An Evaluation of Standardized Canisters in the Waste Management System – 16317[a]

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ABSTRACT

Development of a standardized canister system represents an opportunity to develop an integrated approach to addressing storage, transportation, and disposal issues in the waste management system. However, regardless of timing and method, deployment of such a system would have the potential to cause significant system-wide impacts. This evaluation expands upon previous standardized-canister system evaluations and compares continued loading of dual-purpose canisters (i.e., the status quo) with loading of standardized canister systems in the near term, that is, before repository requirements are known and/or before operating reactors shut down. This evaluation quantitatively compares order-of-magnitude costs and logistics for different standardization scenarios with those of status quo scenarios, provides insight into quantifiable impacts of loading standardized canister systems in the near term, tests system-level analysis tools and associated input, and identifies scenarios for further analysis. This is a technical paper that does not take into account the contractual limitations under the Standard Contract (10 CFR Part 961).

As work on assessing standardized canister system scenarios has progressed, new data for at-reactor and interim storage facility (ISF) operations have been collected and/or generated to provide more realism at the system level, and past scenarios were re-evaluated with this new information. In addition, new scenarios were developed and analyzed that focused on (1) bare fuel transported from reactors to an ISF in re-usable bare fuel casks and deferring deployment of a standardized canister system to the ISF, (2) alternative acceptance strategies based on conclusions from previous systems architecture studies, and (3) the impacts of having to accommodate

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It should be noted that this is a technical report that does not take into account the contractual limitations under the Standard Contract (10 CFR 961). Under the provisions of the Standard Contract, DOE does not consider spent fuel in canisters to be an acceptable waste form, absent a mutually agreed to contract modification.

spent fuel in differently sized canisters for different potential repository geologies. Results of this evaluation indicate that shifting the loading of standardized canisters from the reactor to the ISF does not result in a significant change in total system cost. Results also show that some alternative acceptance strategies could reduce the number of years that spent nuclear fuel (SNF) stays on-site at reactors for cases involving standardized canisters (consistent with previous results that looked at dual-purpose canisters). Finally, incorporating the new at-reactor loading data of small standardized canisters shows a significant system-wide cost reduction when compared to previous estimates of at-reactor loading of small canisters.

INTRODUCTION

The Nuclear Fuels Storage and Transportation Planning Project (NFST) of the Department of Energy (DOE) Office of Nuclear Energy has initiated a quantitative assessment of waste management system strategies for commercial spent nuclear fuel (SNF). Recent work analyzed the current utility status quo (SQ) approach (large dual-purpose canisters [DPCs] optimized for each utility's near-term storage needs) and alternatives such as adopting standardized SNF canister systems [1]. This assessment does not take into account the contractual limitations under the Standard Contract that DOE has in place with nuclear utilities (10 Code of Federal Regulations [CFR] Part 961). Under the Standard Contract (10 CFR 961.11), DOE is obligated to accept only bare SNF. Acceptance of canistered SNF would require mutual agreement to amend the Standard Contract.

This paper provides information on the implications of introducing standardized canister systems into the waste management system and analyzes how different standardized canister strategies would work with future alternatives (e.g., future repository canister-capacity or heat-load limits). This paper reflects research and development efforts to explore technical concepts which could support future decision making by DOE. No inferences should be drawn from this paper regarding future actions by DOE.

BACKGROUND AND MOTIVATION

Currently, nuclear utilities make site-specific determinations of how to manage their SNF. For dry storage, most utilities use high-capacity canisters (able to hold 32 pressurized water reactor [PWR] assemblies or 68 boiling water reactor [BWR] assemblies), and some are beginning to use the latest ultra-high–capacity canisters (able to hold 37 PWR or 87–89 BWR assemblies). Key factors considered by utilities selecting a cask design include worker dose, operational impacts of fuel loading, and cost.

Most utilities are using DPC systems that could also be used to transport SNF off site, although the high-capacity DPCs may have to remain in onsite storage for many years before these loaded canisters are below the thermal and dose limits required for transportation. In addition to transportation requirements, any loaded canisters that will be directly disposed will need to meet repository constraints. An example is emplacement thermal limits, which may require significant cooling times, perhaps 50 years or more after reactor discharge [2], to ensure that thermal loads are compatible with repository design concepts.

