A Proposed Path Forward for Standardization – 17131

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ABSTRACT

Incorporation of a standardized canister system into the commercial waste management system represents an opportunity to develop an integrated approach to storage, transportation, and disposal issues[a]. However, regardless of timing and method, deployment of such a system would have the potential to cause significant system-wide impacts. The current inventory of commercial spent nuclear fuel dry storage systems is diverse and increasing. In addition, the currently loaded systems are large-capacity systems (up to 37 pressurized water reactor assemblies or 89 boiling water reactor assemblies) that are now able to accommodate large (greater than 45 kilowatts) amounts of heat during storage, with the potential to accommodate fairly high heat loads (~32 kilowatts) for transportation as well. A standardized canister system designed with disposition in mind would likely be significantly smaller than the current systems and have dramatically lower heat limit maximums.

Over the past few years, the Department of Energy (DOE) Office of Nuclear Energy Fuel Cycle Technologies Nuclear Fuels Storage and Transportation Planning Project (NFST) has performed a number of system analyses using logistic simulations to evaluate the impacts of incorporating these smaller canisters into the commercial waste management system. These simulations predict the amount of resources (e.g., staff, canisters/casks, railcars, facilities), the size of facilities, and the timing of operations, as well as provide rough order-of-magnitude cost estimates. In addition to system analyses, DOE funded efforts by Energy*Solutions* to develop a generic design of a small-capacity standardized canister system and investigate innovative operational approaches to minimize the at-reactor operational impacts of loading such smaller canisters. A result of Energy*Solutions*' work was the development of a "canister-in-carrier" concept that would allow for loading, storing, transporting, and potentially disposing of groups of small canisters at the same time. With the inclusion of this new concept, the most recent system analyses show that incorporating standardized canister systems into the commercial waste management system has

[a] This technical paper reflects concepts which could support future decision-making by DOE. No inferences should be drawn from this paper regarding future actions by DOE. To the extent this technical paper conflicts with the provisions of the Standard Contract, the Standard Contract provisions prevail.

the potential for some system-wide cost reductions in addition to the flexibility that smaller canisters would provide to the system.

Based on these analyses, the authors of this paper recommend that DOE fund (1) a demonstration of the ability to weld up to four small canisters at the same time to confirm the feasibility and practicality of the canister-in-carrier concept and (2) the development of a more detailed conceptual design for future applications for Certificates of Compliance, if standardized canisters were incorporated into the commercial waste management system. This paper documents both the results of the latest assessment of standardized canister concepts including the canister-in-carrier concept and the authors' recommendations.

INTRODUCTION

The current inventory of commercial spent nuclear fuel (SNF) dry storage systems is diverse and increasing. In addition, the currently loaded systems are large-capacity systems [up to 37 pressurized water reactor (PWR) assemblies or 89 boiling water reactor (BWR) assemblies] that are now able to accommodate large (greater than 45 kilowatts) amounts of heat during storage, with the potential to accommodate fairly high heat loads (~32 kilowatts) for transportation as well.

Over the past few years, the US Department of Energy (DOE) Office of Nuclear Energy Fuel Cycle Technologies Nuclear Fuels Storage and Transportation Planning Project (NFST)[b] has performed a number of system analyses using logistic simulations to evaluate the impacts of incorporating smaller canisters containing commercial SNF that may be able to be stored, transported, and disposed of without opening into the Integrated Waste Management System (IWMS) [1, 2]. In addition to system analyses, NFST contracted AREVA and Energy*Solutions* to develop conceptual designs for incorporating standardized canisters into the IWMS [3, 4]. Following those efforts, NFST contracted Energy*Solutions* to develop a generic design of a small-capacity standardized canister system [5] and then investigate innovative operational approaches to minimize the at-reactor operational impacts of loading smaller canisters [6]. The standardized transportation, aging, and disposal (STAD) canister concepts that were developed were divided into small-capacity (4 PWR or 9 BWR), medium-capacity (12 PWR or 32 BWR), or large-capacity (21- 24 PWR or ~44 BWR) canisters.

