morris, E., Puig, F., Kalinina, E., and Gillespie, S., 2012. *Transportation Storage Logistics Model–CALVIN (TSL-CALVIN)*, FCRD-NFST- 2012-000424, October 2012.