Compared with direct DPC disposal, repackaging of DPCs, if required for a particular geologic disposal concept, would significantly increase system fuel handling operations and associated costs, as well as worker dose. Unloaded DPCs no longer being used in the system would have to be properly managed and might have to be disposed of as low-level radioactive waste (LLW). Doing so would result in additional costs that could be avoided if the SNF were initially loaded into a disposable canister. However, using smaller disposable canisters could introduce additional costs, associated with an increased number of canisters and handling operations that would be avoided if the final repository were capable of disposing of larger canisters.

STRATEGIES AND SCENARIOS

The standardization assessment considers three overarching loading strategies: (1) an SQ strategy that continues using DPC systems as-is without consideration of disposal; (2) a standardized canister strategy (SCS) initially focused on canister capacity options to facilitate future disposal; and (3) an assembly access strategy (AAS) to keep fuel assemblies more accessible for later loading into waste package (WP)-optimal canisters once disposal requirements are determined.

This paper analyzes (1) early adoption of a single standardized canister system at reactor sites or (2) the use of bare SNF transportation casks to transport fuel from reactor sites to the ISF, where the fuel is then loaded into standardized canisters. One assumption underlying this evaluation (and the larger standardization assessment) regarding canister disposal is that smaller canisters are compatible for disposal with more geologies than larger canisters.

The current utility-planning SQ strategy was used as a basis for comparison with standardization alternatives. It is characterized by a continued trend toward higher fuel burnups, larger/higher-heat-load DPCs, higher-capacity canisters, and no action to promote standardization. The SQ strategy continues trends in the use of DPCs for at-reactor storage.

The standardized canister strategy shifts to usage of a standardized canister system in the near term. A set of SCS options were defined by identifying: (1) the type and capacity of a standardized canister system and (2) the timing as to when the standardized canister is loaded. Each initial SCS strategy begins with only a single standardized canister design capacity (e.g., 4 PWR/9 BWR, 12 PWR/32 BWR, or 21 PWR/44 BWR). However, after a repository geology is selected in the simulations, the scenario may transition to a repository-optimal standardized canister design capacity.

The assembly access strategy (also referred to as the “bare fuel strategy”) shifts to bare SNF[b] storage and transportation in the near term using bare SNF transportation casks to ship fuel from reactor sites to the ISF (32 PWR/68 BWR). Note that scenarios for this strategy may also incorporate standardized canisters and/or DPCs in addition to the reuseable bare SNF casks.

Figure 1 shows the three main system strategies and their potential responses to outcomes discussed in this paper. The figure does not show all options for a given scenario, but it illustrates the high-level near-term strategies evaluated. The red arrows show only shifts in practice/strategy (e.g., a move from loading DPCs to loading standardized canister systems), not actual repackaging operations of individual assemblies. The need to repackage is indicated by a yellow star.

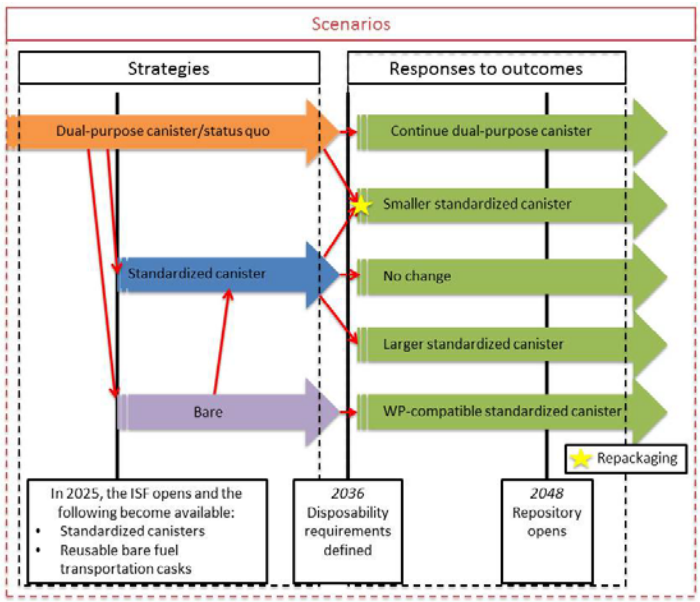

Fig. 1. Three main system strategies and their potential responses to outcomes.

ASSUMPTIONS

Scenarios were constructed by combining each strategy with a response to the outcome based on repository compatibility. The scenarios were then analyzed using the reference scenario assumptions described above. Possible responses to the selection of a repository geology are described below.

No change (*compatible* case): A base case in which it is determined that the standardized canister system/DPC used in the initial strategy is directly disposable in the repository.

