Routing Options for Transporting Commercial Spent Nuclear Fuel in the Continental United States – 17504

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ABSTRACT

The U.S. Department of Energy (DOE) has a goal to develop solutions for the long-term, sustainable management of the nation's spent nuclear fuel and high-level radioactive waste. The DOE is planning for an integrated waste management system to transport, store, and dispose of spent nuclear fuel and high-level radioactive waste from commercial electricity generation, as well national defense activities.

The DOE Office of Nuclear Energy (DOE-NE), Office of Spent Fuel and Waste Disposition's (SFWD) Integrated Waste Management (IWM) program is applying integrated waste management system analysis, system engineering, and decision analysis principles to inform future decisions regarding potential future nuclear waste management system architectures. Integrated waste management system architecture analyses are being conducted to support the future deployment of a comprehensive system for managing nuclear waste that considers all aspects of the back-end of the nuclear fuel cycle (transportation, storage, and disposal). One aspect of a potential future nuclear waste management system is transportation of spent nuclear fuel from the fleet of commercial nuclear reactors to destinations where waste management facilities, such as an interim storage facility, would be located.

Example rail transportation routes from commercial nuclear reactor sites to various locations in the continental U.S. - chosen as hypothetical locations for future waste management system facilities - were evaluated in 2014 using DOE's GIS-based Stakeholder Tool for Assessing Radioactive Transportation (START). The objective of that evaluation was to identify and parameterize generic transportation routes for use in integrated waste management system analyses, the associated uncertainty in these selections, and the uncertainty associated with different transportation route selection criteria.

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A new version of START, version 2.0, was released in 2016, requiring an update to the 2014 generic transportation route determination and evaluation. This paper describes that update, discusses additional results that were not presented in 2014, and provides new recommendations regarding hypothetical 'proxy' destinations for use in future integrated waste management system analysis.

INTRODUCTION

The U.S. Department of Energy envisions the deployment of an integrated system capable of transporting, storing, and disposing of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) from civilian nuclear power generation, defense programs, national security, and other activities. Commercial nuclear power reactors have been generating electricity in the United States for nearly 60 years, and the SNF generated continues to be stored at the reactor sites. The transportation of commercially generated SNF to future waste management facilities, such as an interim storage facility (ISF) or geologic repository, is a key part of the integrated waste management system.

Integrated waste management system analysis, system engineering, and decision analysis principles are being used to inform future decisions regarding potential future nuclear waste management system architectures. System-level analyses of the overall interface between at-reactor, consolidated storage, and ultimate disposition have been underway since 2012 [1-4] to provide the DOE and others with information regarding the various alternatives for managing SNF generated by the current fleet of light water reactors operating in the U.S. The objectives of the integrated waste management system analysis are to:

- Provide quantitative information with respect to a broad range of SNF management alternatives and considerations;
- Develop an integrated approach to evaluating storage, transportation, and disposal options, with an emphasis on system-wide flexibility;
- Evaluate impacts of storage choices on SNF transportation, handling, and disposal options;
- Identify alternative strategies and their respective costs and flexibility factors; and
- Consider a broad range of SNF and HLW factors including repository emplacement capability, thermal constraints, repackaging needs, storage and transportation alternatives, and impacts on utility operations.

These analyses produce a range of transportation-related metrics for different potential future waste management system configurations and operational scenarios. However, in order to generate these output metrics, transportation routes between origin sites and hypothetical destinations must be selected and the attributes of the routes quantified. Since destination sites have yet to be determined, it is necessary to identify generic, hypothetical destination locations for transportation routes in order to conduct preliminary integrated waste management system analyses. It is also necessary to understand the associated uncertainty in the use of hypothetical destination sites along with the uncertainty associated with different transportation route selection criteria.

The analysis presented herein considers rail transportation routes from commercial nuclear reactor sites to hypothetical destinations within the continental U.S.

START

DOE's Stakeholder Tool for Assessing Radioactive Transportation (START) is a web-based routing tool developed by DOE-NE [5]. START is a decision support tool that can evaluate a wide range of transportation options while considering multiple performance objectives. START allows users to generate data for a wide range of transportation routing scenarios.