The systems analyses results suggest the small canister systems show the most promise for providing system-wide flexibility and compatibility with most disposal concepts without substantial cooling time before emplacement. This flexibility has the potential to minimize the number of canisters that will have to be reopened and packaged into a disposal canister or waste package (WP). This paper documents both the system analyses work that has been performed as well as the canister design work that was led by industry teams.

[b] In October of 2016 DOE reorganized, and the Nuclear Fuels Storage and Transportation Planning Project (NFST) has been integrated into the Integrated Waste Management Campaign.

CANISTER DESIGN AND OPERATIONAL CONCEPT ACTIVITIES

A number of industry-led evaluations have been performed over the past 3 years that look at standardized canister design concepts and the potential impacts of incorporating them into a waste management system. These industry-led evaluations were funded through the DOE task order process. In this context, a DOE task order is a procurement where an indefinite delivery/indefinite quantity (IDIQ)/advisory and assisted services (A&AS) contractor is awarded a contract to perform a certain service. To date, three task orders related to standardization have been created:

- Task Order 12: Standardized Transportation, Aging and Disposal Canister Feasibility Study [3, 4]
- Task Order 18: Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems [5]
- Task Order 21: Operational Requirements for Standardized Dry Fuel Canister Systems [6].

Task Order 12

Task Order 12 was initiated to understand the feasibility of standardized canisters in the waste management system. Two contracts were awarded; the two contract teams were led by Energy*Solutions* and AREVA. Each team submitted a report to DOE during June of 2013 [3, 4]. Both teams developed concepts for three canisters of different capacities: small, medium, and large. As shown in Figure 1, Energy*Solutions* proposed “until the repository is selected, maintain a multi-STAD canister approach comprising of a small (4 PWR/9 BWR), medium (12 PWR/32 BWR) and large (24 PWR/68 BWR) configuration.” As shown in Figure 2, AREVA proposed “Carry forward three canister options (one small [1 PWR/2 BWR], one medium [4 PWR/9 BWR], and one large [21 PWR/44 BWR]) to the conceptual and preliminary design phases.”

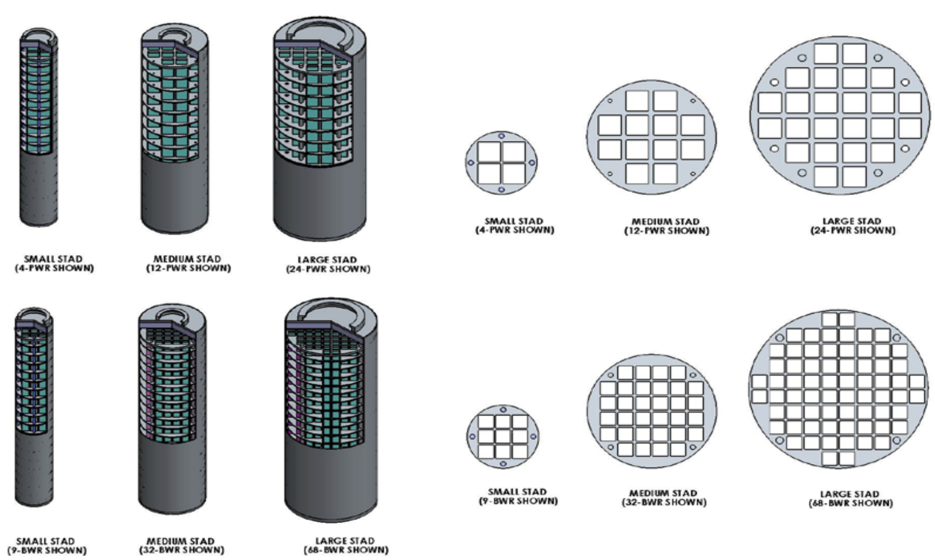

Figure 1. Families of standardized canister systems proposed by Energy*Solutions*.