[b]*Bare SNF* references noncanistered assemblies that can be loaded into a transportation cask with the intent of removing those assemblies from the cask in the near future. Generally, no welding or cutting would be required.

Change to smaller canister or change to larger canister (*incompatible* case): A contingent case in which the optimal WP capacity or size is determined to be inconsistent with the capacity or size of the canister used in the initial strategy. At that time, all future SNF is loaded into repository-optimal standardized canister systems. The already-canistered SNF is dispositioned depending on the specific case.

- If the initial strategy involves standardized canister systems or DPCs that are larger than repository-compatible canisters, the already-loaded standardized canister systems/DPCs would be reopened at the repository, the contents loaded into disposal packages, and the canisters disposed of as LLW.

- If larger standardized canister systems are determined to be compatible with the repository, the small, standardized canister systems already loaded would not be repackaged. Instead, the loaded smaller canisters would be disposed of in individual disposal overpacks.[c] For this evaluation, all canister systems are assumed to be feasible. In other words, regardless of the number, size, or capacity of a canister system, cask manufacturers and vendors are able to produce the needed canisters. It is assumed that material is available and vendors have the capability to increase production to meet demand. Because the 4PWR/9BWR standardized canister system is expected to be compatible with the most restrictive disposal environments under consideration, those standardized canister systems are always assumed to be disposable without repackaging.

The reference NFST commercial SNF projections were selected for all strategies and scenarios. The reference inventory projection assumed that all reactors operate for 60 years with no early shutdowns, additional extensions, or new reactors coming online (also referred to as “No replacement Nuclear Power Generation”). Exceptions were those reactors that have already shut down[d] and those that have announced a shutdown date[e].

A system acceptance rate of 3,000 MTHM (metric tons of heavy metal) annually and a oldest-fuel-first (OFF) allocation priority/youngest-fuel-first (YFF) acceptance priority were selected for all strategies and scenarios unless otherwise specified. SNF from shutdown sites (sites where all operating reactors have been shut down) is assumed to be allocated and accepted first.[f] After that time, the SNF would be allocated with an OFF procedure and accepted with a YFF procedure. For the purposes of this paper,

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[c] Note that if the source of incompatibility with the site were not the size or capacity of the canisters but were actually the effects of the specific site geochemistry on the internals (especially postclosure criticality control measures), the small canisters might require repackaging as well.

[d] Big Rock Point, Haddam Neck, Humboldt Bay 3, LaCrosse, Maine Yankee, Rancho Seco, Trojan, Yankee Rowe, Zion 1 and 2, Kewaunee, Crystal River 3, San Onofre 1, 2, and 3, Vermont Yankee, Indian Point 1, Millstone 1, Dresden 1

[e] Oyster Creek

[f] Reactor sites that have already shut down include Big Rock Point, Haddam Neck, Humboldt Bay, LaCrosse, Maine Yankee, Rancho Seco, Trojan, Yankee Rowe, Zion, Crystal River, Morris, Vermont Yankee, Kewaunee, and San Onofre. Oyster Creek has announced a shutdown date. It should be noted that Morris is not a reactor site but an away-from-reactor spent fuel pool.

Allocation priority refers to the priority in which SNF shipments are allocated to reactor sites and how much is shipped from each site in a given year; and *Acceptance* priority refers to what SNF is assumed to be provided by the utility from their site(s) and accepted for transport by the waste management system in any year. An OFF allocation priority is used to determine the amount of SNF (MTHM) that is allocated for reactor sites based on the Standard Contract. A YFF, minimum 5-year out-of-reactor fuel acceptance prioritization is used to determine which fuel assemblies are transported within the allocated MTHM amount for each reactor site.

The assumed storage and transportation overpack capacities for canisters used in this assessment can be seen in TABLE I.

TABLE I. Overpack capacity as a function of canister size

Canister size	Storage capacity	Transportation capacity
4 PWR / 9 BWR	4	4
12 PWR / 32 BWR	1	1
21 PWR / 44 BWR	1	1
DPC[g]	1	1

The following ISF assumptions were applied consistently to all scenarios:

- Before a full-scale ISF is constructed, a pilot ISF accepts DPCs from shutdown sites (sites where all operating reactors have been shut down).
- Operations expand to a canister receipt capability of 3,000 MTHM per year at a full-scale ISF co-located with the pilot. It is assumed that full receipt capability is available in 2026 (the ramp-up period is during the Pilot ISF phase, consistent with the ISF reference scenario). A canister-only ISF is consistent with the initial focus on standardized canister systems loaded at reactor sites.
- The ISF stores SNF from reactors until the repository opens. The ISF receives and handles all SNF on the way to the repository.
- No packaging/repackaging for disposal is performed at the ISF.
- Standardized canister systems are stored at the ISF as described and the storage capacity is not constrained.

