Initial Standardized Canister System Evaluation

Fuel Cycle Research & Development

Prepared for US Department of Energy
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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 Part 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.

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HISTORY OF CHANGE

Rev. 0	Initial Issuance on 08-29-2014.
Rev. 1	Revised to incorporated comments from Department of Energy.

EXECUTIVE SUMMARY

This report documents an initial evaluation of integrating standardized canisters into the nuclear waste management system, which is an intermediate step in the quantitative assessment of standardization. This is a technical report that 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 UNF. Acceptance of canistered UNF would require a mutual agreement to modify the contract. This report reflects research and development efforts to explore technical concepts which could support future decision making by DOE. No inferences should be drawn from this report regarding future actions by DOE.

The evaluation focuses on scenarios in which standardized canisters designed for storage, transportation, and disposal are loaded at reactors before being stored onsite or shipped to an interim storage facility (ISF) or repository. Other strategies, such as shipment of bare fuel to an ISF and using standardized canisters for storage and subsequent transportation and disposal from that point forward, will be evaluated in future studies. This report highlights preliminary observations, identifies needed information moving forward, and guides future evaluation work. **No observations in this report should be considered final, as additional system model logic verification, data verification, and collection are ongoing and will impact these observations.**

The larger standardization assessment is a multi-year undertaking with a goal to fully understand the impacts of integrating standardized canister systems into the waste management system. At its conclusion, the standardization assessment will quantify the relative impacts (cost, operational, etc.) on the nuclear waste management system if standardization strategies are selected before disposal requirements are known. These impacts will be quantified whether the standardization strategies are determined to be compatible or incompatible with the final repository concept. Standardization options are of significant interest in the context of the Administration's *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste* (Strategy) (Ref. 1), which includes a consent-based siting process. A consent-based siting process keeps all generic repository concepts as potential options. Because the repository site and design is not yet determined, it is important to quantify and understand how changing canister-related options may impact the waste management system. This initial evaluation report details how initial (i.e., near-term) standardization strategies (including no standardization) might be impacted by the ultimate determination of waste package[1] (WP) size.

The most prominent observation from this initial evaluation is that there are significant data collection and verification needs in order to draw the necessary conclusions from future evaluations. Experience and data on loading small (4 pressurized water reactor [PWR], 12 PWR, or 21 PWR assemblies) capacity canister systems are limited. Therefore, the assumptions related to at-reactor loading in this report have a great deal of uncertainty. To address this need, DOE released a statement of work (SOW) to quantify at-reactor impacts and identify potential impact mitigation measures. Another data area with a great deal of uncertainty is the repackaging of spent nuclear fuel (SNF) stored in welded canisters (e.g., dual-purpose canisters [DPCs]). In this report, the cost/operational estimates for a repackaging facility are based on the Nuclear Fuels Storage and Transportation Planning Project (NFST) Fiscal Year (FY)12 System Architecture report (Ref. 2). Since that report, DOE has collected addition information on repackaging large DPCs (Refs. 3 and 4). This information will be used in future analyses.

There are a number of strategy specific observations. These observations are based on relatively rough cost estimates specifically related to at-reactor loading of smaller standardized canisters as well as stand-

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[1] In this evaluation, a standardized canister and the waste package-compatible canister are assumed to be the same physical canister; the canister would be placed in a storage overpack to become part of the storage system or be placed in a waste package overpack to become part of the engineered barrier system in a geologic repository.

alone repackaging of non-dual-purpose canisters and do not take into account system costs and benefits that are not readily quantifiable. One observation is that 4 PWR canisters are the most expensive and most challenging option from an operations perspective if they are loaded at reactors using the current canister loading approaches. Based on current assumptions, if a WP size is determined to be 4 PWR, system analysis tools calculate that loading larger storage and transportation canisters at reactors and repackaging the fuel into smaller containers later would be more cost effective than loading smaller canisters at reactors. The logistical challenges associated with managing (storing, transporting, etc.) up to eight times more canisters than the current dual-purpose canister (DPC) strategy also must be considered. This observation is highly dependent on the assumptions for at-reactor loading operations, as well as the repackaging assumptions.

Another observation is that, under the assumptions for this initial evaluation, relative system costs[2] for the 12 PWR, 21 PWR, and current DPC strategies are fairly equivalent for any given WP size. The 12 PWR canisters have some advantages since they may accommodate a broader range of disposal options without additional repackaging. However, the wait-and-see approach (i.e., continuing to load DPCs until the WP is determined) shows similar cost estimates and would avoid impacting utility operations until additional repository details are known.