A user can create routes between origin and destination points based on four route selection criteria (minimum travel time, minimum distance, minimum population, and a combination of minimum travel time and minimum population with the user able to select different weighting factors). Heavy-haul truck, legal weight truck, rail, barge, or multi-modal routes can be created and analyzed. Route attributes such as distance traveled, total travel time, and population along the route in a pre-defined buffer distance are produced for each route.

A previous version of START was used in 2014 to identify hypothetical 'proxy' destinations for waste management system facilities and example associated transportation routes for use in integrated waste management system analyses [6]. This work expands upon the 2014 effort and takes into account the modifications and enhancements incorporated in version 2.0 of the START software. These modifications and enhancements include: updated data layers based on 2015 sources, a new rail network, and improved highway routing algorithms.

ROUTE GENERATION

START was utilized to generate example rail routes between commercial nuclear reactor sites and various locations in the continental U.S. Routes were generated from all 74 commercial nuclear reactor sites, including both operating and shutdown nuclear reactors. Before selecting the route origin, each commercial nuclear reactor site was evaluated to determine if it had direct rail access through the review of satellite imagery of the sites using internet mapping applications. If direct rail access to a site was available, the route origin was placed at the site.

If direct rail access was unavailable at a site, the nearest reasonable location was identified where a large transportation cask could be trans-loaded from a heavy-haul truck to a rail car. This location was used as the origin for the site. It is recognized that it may be possible to transport SNF via barge to an intermodal site where SNF casks would be transferred to a rail car. However, barge-to-rail transfer sites were not considered as origins in this analysis. Sites without direct rail access are:

Big Rock Point	Grand Gulf	Oyster Creek	Seabrook
Browns Ferry	Connecticut Yankee	Palisades	South Texas
Callaway	Hope Creek	Peach Bottom	St. Lucie
Calvert Cliffs	Humbolt Bay	Perry	Surry
Cooper	Indian Point	Pilgrim	Turkey Point
Diablo Canyon	Kewaunee	Point Beach	Watts Bar
Fitzpatrick	Nine Mile Point	River Bend	Yankee Rowe
Ginna	Oconee	Salem	

The approximate geographic centers of each state in the continental U.S. were selected as destination locations. In some cases, state size and proximity lead to a decision to group states together. This was done for Delaware and Maryland, as well as for the New England states of Massachusetts, Rhode Island, Connecticut, New Hampshire, Vermont, and Maine. The approximate centers of each of the regions designated by the Nuclear Regulatory Commission (NRC) for regulatory and oversight purposes were also selected as destination locations. Due to its large size, NRC Region IV (west) was divided into a northwest region and a southwest region as shown in Figure 1.

These groupings resulted in 42 total “state-center” destinations and 5 “NRC region-center” destinations. In total, 3,108 reactor site to “state-center” routes and 370 reactor site to “NRC region-center” routes were generated in START using the “minimum travel time” route selection criterion and the attributes of each route were collected.

ROUTE ANALYSIS

The amount of time that a transportation asset, such as a rail car or a transportation cask, is in use is important in integrated waste management system analysis because it affects the number of transportation assets that would be necessary to complete clearing of all SNF from the reactor sites. This overall time includes the time required to stage the assets at the reactor sites, load SNF casks onto the rail cars, conduct pre-shipment inspections, and travel to the destination site (including any stops for fuel, crew changes, and inspections). However, START only outputs the time the transportation assets would be traveling between the origin and destination sites and does not include any stops for fuel, crew changes, and inspections. Delays associated with stops along the route are currently not known, but are likely to be proportional to the length of a route (and the time in transit along a route). In addition, several other factors that could cause delay, such as the time to load transportation casks and/or the time to transfer transportation casks from heavy haul trucks to rail cars, are site-specific and would be the same for any routes between a site and the destination.