The repository assumptions also were applied consistently to all scenarios.

- Three repository concepts are assumed for this report: clay, salt and open-mode. The corresponding optimal-WP sizes for each of these concepts are 4P, 12P, and 21P, respectively.

[g] DPCs used in this paper are based on the storage systems currently in use at reactors, and have variable canister sizes.

- There is 3,000-MTHM/year receipt and emplacement, assuming no ramp-up for this evaluation.
- The surface storage capacity for canistered SNF and for WPs before emplacement is not constrained.
- All packaging/repackaging for disposal is performed at the repository having unlimited capacity.

The assumed dates are based on the Administration's Strategy [2] where applicable[h].

- ISF accepts DPCs from shutdown reactors in 2021.
- Standardized canister systems and bare SNF transportation casks are available in 2025.
- ISF accepts DPCs/standardized canister systems at large scale from operating and shutdown reactors in 2026.
- A repository is sited in 2026, disposability of canisters is known with high confidence in 2036, and the repository opens in 2048.

RESULTS AND OBSERVATIONS

This paper evaluated the impact of incorporating standardized canisters in the waste management system. Therefore, one of its primary purposes is to understand results in the context of the system computational model inputs, boundary conditions, and assumptions. Cost information is used to show how management strategies and future events affect relative costs.

Rough Order of Magnitude (ROM) Total System Costs

To eliminate variation due to differing repository concepts, cost comparisons were made among different scenarios while holding the final selected repository geology constant. In Fig. 2, the first three columns represent scenarios in which SNF is loaded into standardized canisters at reactor sites beginning in 2025. The next three columns represent scenarios in which bare SNF is transported from the reactors beginning in 2025 and then the SNF is packaged into standardized canisters at the ISF upon receipt. The seventh column is the corresponding SQ scenario. The open-mode concept is presented first, but the other repository types result in similar trends and are shown later in this section. Figure 2 presents the ROM total system cost results as a percentage of the total ROM system cost of the SQ scenario where an open-mode repository is ultimately selected.

[h] As noted in the Administration's Strategy, new legislation would be necessary in order to enable the timely deployment of the identified system elements.

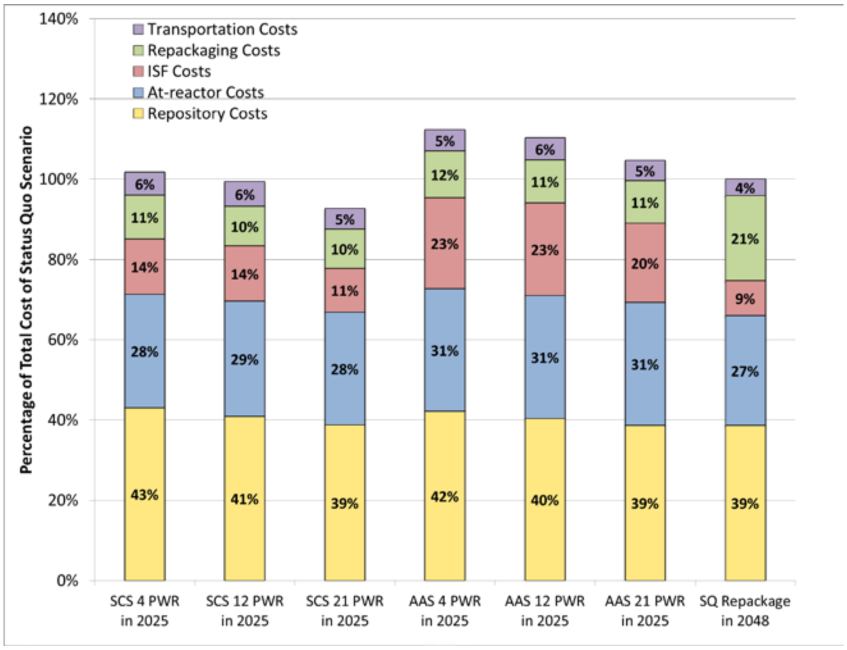

Fig. 2. Total cost relative to the status quo scenario (OFF allocation strategy) for various standardization scenarios if ultimate disposal is in an open-mode repository requiring a 21 PWR WP.