None of the standardization strategies examined significantly enhances the ability to remove SNF from shutdown reactors. The opening of an ISF has a greater impact on the ability to remove all of the SNF from a shutdown reactor site. However, if higher acceptance rates and/or acceptance priorities designed to clear shutdown sites as soon as possible were assumed, there is a potential for standardized canisters to be able to clear sites faster due to their ability to address time dependent transportation limitations (some DPCs are not immediately transportable due to thermal and dose constraints). It may be useful to examine scenarios with higher acceptance rates or different acceptance priorities to explore this possibility.

The last significant observation from this initial evaluation, in which all fuel is canistered before it is shipped from the reactors, is that the addition of an ISF to the system does not change the relative impacts of standardization. In the canister-only scenarios that were evaluated in this assessment, the benefits of an ISF are generally separate from those of standardization. However, this initial evaluation did not address the acceptance of bare fuel from the reactor sites, which is only an option if there is a destination (i.e., an ISF) for the SNF.

It should again be noted that under the Standard Contract (10 CFR 961.11), DOE is obligated to accept only bare used nuclear fuel. Acceptance of canistered used nuclear fuel would require an amendment to the Standard Contract.

The larger standardization assessment will quantify the potential system benefits of standardization that are not considered in this initial evaluation. In order to accurately quantify these benefits and to gain confidence in the evaluation observations, the following questions need to be addressed.

- How accurate are the at-reactor loading costs and times for small canisters and how sensitive are the observations to these costs and times?
- How accurate are the capital costs for small canisters and how sensitive are the observations to uncertainties in the capital costs?
- Are the multi-canister concepts used in this evaluation realistic? Are there other concepts that should be evaluated?

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[2] The relative system rough order of magnitude (ROM) costs in this evaluation include at-reactor, interim storage, repackaging, and transportation costs. They do not include any repository costs (with the exception of the repackaging facility) nor do they include other system costs such as licensing, implementation, etc.

- What are the cost and operational impacts of repackaging standardized canisters (e.g., 12 PWR, 21 PWR) into smaller (e.g., 4 PWR) canisters?

Along with improved confidence in evaluation parameters, the following scenarios will be explored in the next evaluation:

- Bare fuel movement from reactors to an ISF
- Accelerated acceptance rates and alternative acceptance priorities
- Disposal assuming different repository design concepts for different geologic media
- Additional scenarios related to those analyzed in this evaluation

CONTENTS

FIGURES

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TABLES

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ACRONYMS

BWR	boiling water reactor
DOE	US Department of Energy
DPC	dual-purpose canister
FCRD	Fuel Cycle Research and Development
FY	fiscal year
ISF	interim storage facility
ISFSI	independent spent fuel storage installation
LLW	low-level radioactive waste
MDO	management and disposal organization
MTHM	metric tons of heavy metal
MRS	monitored retrievable storage
NFST	Nuclear Fuels Storage and Transportation Planning Project
OFF	oldest fuel first
PWR	pressurized water reactor
ROM	rough order of magnitude
SNF	spent nuclear fuel
TAD	Transportation, Aging, and Disposal
TSL-CALVIN	Transportation Storage Logistics- CRWMS (Civilian Radioactive Waste Management System) Analysis and Logistics Visually Interactive
WP	waste package
YFF	youngest fuel first

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INITIAL STANDARDIZED CANISTER SYSTEM EVALUATION

1. INTRODUCTION

This report details the fiscal year (FY) 2014 initial standardized canister system evaluation. It fulfills the Level 2 Milestone M2FT-14OR0904022 in the Standardization Assessment work package, FT-14OR090402. 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.

The Nuclear Fuels Storage and Transportation Planning Project (NFST) of the US Department of Energy (DOE) Office of Nuclear Energy (NE) has initiated a quantitative assessment of waste management system strategies. The assessment will analyze the current utility status quo approach (large dual-purpose canisters [DPCs] optimized for each utility’s near-term storage needs), along with alternatives such as adopting standardized spent nuclear fuel (SNF) canister systems. It should again be noted that under the Standard Contract (10 CFR 961.11), DOE is obligated to accept only bare used nuclear fuel. Acceptance of canistered used nuclear fuel would require an amendment to the Standard Contract. This assessment does not take into account the contractual limitations under the Standard Contract that DOE has in place with nuclear utilities (10 CFR Part 961). Under the Standard Contract, DOE is obligated to accept only bare UNF. Acceptance of canistered UNF would require a mutual agreement to modify the contract.