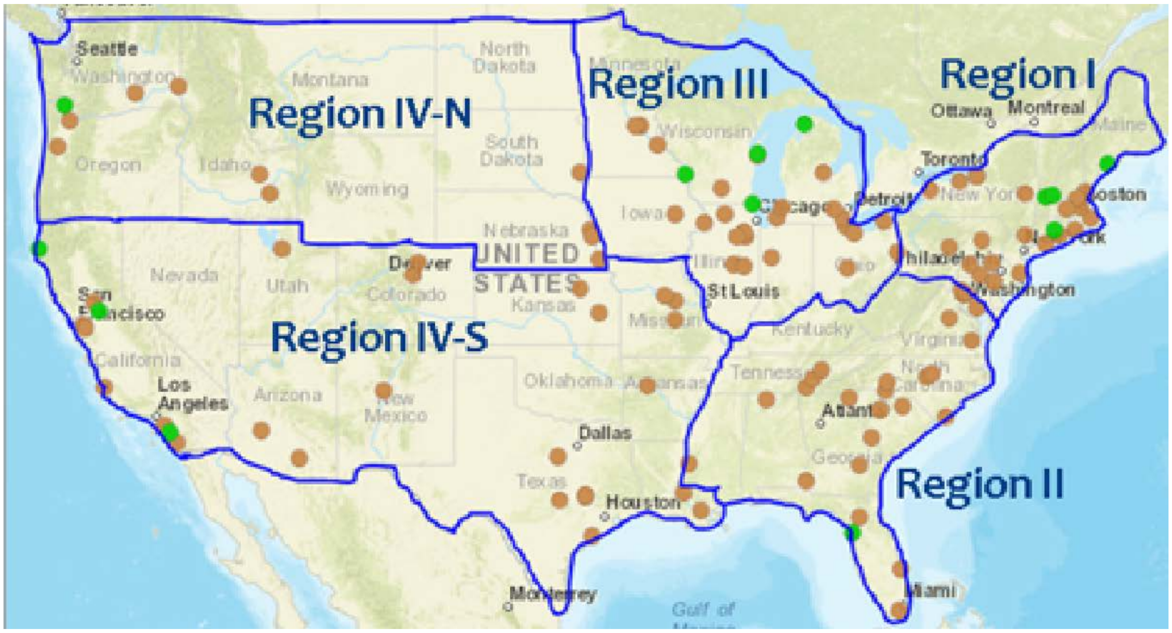

Fig. 1. Nuclear Reactor Sites and NRC Regions Used in Transportation Routing Analysis

Given this, an appropriate metric to use to determine hypothetical ‘proxy’ destinations for use in future integrated waste management system analysis is the total amount of time that transportation assets would be in transit while transporting all SNF from a reactor site over its operational lifetime to a destination site. This analysis compares the total time that transportation assets would be in transit while transporting all SNF along routes from all sites to destinations at “state-center” with destinations at “NRC region-centers.”

This total transit time was estimated using Equation 1 using the time to transport SNF on a route between a reactor site and a destination location that is provided by START.

$$T_{Dest} = \sum_{N_{Sites}} \left(N_{Ship-Site} \times t_{Site-Dest}\right) \qquad \text{Eq. 1}$$

Where:

- T_{dest} = Total time that transportation assets would be in transit while transporting all SNF from all sites to a destination
- $t_{site\text{-}dest}$ = Total time needed to transport all SNF from a single site to a destination (START output for each route)
- $N_{Ship\text{-}Site}$ = Total number of shipments needed to remove all SNF from a site
- N_{Sites} = Total number of sites (74)

The total number of shipments needed to remove all SNF is estimated using Equation 2.

$$N_{Ship-Site} = \frac{I_{SNF-Site}}{C_{Capacity} \times TR_{Size}} \qquad \text{Eq. 2}$$

Where:
- $N_{Ship\text{-}Site}$ = Total number of shipments needed to remove all SNF from a site
- $I_{SNF\text{-}Site}$ = The amount of SNF that will ultimately be generated at a site
- $C_{Capacity}$ = The capacity of a SNF transportation cask
- TR_{size} = The number of casks that would be carried on a train

The inventory of SNF that would be generated by all reactors on a site over their operational lifetimes, measured in terms of Metric Tons of Heavy Metal (MTHM) was obtained for every reactor site [7]. It was assumed that the capacity of a SNF transportation cask was 10 MTHM and that a train would carry 3 casks. It is recognized that the actual train capacity (or train consist size) could be larger or smaller, depending on factors such as the availability of transportation casks and rolling stock, availability of space at the loading site to stage railcars, and turnaround times for cask loadings.

The estimated total amount of time that would be needed to transport all SNF from all reactor sites over their operational lifetime to a destination site at the center of each state and at the center of each NRC region is shown in Tables I(a) – I(e). Table I also shows the difference in the total travel times between a destination at the center of an NRC region and a destination at the center of each state in that region.