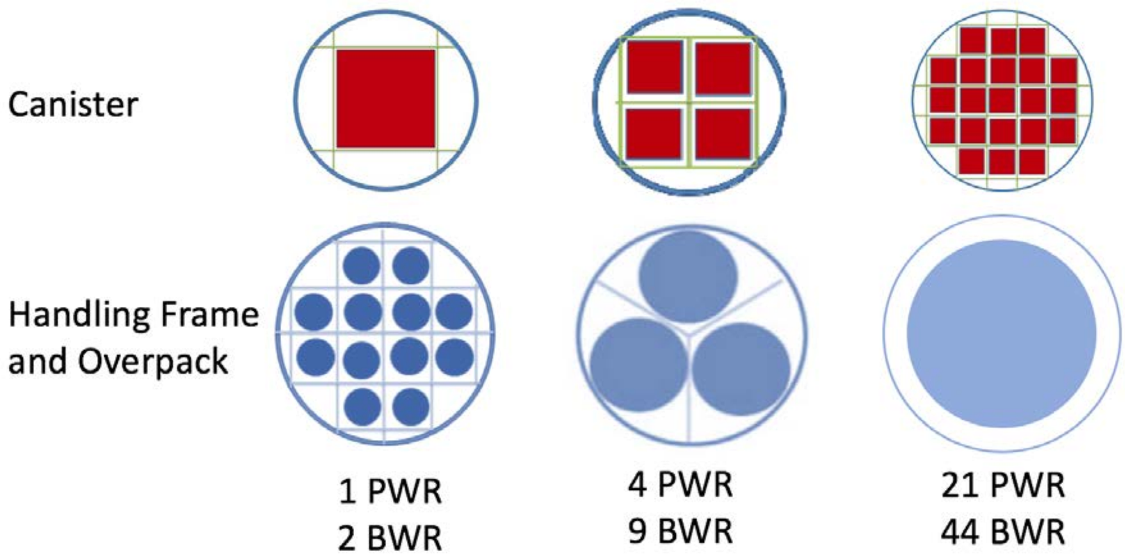

Figure 2. Families of standardized canister systems proposed by AREVA (Illustrated canister capacity is based on PWR assemblies).

In addition, both teams recommended that standardized canisters not be adopted in the IWMS until after the reactors stop operating and shut down. AREVA suggested to "develop a business plan for the adoption of the STAD when the reactor enters D&D," whereas Energy*Solutions* suggested that "operating nuclear reactors should not be mandated to package their used nuclear fuel (UNF)[c] into small or medium size STAD canisters … once an operating site is shutdown, the site operator will have flexibility for loading UNF from the spent fuel pool (SFP) into STAD canisters." Thus the teams identified that the reactor operations may be impacted by loading of smaller canisters. As a result of the recommendations of the Task Order 12 reports, two follow-on activities were begun:

1. Follow-on analysis work analyzed three different standardized canister sizes: small (4 PWR/9 BWR [4]), medium (12 PWR/32 BWR [4]), and large (21 PWR/44 BWR [5]).
2. Additional evaluations were initiated to understand and potentially mitigate potential at-reactor impacts of loading small canisters.

Task Order 18

As a result of both Task Order 12 [3, 4] and the FY 2014 systems analysis [1] of standardized canisters, Task Order 18 was initiated. One contract was awarded to an Energy*Solutions*-led team, and the team delivered their final report in May of 2015 [5]. This task order developed a generic design for a small standardized canister system as illustrated in Figure 3.

[c] In this report, UNF and SNF are used synonymously.