The assessment will analyze how different standardized canister strategies would work with future contingencies. Each strategy/response pairing or scenario will be quantitatively evaluated using defined metrics. At its conclusion, this assessment will provide information on the implications of introducing standardized canister systems into the waste management system.

This report presents the initial evaluation of several scenarios. The results from this initial report will inform decisions on the scope of future evaluations. It provides a better understanding of which scenarios should be explored in more detail and indicates areas where additional information is needed.

This standardized canister system assessment is focused on providing research and development to address the fundamental question: “Is this worth doing?”

If the standardized canister assessments answer the “Is this worth doing?” question in the affirmative, then the next question will be “How could these strategies be implemented?” To clarify, this assessment is focused on the question of the value of standardized canister systems. Implementation of standardized canister systems is an issue only described in this assessment as assumptions related to specific scenarios (e.g., standardized canisters will be loaded at operating reactors. The question “How will these scenarios be implemented?” is beyond the scope of this assessment.

1.1 Background and Motivation

Currently, nuclear utilities make site-specific determinations on how to manage their SNF. For dry storage, most utilities are using high-capacity canisters (those 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 (those able to hold 37 PWR or 87/89 BWR assemblies). Key factors in utility decision-making relative to cask design selection 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, though the high-capacity DPCs may have to remain in on-site storage for many years before these loaded canisters are below the thermal and dose limits required for transportation. In addition to transportability requirements, any loaded canisters that will be disposed of will need to meet repository constraints. An example is emplacement thermal limits, which may require significant aging times, perhaps fifty years or more after reactor discharge (Ref. 5) to ensure the thermal loads are compatible with repository design concepts. DOE is actively evaluating the feasibility of direct DPC disposal.

Repackaging DPCs, if required for a particular geologic disposal concept, would result in a significant increase in overall system fuel handling operations and associated costs as well as additional worker dose compared with direct DPC disposal. Unloaded DPCs that are no longer being used as part of the system would have to be properly managed and may have to be disposed (most likely as low-level radioactive waste [LLW]), resulting in additional system cost that could be avoided if the SNF could initially be loaded into a disposable canister. However, it should also be recognized that use of smaller, disposable canisters may introduce certain additional system costs, e.g. those associated with an increased number of canisters and handling operations. Hence, a systematic assessment of the potential benefits and drawbacks of various approaches is important to inform any future decisions.

The idea of a canister system capable of storage, transportation, and disposal without repackaging has been developed and discussed for many years. The past work considered the Transportation, Aging, and Disposal (TAD) canister system and the Multi-Purpose Canister system developed to be compatible with a repository in volcanic tuff (Refs. 6 and 7). The potential benefits of this type of system include the following:

- Reduced overall system cost[3]
- Increased flexibility and/or reduced sensitivity to future decisions and changes to waste management requirements
- Simplified handling and licensing at an interim storage, repackaging, or reprocessing facility and/or repository (Ref. 8)
- Simplified transportation hardware and operations
- Simplified interim storage facility (ISF)[4] design and operations
- Reduced uncertainties associated with waste acceptance and system performance
- Minimized amount of repackaging
- Reduced handling of individual SNF assemblies, leading to reduced probability of assembly mishandling or drops, as well as reduced concerns related to fuel condition following extended storage and transportation

Though there are potential benefits, there are two outstanding issues in regards to standardization.

1. Because a repository has not been selected, there are no site-specific disposal requirements[5] for the waste package (WP).

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[3] The NWPA Section 111(b)(4) established the Nuclear Waste Fund, composed of payments made by the generators and owners of high-level radioactive waste and spent nuclear fuel, that will ensure that the costs of carrying out activities relating to the disposal of such waste and spent fuel will be borne by the persons responsible for generating such waste and spent fuel. Thus the potential for reducing overall system costs may provide an incentive to adopting changes to the current status quo.

[4] The terms “Interim Storage Facility” (ISF) and “Consolidated Interim Storage Facility” (CISF) are used interchangeably in this report. Both refer to an away-from-reactor storage facility.

[5] The term “requirement” is used only in the context of this evaluation and is not intended to establish formal design or regulatory requirements.