Shifting the loading of standardized canisters from the reactor to the ISF results in a slight increase (~7–13% in all scenarios) in total system cost when the OFF allocation strategy is used. The cost increase is due to the cost at reactors of keeping spent fuel pools (SFPs) open after reactors shut down.

Repository costs are increased by the upstream waste management strategies if more, smaller-capacity canisters are disposed of when a repository could accommodate larger canisters.

In the scenarios shown in Fig. 2, transportation costs make up 4–6% of the total system cost (and never more than 10% under all scenarios). Transportation costs are only slightly impacted by whether the initial loading strategy is compatible or incompatible with the repository medium, repository thermal emplacement limits, fuel selection strategy, and direct transportation from reactor sites to the repository.

Figure 3 presents the ROM total system cost results as a percentage of the total ROM system cost of the SQ scenario where a salt repository is ultimately selected. As Fig. 3 shows, salt repository scenarios show similar cost trends across various waste management system elements when compared to open-mode repository scenarios.

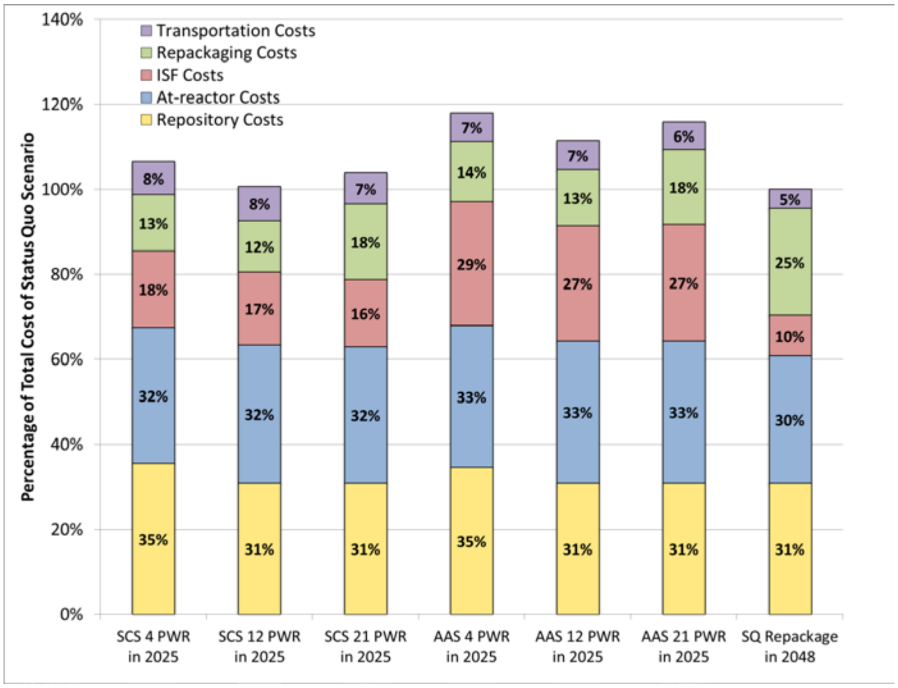

Fig. 3. Total cost relative to the status quo scenario for various standardization scenarios if ultimate disposal is in a salt repository requiring a 12 PWR WP.

Figure 4 presents the ROM total system cost results as a percentage of the total ROM system cost of the SQ scenario where a clay repository is ultimately selected.