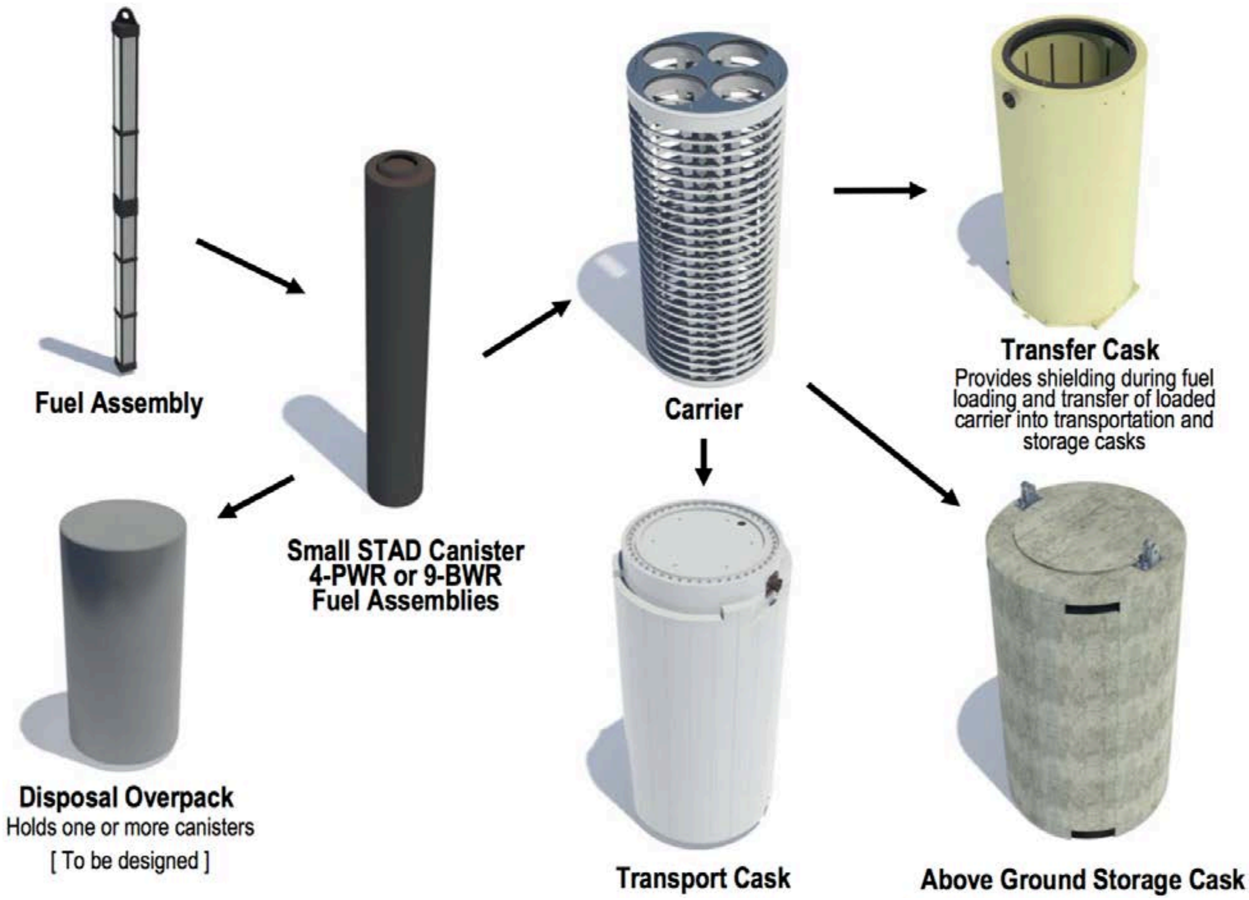

Figure 3. Overview of the small standardized canister system as developed by Energy*Solutions.*

This work provided more details on the potential design and cost estimates for a small standardized canister system, including the ability handle 4 canisters in a single carrier to allow for more efficient activities. This canister-in-carrier design locates and supports four small canisters, during loading operations, storage conditions, or transport conditions. Use of the carrier is based on reducing the number of primary loading and handling operations and it also provides opportunities for parallel welding, non-destructive examination, and drying operations to be performed. In this role, the carrier is the primary transfer component when loading the canisters.

Task Order 21

In parallel with Task Order 18 [5], Task Order 21 was initiated to develop a better understanding of the potential handling and loading impacts of using standardized canister systems at reactor sites. Task Order 21 was also awarded to an Energy*Solutions*-led team, and the final report was delivered in June of 2015 [6]. The team developed baseline and optimized loading options for the different standardized canister concepts. The maximum number of assemblies that would be able to be loaded into different standardized canister systems is detailed in TABLE I.