2. Any change in canister design has the potential to impact utility operations if these new canisters are loaded at operating reactor sites.

The motivation behind this assessment is to better understand and quantify the impacts of incorporating SNF canister standardization into the waste management system to provide a basis for future policy decisions. The major attributes that will be quantified are system-wide cost benefits and operational impacts such as timeframes and doses. While it is true that there are no repository-specific disposal requirements, it is not clear that the status quo of continuing to load large DPCs is the most effective strategy for the entire nuclear waste management system. This assessment will quantify the impacts of continuing with the status quo versus adopting standardized canister systems at some point in the nuclear waste management system. It will analyze the impacts of choosing to load larger canisters and then having to repackage into smaller canisters as well as the opposite scenario where small canisters are initially loaded but at some point it is determined that larger canisters can be used for disposal.

Besides the lack of site-specific disposability requirements, the other major issue is the potential operational and financial impact of loading smaller capacity canisters at power plant sites. The nuclear utilities have a finite time interval to perform dry storage loading campaigns between refueling outages, and loading lower-capacity canisters is expected to negatively impact the amount of SNF that could be loaded in a given interval. As part of this standardization assessment, the time available for canister loading at reactor sites, the durations of loading operations, and the potential durations of loading lower-capacity canisters will all be researched. NFST realizes that this issue is of significant interest to the utilities and, as such, plans to engage industry to look at advanced and innovative techniques in regards to loading, drying, welding, etc.

Successful conclusion of this assessment will lay the groundwork for providing a basis for potential future policy decisions in regards to standardization and integration in the waste management system. This assessment will likely be composed of multiple evaluations, the first of which is presented in this report. Each evaluation will inform future evaluations and identify areas where more information is needed.

1.2 Strategy, Response to Outcome, and Scenario Definitions

The focus of this assessment is an evaluation of waste management system strategies that include both the current utility status quo approach (large DPCs optimized for each utility’s near-term storage needs) and alternatives that include adopting some form of standardized SNF canister which may improve overall system operation.[6] A primary analytic objective will be to determine the response of each standardized canister strategy to future contingencies that differ significantly from the planning basis underlying the strategy.

An important objective of the use of standardized SNF canisters is to avoid the possible need to cut open and dispose of a large number of welded canisters (i.e., DPCs) that might turn out to be incompatible[7] with the characteristics of the repository site that is selected. Therefore, this potential incompatibility is the primary focus of this initial evaluation. This assessment does not try to answer the question of why certain contingencies may occur; instead, it focuses on the impacts on the system as a whole if those contingencies do occur and on identifying significant differences among strategies with respect to those impacts. This fiscal year 2014 (FY14) work specifically looks at the reactor, ISF, repackaging facility, and transportation impacts. The repository impacts will be assessed in future work. For purposes of this

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[6] Potential standardization of overpacks for transportation or storage of SNF canisters is not the focus of this evaluation. Vendors are already working on this possibility for their own canisters, and if a standardized canister system of some sort proves to be desirable, then the appropriate overpacks would be designed as part of the system.

[7] “Incompatible” is defined to include non-technical concerns such as a possible requirement that for disposal in a particular geologic medium, large DPCs or standardized canister systems would have to be stored for a longer period than is deemed acceptable.

initial FY14 evaluation, the impacts considered will be those that might result from incompatibilities related to the capacity and size of the canisters.

2. STRATEGIES AND SCENARIOS

In this evaluation and the larger standardization assessment, the following terms have specific meanings. A “strategy” is a relatively near-term (within the next 10–15 years) policy decision to either implement or not implement a specific plan for standardized canister systems (e.g., begin loading smaller standardized canister systems at reactor sites). A “response to outcome” is a course of action to be taken after a particular outcome becomes known, such as the definition of disposal requirements following a determination of the geologic medium. A “scenario” consists of both the strategy and response to outcome and includes assumptions on how both of these would be implemented. Strategies are different initial conditions for the system (system start), whereas scenarios encompass the entire time period of the system, including initial/boundary conditions (system start to finish) for an assumed outcome and response to that outcome.

This assessment considers three strategies: (1) a status quo strategy that continues use of DPC systems with no actions taken to increase the likelihood that DPCs can be used for storage, transportation, and disposal; (2) a standardized canister strategy initially focused on canister capacity options to facilitate future disposal; and (3) an assembly access strategy to keep fuel assemblies more accessible for later loading into waste-package-compatible canisters once the disposal requirements are determined. In this evaluation, the status quo strategy (1) and the standardized canister strategy (2) are analyzed.