Table I. Total Travel Time to Transport all Commercial SNF from all Reactor Sites to Hypothetical Destinations

a) Transport Destinations: Northeast Region

		MD-DE	New England	NJ	NY	PA
		Region I (Northeast)				
Total time needed to transport all SNF from all sites to a destination (transportation - days)	State Center	8969	14605	10277	10544	10752
	Region Center	10764				
State - Region Center Difference	transportation-days	1795	-3841	487	219	12
	%	17%	-36%	5%	2%	0%

Transportation-days are the number of days that transportation assets are in transit for the transportation of all SNF from all reactor sites to the destination.

Table I (cont.). Total Travel Time to Transport all Commercial SNF from all Reactor Sites to Hypothetical Destinations

b) Transport Destinations: Southeast Region

		AL	FL	GA	KY	LA	MS	NC	SC	TN	VA	WV
		Region II (Southeast)										
Total time needed to transport all SNF from all sites to a destination (transportation - days)	State Center	8456	11281	9028	8239	10923	10144	9878	8902	8090	8925	11692
	Region Center	8270										
State - Region Center Difference	transportation-days	-186	-3011	-758	32	-2653	-1874	-1607	-632	180	-655	-3421
	%	-2%	-36%	-9%	0%	-32%	-23%	-19%	-8%	2%	-8%	-41%

Transportation-days are the number of days that transportation assets are in transit for the transportation of all SNF from all reactor sites to the destination.

c) Transport Destinations: Midwest Region

		IA	IL	IN	MI	MN	OH	WI
		Region III (Midwest)						
Total time needed to transport all SNF from all site to a destination (transportation-days)	State Center	10303	8692	8536	10156	12870	10313	10527
	Region Center	9417						
State - Region Center Difference	transportation-days	-886	725	881	-739	-3453	-896	-1110
	%	-9%	8%	9%	-8%	-37%	-10%	-12%

Transportation-days are the number of days that transportation assets are in transit for the transportation of all SNF from all reactor sites to the destination.

d) Transport Destinations: Northwest Region

		ID	MT	ND	NE	OR	SD	WA	WY
		Region IV-N (Northwest)							
Total time needed to transport all SNF from all site to a destination (transportation-days)	State Center	19044	17999	14442	12578	24123	15358	22624	16036
	Region Center	17990							
State - Region Center Difference	transportation-days	-1054	-9	3548	5412	-6133	2632	-4633	1954
	%	-6%	0%	20%	30%	-34%	15%	-26%	11%

Transportation-days are the number of days that transportation assets are in transit for the transportation of all SNF from all reactor sites to the destination.

Table I (cont.). Total Travel Time to Transport all Commercial SNF from all Reactor Sites to Hypothetical Destinations

e) Transport Destinations: Southwest Region

		AR	AZ	CA	CO	KS	MO	NM	NV	OK	TX	UT
		Region IV-S (Southwest)										
Total time needed to transport all SNF from all site to a destination (transportation-days)	**State Center**	9603	18286	22589	14726	11910	10292	14559	20601	11437	13881	19847
	Region Center	15988										
State - Region Center Difference	**transportation-days**	6385	-2299	-6601	1262	4077	5696	1429	-4613	4551	2106	-3859
	%	40%	-14%	-41%	8%	26%	36%	9%	-29%	28%	13%	-24%

Transportation-days are the number of days that transportation assets are in transit for the transportation of all SNF from all reactor sites to the destination.

RESULTS

The total travel times needed to transport all commercial SNF from all reactor sites over their operational lifetime to a hypothetical destination site estimated using START version 2.0 are compared to those estimated in a prior version of START (version 1.0) [6] in Table II. The results compare well for the Northeast, Southeast, and Midwest regions. The minor differences are attributed to slightly different choices in destination locations and due to the changes in the rail network used in START version 2.0. The differences are much larger in the Northwest and Southwest regions. This is attributed to the current selection of destinations that are closer to the center of the regions than those selected in START v1.0.

From the data found in both Tables I and II, and consistent with the START v1.0 results [6], it can be seen that a destination located in the southeast would have the lowest total transportation travel time, with the Midwest and northeast regions being slightly longer. Destinations located in the northwest or southwest would result in significantly longer travel times. This is due to the fact that the majority of the reactor sites in the U.S. are located in the eastern half of the country.