TABLE I. Maximum number of assemblies per 12-week loading campaign as a function of different canister capacities, as developed by Energy*Solutions.*

System	Assemblies Per 12-Week Campaign			
	Baseline		Optimized	
	BWR	PWR	BWR	PWR
DPC (ref)	1131	555		
Large STAD	660	357	836	420
Medium STAD	608	252	768	300
Small STAD-in-Can	468	224	756	352
Small STAD-in-Carrier	504	240	864	400

This task order showed that, with more advanced handling concepts and with additional infrastructure/equipment, small canisters could be loaded at operating reactor sites with minimal operational impacts.

OVERVIEW OF PREVIOUS STANDARDIZATION EVALUATIONS

A total of 112[d] scenarios were evaluated during the course of a 3-year standardization assessment, including scenarios from a FY 2014 evaluation [1], a FY 2015 evaluation [2], and a FY 2016 evaluation[e]. In this context, a scenario consists of

- an initial strategy: in standardization studies, this is often the size of canister loaded prior to knowledge about WP requirements;
- an outcome: the selection of a repository type and associated WP size;
- a response to outcome: often, sites switch to loading WP-compatible canisters, and canisters that are already loaded are repackaged into WP-compatible canisters; and
- assumptions regarding when and where strategies would be implemented.

These scenarios were then grouped into classes. The three main classes were Status Quo (SQ), Standardized Canister (SC), and Assembly Access (AA). Each class consists of several combinations of initial strategies and outcomes, holding the assumptions and boundary conditions constant. Additionally, in FY 2016, two hybrid classes, HC1 and HC2, were developed as subsets of the Assembly Access class. A summary of each scenario class is available in TABLE II.

[d] Note that some scenarios were rerun in the following years to quantify the impacts of improved input data and assumptions as well as to provide a baseline for comparison.
[e] Additional details of FY 2016 evaluation will be provided in future conference proceedings.

TABLE II. Summary of scenario classes investigated in FY 2014, FY 2015, and FY 2016.

Fiscal Year	Class	At-reactor DPC loading	At-reactor standardized canister loading	At-reactor waste package loading	ISF open	Repository open	Allocation priority	Notes
14	SQ1	Only DPC	None	None	None	2048	OFF[f]	
14	SQ2	Only DPC	None	None	2025+	2048	OFF	
14	SQ3	DPC to 2035	None	2036+	None	2048	OFF	
14	SQ4	DPC to 2035	None	2036+	2025+	2048	OFF	
14	SC1	DPC to 2024	SC 2025–2035	2036+	2025+	2048	OFF	
14	SC2	DPC to 2024	SC 2025–2035	2036+	2030+	2048	OFF	
14	SC3	DPC to 2024	SC 2025–2035	2036+	None	2048	OFF	
14	SC4	DPC to 2029	SC 2030–2035	2036+	2030+	2048	OFF	
14	SC5	DPC to 2024	SC 2025–2029	2030+	2025+	2042	OFF	
14	SC6	DPC to 2024	SC 2025–2039	2040+	2025+	2052	OFF	
15	SQ5	Only DPC	none	2036+	2025+	2048	OFF	Rerun of SQ4
15	SC7	DPC to 2024	SC 2025–2035	2036+	2025+	2048	OFF	Rerun of SC1
15	SC8	DPC to 2024	SC 2025–2035	2036+	2025+	2048	DS-SD[g]	
15	SC9	DPC to 2024	SC 2025–2035	2036+	2025+	2048	P-SD[h]	
15	AA1	DPC to 2024	AA 2025–2035	2036+	2025+	2048	OFF	
15	AA2	DPC to 2024	AA 2025–2035	2036+	2025+	2048	DS-SD	
15	AA3	DPC to 2024	AA 2025–2035	2036+	2025+	2048	P-SD	
15	AA4	DPC to 2024	AA 2025–2035	2036+	2025+	2048	OFF	Canisters go directly to repository after 2048
15	AA5	DPC to 2024	AA 2025–2035	2036+	2025+	2048	OFF	Enforced repository thermal constraints
16	SQ6	Only DPC	None	None	2025+	2048	OFF	Rerun of SQ2
16	SQ7	DPC to 2035	None	2036+	2025+	2048	OFF	Rerun of SQ4

[f] Oldest fuel first (OFF) allocation priority strategy.
[g] Allocation priority dry storage–shutdown (DS-SD) based on goals of (1) priority to shutdown sites, (2) elimination of transfer from pool to dry storage after acceptance begins, and (3) clearing remaining shutdown sites in license expiration sequence (at 3,000 MTHM/yr).
[h] Allocation priority post-shutdown (P-SD) based on goals of (1) priority for shutdown sites and (2) only accepting SNF from sites post-shutdown (at 3,000 MTHM/yr).