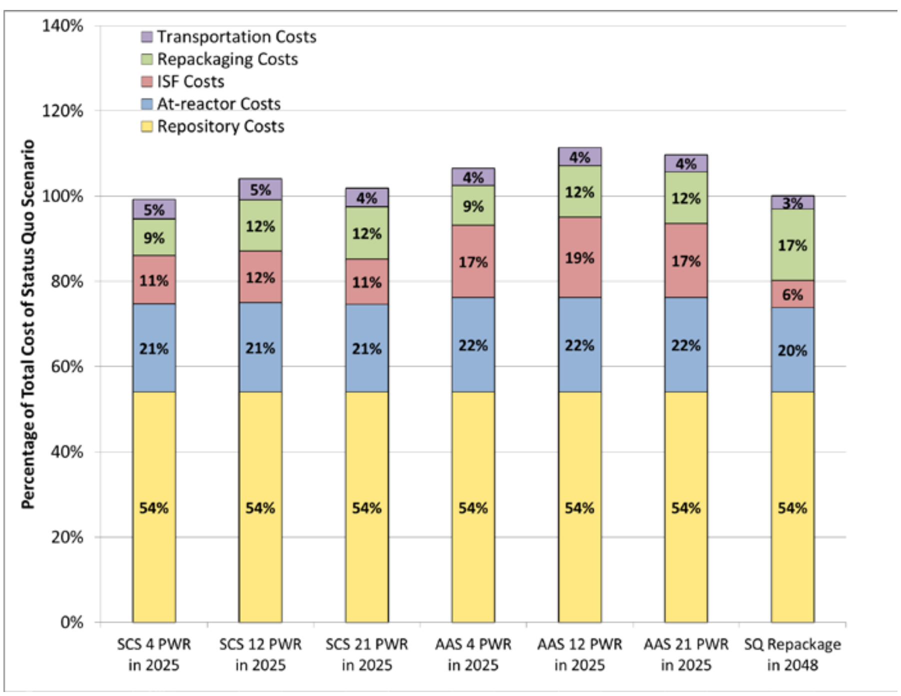

Fig. 4. Total cost relative to the status quo scenario for various standardization scenarios if ultimate disposal is in a clay repository requiring a 4 PWR WP.

As can be seen in Fig. 4, clay repository scenarios show similar cost trends to open-mode and salt repository scenarios.

Different allocation strategies were also investigated. For the scenarios investigated in Fig. 5, the initial standardized canister that was loaded was later confirmed to be the WP size (i.e., "compatible"). Figure 5 shows the ROM cost estimates for different allocation strategies (DS-SD[i], P-SD[j], and OFF) in an open-mode repository.

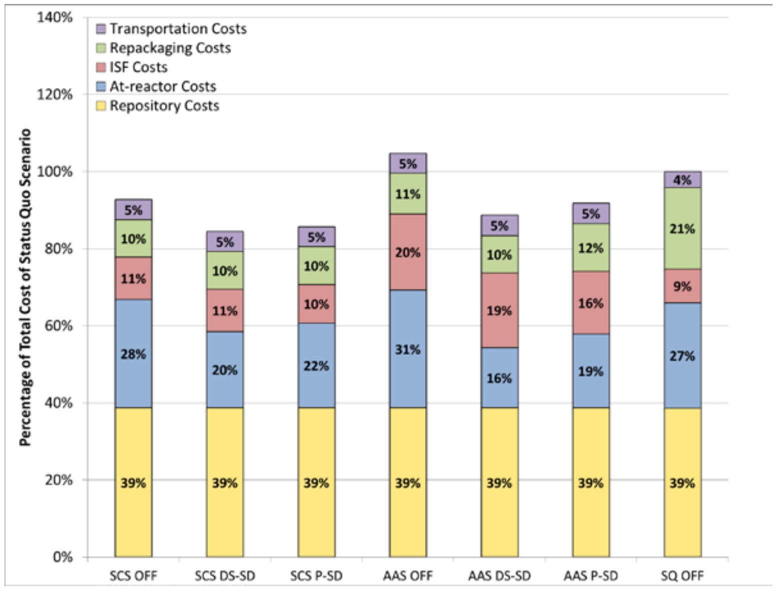

Fig. 5. Total cost relative to the status quo scenario for different scenarios and strategies if ultimate disposal is in an open-mode repository requiring a 21 PWR WP for different allocation strategies.

For scenarios using the three different allocation strategies in an open-mode repository, adopting a DS-SD allocation strategy results in the lowest ROM total system cost, followed closely by the P-SD allocation strategy. Scenarios using the OFF allocation strategy result in the highest total system cost. As previously seen, the assembly access scenarios are more expensive than the standardized canister scenarios for all allocation strategies (however, the difference between the two is reduced if a site-specific (DS-SD or P-SD) allocation is used instead of an OFF allocation). The increased cost stems from the increased time that SFPs are assumed to remain open in assembly access scenarios. For standardized canister scenarios, SFPs are closed 5 years after final discharge; but they remain open until the site is cleared in the assembly access scenarios. For these scenarios, the analysis indicates

[i] Allocation priority Dry Storage – ShutDown (DS-SD) based on goals to (1) give priority to current shutdown sites, (2) eliminate additional transfer of SNF from the SFPs to onsite dry storage (DS) once acceptance begins, and (3) clear remaining shutdown sites (SDs) in order of license expiration date as soon as possible while maintaining the overall allocation/acceptance rate at 3,000 MTHM/year

[j] Allocation priority Post-ShutDown (P-SD) based on goals to (1) give priority to current shutdown sites, (2) allocate/accept only from other sites post-shutdown (PS) while maintaining the overall allocation/acceptance rate at 3,000 MTHM/year

that it is most expensive to use an OFF allocation strategy and least expensive to use one of the two site-specific allocations examined here, with a slight preference for eliminating additional dry storage at reactors, i.e. the DS-SD allocation strategy.