It is important to emphasize that the actual travel times to a future destination would either be shorter or longer than those for the region centers, depending on the final designated location and the actual routes selected. The uncertainty due to lack of knowledge regarding the destination location can be seen for specific states in Table I and is summarized in Table III. Table III provides the range in the difference in total travel times between destinations at the center of a region and at the center of each state in that region, expressed as a percentage.

Table II. Comparison of Total Travel Time to Hypothetical Destinations at U.S. Region Centers: START v1.0 to START v2.0

Destination Region	Total Estimated Travel Time START 1.0 (days)	Total Estimated Travel Time START 2.0 (days)
Northeast (Region I)	11,700	10,764
Southeast (Region II)	8,700	8,270
Midwest (Region III)	9,400	9,417
Northwest (Region IV-N)	21,600	17,990
Southwest (Region IV-S)	15,000	15,988

Times based on the use of the START "Minimum Travel Time" route selection criterion

Prior analysis of potential integrated waste management system architectures indicate that transportation costs are typically on the order of 10% or less of the overall waste management system costs [6]. In addition, the actual transportation time is only a portion of the time that transportation assets would be in use. For example, those assets may also be in use while being loaded at the reactor sites and unloaded at an ISF. These times may be on the order of or larger than the time required to transport the SNF itself. Thus, the uncertainty associated with using generic representative proxies for the destination of waste management system facilities is not expected to be significant with respect to waste management system architecture analyses.

The earlier analysis with START v1.0 [6] recommended that the northeast, southeast, and midwest regions be combined and one hypothetical 'proxy' destination be used in future integrated waste management system analysis. The results shown above do not support such a combination because of the larger differences between regions and the range of uncertainty across each region. It is recommended that centers in each of these regions be considered as representative 'hypothetical' destinations for use in waste management system analyses. The earlier analysis with START v1.0 [6] also recommends that NRC Region IV (west) be split into a northwest and a southwest region. The results shown above support that recommendation.

The uncertainty associated with route selection criteria was quantified in the earlier evaluation with START v1.0 [6]. Those results indicated that the "minimum population" route selection criterion increases travel times by a factor ranging from 1.8 to 2.9 as compared to using the "minimum travel time" criterion for the selection of all routes, depending on the region. The "minimum sensitive environmental area" criterion for the selection of all routes was found to increase travel times by a factor of 2.9 to 4.5, compared to using the "minimum travel time" criterion, again depending on the region.

Table III. Travel Time Difference: Region Centers and State Centers

Region	Total Estimated Travel Time to Region Center (days)	Range in Difference Between Region and State Centers
Region I (Northeast)	10,764	(-36%) – (+ 17%)
Region II (Southeast)	8,270	(-41%) – (+ 2%)
Region III (Midwest)	9,417	(-37%) – (+ 9%)
Region IV-N (Northwest)	17,990	(-34%) – (+30%)
Region IV-S (Southwest)	15,988	(-41%) – (+ 40%)

Range in Difference Expressed as the minimum and maximum of (Region Center – State Center) / Region Center from the results shown in Table I

While this current effort did not repeat that quantification of travel time variation according to different route-selection criteria using START v2.0, it is expected that the results would be similar. Consistent with the previous work [6], it is recommended that for the purposes of future integrated waste management system analysis, the "minimum travel time" routing criterion be used for the selection of all routes between the reactor sites and the hypothetical 'proxy' destinations.

CONCLUSION

Hypothetical 'proxy' geographic destinations were used in this analysis for the purpose of quantifying a range of cumulative travel times for transportation of all commercial spent nuclear fuel in the US to a currently unknown storage or disposal location. Hypothetical destinations, distributed across the continental U.S., were used to generate example rail transportation routes, with associated travel times, from all U.S. nuclear power plant sites. While locations of storage and/or disposal facilities are as yet unknown, it is useful to conduct systems analysis to estimate various attributes of an integrated waste transportation system, including logistics needs, schedules, and costs for various activities, including SNF transportation.

Based on the analysis conducted here, it is recommended that the centers of five regions of the continental U.S. be used as hypothetical 'proxy' locations in future integrated waste management system analyses.

It is also recommended that the START "minimum travel time" routing criterion be used for the selection of all example routes between the reactor sites and the representative 'generic' proxy locations for simulating transportation logistics in future waste management system analyses.

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