16	SC10	DPC to 2024	SC 2025-2035	2036+	2025+	2048	OFF	Rerun of SC1/SC7
16	HC1 (AA)	DPC to 2024	HC 2025-2035	2036+	2025+	2048	OFF	Load SFP into standardized canisters 5 years after reactor shutdown
16	HC2 (AA)	DPC to 2024	HC 2025-2035	2036+	2025+	2048	OFF	Load SFP into DPCs five years after reactor shutdown

Status Quo (SQ) Classes

Status quo scenarios assume that large dual-purpose canisters (DPCs) will continue to be loaded at utility sites at least until a WP specification is determined, which is assumed to be in the 2030s. These scenarios were developed to provide a baseline to compare against other strategies. In SQ scenarios, all DPCs are repackaged into canisters that are small enough to be placed in a repository[i]. Status quo class SQ4 was rerun as SQ5 in FY 2015 to provide a baseline for comparison with other FY 2015 scenarios. In FY 2016, classes SQ2 and SQ4 were rerun as SQ6 and SQ7.

Standardized Canister (SC) Classes

Scenarios in standardized canister classes assume that reactor sites continue to load DPCs in the near term and switch to loading standardized canisters in the mid-2020s, before WP size requirements are known. After a WP sized for the repository is determined in the mid-2030s, utility sites switch to loading WP-compatible canisters. If the canisters loaded in the 2020s are larger than the announced WP size, they are repackaged into WP-compatible canisters at a repackaging facility.

Assembly Access (AA) Classes

Assembly access classes shift the loading of standardized canisters from individual reactor sites to an interim storage facility (ISF) using reusable, bolted-lid transportation casks. These casks are loaded at reactors sites and transported to an ISF. Once at the ISF, the assemblies are placed in standardized canisters. In FY 2015, assembly access scenarios resulted in SFPs remaining open long after reactor shutdown, so hybrid classes (HCs) were defined in the FY 2016 study. In the hybrid classes, the reusable, bolted closure transportation casks are again used to transfer SNF to the ISF, but SFPs are forced to empty into dry storage 5 years after the last reactor at a site is shut down.

[i] All scenarios discussed in this paper assume a repository begins operation in 2048. In scenarios where repackaging is necessary, the repackaging would occur at the repository after it begins operation.

Evaluation Scenario Focuses

In the FY 2014 evaluation, 14 scenarios in the status quo class were evaluated to provide a baseline for comparison to scenarios in which standardized canister systems were introduced into the IWMS; 38 standardized canister scenarios were evaluated that all involved the loading of standardized canisters at the reactor sites.

In the FY 2015 evaluation, 50 scenarios were analyzed to provide further insight into the impacts related to near-term implementation of standardized canister systems with a focus on shifting the loading of standardized canisters to the ISF as well as incorporating new canister design and loading information.

In the FY 2016 evaluation, an additional 10 scenarios (two scenarios in five different classes) were analyzed to provide further insights into the impacts of implementation of standardized canister systems with a focus on at-reactor SFP management and repackaging facility design impacts. Some scenarios that were run in the FY 2014 evaluation were repeated for the FY 2015 and FY 2016 evaluations with updated data. *However, because of the changes in results due to the new data, comparisons should not be made between results from the FY 2014, FY 2015, and FY 2016 evaluations.* To simplify results comparisons, the rerun classes were given a new numbering scheme to distinguish them and to ensure consistent data with other scenarios that were evaluated in that fiscal year's evaluation.

RESULTS FROM PAST EVALUATIONS

Current Understanding of Standardized Canister Impacts

Based on 3 years of analysis and the current understanding of infrastructure and operating costs, standardized canisters could be incorporated into the IWMS with no substantial increase in system-wide[j] costs.