Shutdown Reactor-Years

One objective of this evaluation is to quantify the nonproductive use of reactor sites. Once the reactors have shut down at a site, the site cannot be repurposed until the SNF has been removed. To measure the impact of the presence of SNF, the number of years after the reactor shuts down until all of the SNF is off site was quantified. This evaluation shows that the effects of changing the loading strategy were negligible unless the allocation strategy was changed. All scenarios using the OFF allocation strategy had nearly identical shutdown reactor-years. The DS-SD and P-SD allocation strategies substantially reduced the number of shutdown reactor-years compared with the OFF allocation strategy. The trend is illustrated in Fig. 6.

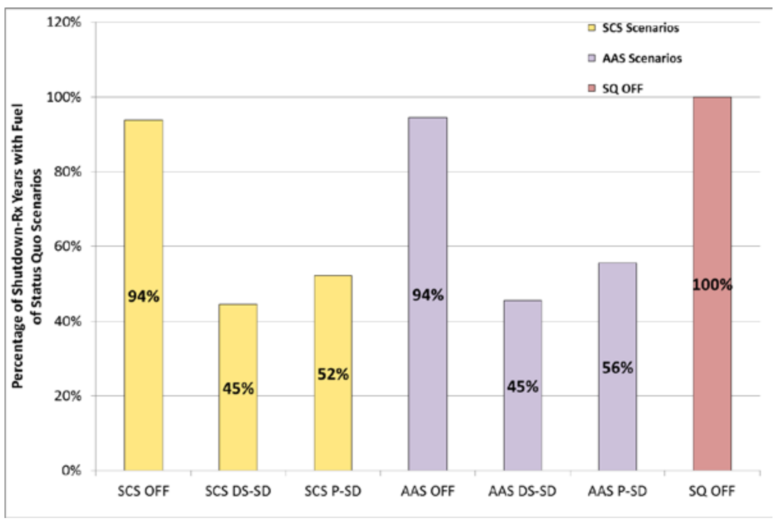

Fig. 6. Percentage of total reactor shutdown years of the status quo scenario with different allocation strategies and loading scenarios.

The SCS OFF and AAS OFF scenarios do not really differ and are slightly less than the SQ OFF scenario. This is because for the SQ OFF scenario, the thermal limits for transport for the large DPCs are lower on a per-assembly basis than for the smaller 4P, 12P, and 21P standardized canisters. As a result, very hot fuel must sit at the reactor until it is below the transportable limit. The cooling of the fuel takes a significant amount of time and increases the number of shutdown reactor-years for the SQ OFF scenario.

LLW

Another metric examined in addition to cost was the amount of LLW generated in different scenarios. Figure 7 illustrates the estimated volume of LLW which would be generated from repackaging operations for different initial strategies and final repository concepts.

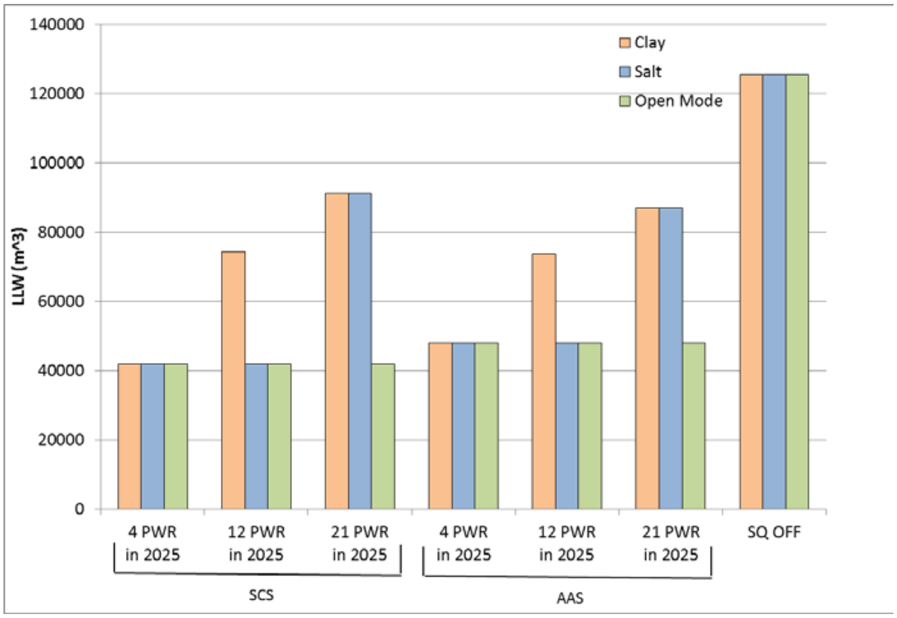

Fig. 7. Estimated low-level waste volume from repackaging operations for different initial strategies, allocation strategies, and final repository types.