- Shifting to loading of standardized canisters either before or when the repository concept was selected reduced the total cost of the system by between 2% and 8% when compared to the current "business as usual" approach of continuing to load large DPCs. Thus, continuing to load DPCs (e.g., the status quo) appears to increase the total system life-cycle cost when compared to loading smaller canisters before the repository concept has been determined, assuming that disposal of DPCs is determined to be unfeasible[k]. This occurs because the costs of procuring, loading, storing, and transporting DPCs and then *repackaging* the fuel in the DPCs into smaller

[j] Note that the location of where those costs occurred would change depending on the specific implementation of standardized canisters.

[k] The ability to directly dispose of DPCs (i.e., without opening the canister) in a repository will be a function of both the repository (unknown at this time) and the designs of the individual DPCs. There are three main concerns with large canisters at a repository: thermal loads, criticality control, and operational impacts. The possibility of direct disposal is outside the scope of this paper and was not considered.

WP-compatible canisters were larger than the costs of procuring, loading, storing, and transporting WP-compatible canisters.
- The total system costs are relatively unchanged regardless of the location that standardized canisters are loaded.
- Repository costs are up to slightly more than half (in some scenarios) of total system rough order of magnitude (ROM) costs and are increased if more smaller-capacity canisters are disposed of when the repository could accommodate larger canisters.
- For most scenarios, the transportation costs are between 4% and 6% of the total costs.

Other Previous Work

In FY 2012 and FY 2013, NFST evaluated more general system alternatives [7]. Though not specific to standardized canisters, these evaluations looked at some scenarios that involved moving assemblies in bolted-lid, reusable transportation casks as well as loading smaller canisters (i.e., standardized canisters). The previous work resulted in a few conclusions that are still valid, based on current understanding:

- Smaller WP sizes have a significant impact on packaging/repackaging facility and transportation system requirements.
- At-reactor operational and logistic constraints could affect the actual rate that SNF could be loaded into dry storage canisters or transported off-site.
- Alternative strategies for accepting SNF from reactor sites could accelerate the clearing of SNF; however, the potential benefits that could be realized depend on the manner in which SNF is transported from the reactor sites.
- The use of standardized systems, equipment, and operations should be considered during the development of an integrated UNF storage, transportation, and disposition system.
- The total life- cycle cost of the entire IWMS is not significantly affected by the speed of or distance of transportation between facilities.

The first system-wide standardization evaluations in FY 2014 were based on fairly low-fidelity information related to costs of standardized canisters, packaging and repackaging operations, and repository costs. As such, some of the results changed dramatically as new higher-fidelity information was incorporated into the studies in FY 2015 and FY 2016. The results that have been confirmed are listed below.

- The use of standardized canisters had a relatively minor impact on the number of years that the reactor sites store SNF after the reactor has shut down for the 3,000 metric tons of heavy metal (MTHM)/year receipt rate with a youngest fuel first[l] (YFF) acceptance priority combined with an oldest fuel first (OFF) allocation[m] priority assumed in the FY 2014 evaluation.

[l] The youngest-fuel-first strategy applies to fuel that has been out of the reactor at least 5 years.
[m] Allocation determines which reactor sites ship and how much SNF is shipped from each site in a given year. Acceptance refers to what SNF is actually shipped by the utility and accepted by the waste management system in any year. Allocation priority is controlled by the Standard Contract.

- Unless direct disposal of DPCs is feasible and selected, a major repackaging effort will be needed, regardless of future standardization options.
- Incorporating an ISF that handles only canistered fuel did not change the overall standardization trends.
- Transportation ROM costs were highest for smaller canister scenarios, although the total range of transportation costs was never more than 12% of total IWMS costs[n].
- Transportation miles for both the rail consist and the cask were calculated to be highest for the 12 PWR canister scenarios, since these scenarios have smaller transportation cask capacities than all other scenarios, assuming that four of the 4-PWR-sized canisters could be loaded into a single transportation overpack (i.e., 16 PWR assemblies per transportation package).

The second system-wide standardization evaluation in FY15 [2] incorporated more accurate at-reactor loading costs as well as canister costs. It also included repository costs. The results from that study that have been confirmed are listed below.

- Alternative acceptance strategies (such as dry storage shutdown [DS-SD][o] and post shutdown [P-SD][p]) could reduce the number of years that SNF stays on reactor sites after reactor shutdown for scenarios involving standardized canisters.
- Repackaging costs decrease slightly with increasing WP size. Repackaging costs were highest for scenarios with 4-PWR WPs and lowest for scenarios with 21 PWR WPs.
- Repository costs make up 30–50% of total system ROM costs and increase if more smaller-capacity canisters are disposed of when the repository could accommodate larger canisters.
- Incorporating the new at-reactor loading data results in a significant system-wide cost reduction when compared to previous estimates [1] for at-reactor loading of small canisters. For example, at-reactor costs for loading 4-PWR canisters at reactors after 2025 was reduced from $56.7B in the FY 2014 evaluation [1] to $34.9B in the FY 2015 evaluation. This difference is mainly due to reduced cost estimates for loading small canisters.
- The transportation costs are no more than 10% of total IWMS costs in any scenario and only slightly impacted by the right or wrong guess regarding the repository medium, repository thermal emplacement limits, fuel selection strategy, and direct transportation from the reactor sites to the repository.

[n] Note that repository costs were not considered.

[o] Allocation priority DS-SD is based on goals of (1) priority to shutdown sites, (2) elimination of transfer from pool to dry storage after acceptance begins, and (3) clearing remaining shutdown sites in license expiration sequence (at 3,000 MTHM/yr).

[p] Allocation priority P-SD is based on goals of (1) priority to shutdown sites and (2) only accepting SNF from sites post-shutdown (at 3,000 MTHM/yr).

POTENTIAL PATH FORWARD

There are a number of future activities that would further develop the standardized canister concept. This section provides three options that could move standardization in the IWMS from a paper study to a real world application.

Engineering Demonstrations

Based on the results of 3 years of systems analyses, standardized canisters appear to be a feasible part of an IWMS. As such, the next step is to show that the assumptions related to canister loading operations are realistic. One such confirmatory engineering study is to demonstrate that the parallel welding of multiple small canisters is feasible. After such a study, additional engineering studies related to parallel drying should be performed. After these two separate-effect demonstrations, the next step would be an integrated cold demonstration that would take lessons learned from both the separate-effect demonstrations (welding and drying) as well as updated concepts based on the parallel design activity (see next section). Once a cold integral test of the system is performed, the next step is to move forward with a real-world, hot demonstration. These step-wise demonstrations are truly needed to provide confirmation that the canister-in-carrier concept is both defendable and operationally efficient.

Conceptual Design to Support Future Licensing Actions

To date, the design of a standardized canister system has been pre-conceptual. However, due to the long design and procurement timelines of SNF canisters, it would be wise to begin detailed design of a canister-in-carrier concept. As a relatively new concept, both the design cycle and the regulatory review timelines have some degree of uncertainty. Moving forward with a detailed design to support a future licensing action would alleviate some of this uncertainty without committing to full licensing actions.

Additional System Analyses

In addition to engineering work, there are additional analyses related to standardization that could be performed in the near future. The evaluation of different capacity canisters as well as canister designs that improve repackaging (if necessary) efficiency could be performed. In addition, standardized storage overpacks and standardized transportation overpacks could be used to help with centralized facility operations and could minimize transportation hardware and ancillary equipment. The scale of these efficiencies has not been evaluated previously and thus is an area where additional information would be beneficial.

CONCLUSION

As described above, standardized canisters could be used to simplify the IWMS operations, to minimize the amount of SNF that may need to be repackaged, and to support integration throughout the IWMS. However, additional engineering demonstrations and more detailed design and licensing efforts are required to make these potential benefits available. Thus the authors of this paper recommend that DOE initiate engineering demonstrations and, in parallel, move forward with detailed design of a small canister system to facilitate the potential for future full-scale demonstrations and licensing activities.

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