As expected, the total amount of waste generated from repackaging operations is highest when all SNF is loaded into DPCs at reactors (SQ scenarios) and next-highest when the initial standardized canisters loaded are incompatible with the repository (too large).

SUMMARY

This paper documents an evaluation of integrating standardized canisters into the management system for commercial SNF. It does not take into account the contractual limitations under the Standard Contract (10 CFR Part 961) that DOE has in place with nuclear utilities. Under the Standard Contract, DOE is obligated to accept only bare SNF. Acceptance of canistered SNF would require a mutual agreement to modify the contract. This paper reflects research and development efforts to explore technical concepts that could support future decision making by DOE. **No inferences should be drawn from this paper regarding future actions by DOE.**

This paper quantitatively compares order-of-magnitude costs and logistics for different standardization scenarios with SQ scenarios and provides insight into quantifiable impacts of loading standardized canister systems in the near term. It highlights preliminary observations, identifies needed information moving forward, and guides future evaluation work. **No observations in this paper should be considered final, as additional system model logic verification, data verification, and collection are ongoing and could impact these observations.**

The following observations can be drawn from this evaluation:

(1) Shifting the loading of standardized canisters from the reactor to the ISF results in a slight increase (~7–13%) in total system cost in scenarios when the OFF allocation strategy is used. The total system cost increase is due to the cost at reactors to keep SFPs open after shutdown. This is the case both for scenarios in which bare SNF transportation casks are used to transport bare SNF from the reactor sites to the ISF, and scenarios not involving bare fuel transport in which SFPs close 5 years after reactors shut down.

(2) Alternative acceptance strategies (such as DS-SD and P-SD) could reduce the time SNF stays on reactor sites after reactor shutdown for scenarios involving standardized canisters. This is consistent with previous results that investigated DPCs.

(3) Repackaging costs were found to decrease slightly with increasing WP size. Repackaging costs were highest for scenarios repackaging into 4 PWR WPs and lowest for scenarios repackaging into 21 PWR WPs.

(4) Repository costs make up 30–54% of total system ROM costs and are increased by the upstream waste management strategies if more, smaller-capacity canisters are disposed of when the repository could accommodate larger canisters.

(5) Incorporating the new at-reactor loading data shows a significant system-wide cost reduction compared with previous estimates [3] of at-reactor loading of small canisters. For example, at-reactor costs for loading 4 PWR canisters at reactors after 2025 was reduced by ~40% from the initial evaluation [3], mainly as a result of reduced loading cost data associated with small canisters due to the assumption of processing four small canister in parallel.

(6) Transportation costs are no more than 10% of total costs in any scenario and are only slightly impacted by whether the initial loading strategy is compatible or incompatible with the repository medium, repository thermal emplacement limits, fuel selection strategy, and direct transportation from the reactor sites to the repository.

The largest areas of uncertainty in these results are related to repackaging. In the future, to fully quantify standardization impacts, more detailed design concepts for repackaging and bare SNF receipt and shipping should be developed. It should again be noted that under the Standard Contract (10 CFR 961.11), DOE is obligated to accept only bare SNF. Acceptance of canistered SNF would require an amendment to the Standard Contract.

REFERENCES

1. J.J. Jarrell, R.A. Joseph III, J.A. Fortner, R.E. Hale, R.L Howard, E.A. Kalinina, G. M. Petersen, and R.B. Wilkerson. Initial Evaluation of Standardized Canisters in the Waste Management System. International High Level Radioactive Waste Management Conference, April 12–16, 2015.
2. US Department of Energy. *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste*. January 2013.a1b

3. J. Jarrell, R.A. Joseph III, R. Howard, R. Hale, G. Petersen, B. Wilkerson, J. Fortner, and E. Kalinina. *Initial Standardized Canister System Evaluation.* FCRD-NFST-2014-000084, prepared for the US Department of Energy, August 2014.