Each of these strategies and their associated options are described in the following sub-sections. Not all combinations and permutations of the options are evaluated in this report. An initial set of strategies has been selected to determine the types and bounds of impacts that can be expected. These have been marked with an asterisk. Additional strategies will be defined and evaluated as needed based on this initial evaluation.

One assumption that is underlying this evaluation (and the larger standardization assessment) in regards to disposal of canisters is that smaller canisters are compatible for disposal with more geologies than larger canisters. This assumption is discussed in References 5 and 9.

2.1 Status Quo Strategies[*]

The current utility-planning status quo strategy will be used as a basis for comparison with standardization alternatives. This strategy is characterized by the following:

- Continued trend toward higher burnups, larger/higher heat-load DPCs, and higher capacity canisters
- No federal action to promote standardization of any kind

The status quo strategy involves continuation of trends in the use of DPCs for at-reactor storage.

2.2 Standardized Canister Strategies

Standardized canister strategies are defined by selecting from the following options: (1) a choice of a standardized canister system, (2) a choice of location for standardized canister loading, and (3) a choice of

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[*] Strategies marked with an asterisk are the initial focus of this evaluation.

when the standardized canister is loaded. This evaluation will focus on strategies involving early adoption of a single standardized canister system at reactor sites.

There are many options for the type of canister system, the location to load the canister system, and the timing to begin those loading operations. The major options are listed in this section and those marked with an asterisk are the focus of this initial evaluation. The selected strategies give a range of options for standardized canister systems and will help determine appropriate, additional strategies as the larger standardization assessment moves forward.

2.2.1 Canister system capacity and type

The options for the standardized canister strategies consist of differently sized welded and/or bolted canister systems with different capacities. The capacities selected for this evaluation are based on past studies (Refs. 10 and 11), though additional capacities are possible. For further clarification, each strategy will consist of only a single standardized canister design (e.g., 4 PWR/9 BWR, 12 PWR/32 BWR). However, once a repository is known, the strategy will transition to a repository-compatible design (see additional details in Section 2.4). Canister sizes that may be considered include:

- 1 PWR/2 BWR canister
  - Loaded, stored, and transported individually
  - Loaded in a multi-canister cask for storage and transportation[8]
- 4 PWR/9 BWR canister
  - Loaded, stored, and transported individually
  - Loaded in a multi-canister cask for storage and transportation*
- 12 PWR/32 BWR canister
  - Loaded, stored, and transported individually
  - Loaded in a multi-canister cask for storage (not transportation)*
- 21 PWR/44 BWR canister*
- 32 PWR/68 BWR canister
- 37 PWR/89 BWR canister*

Some options related to the largest capacity above, which may be explored in later studies, involve standardizing DPC systems (the canister and/or overpack) with an objective of improving operational efficiencies and/or feasibility related to loading, storage, and/or transportation, as well as potential direct disposal possibilities. Some potential options are identified below.

- Addition of standardized post-closure criticality control features to enhance the likelihood that the DPCs will remain sub-critical
- Specification of loading configurations for DPCs that will mitigate potential thermal incompatibility with transportation requirements or future repository design concepts
- Transition to a bolted-lid, smaller capacity, standard DPC. This could stop the growth of an inventory of large, welded DPCs that might have to be cut open and disposed of so that the contained SNF can be repackaged into disposal-compatible containers

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[8] A multi-canister cask concept allows multiple canisters to be loaded into a single cask to simplify cask operations, storage, and transportation. The individual canisters would be readily accessible for future canister movements.

2.2.2 Location and timing of canister loading operations

There are three potential options for the location to load canisters and each location has options for the timing to begin loading operations.

- At reactors[9]
    - Starting as soon as possible*
    - After shutdown
    - After disposal package characteristics are known
- At an ISF
    - When acceptance starts
    - After disposal package characteristics are known
- At the repository.

To simplify the comparison of strategies, it is assumed that purpose-built WPs loaded at the repository will use a standardized inner canister with a disposal overpack, even though the storage and transportation capabilities of the standardized canister system may not be used[10].

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[9] It should be noted that in this evaluation all canisters, regardless of size, are assumed to be loaded using current utility procedures (i.e., no parallel operations or optimizations are assumed for smaller canister loading operations).

[10] In this evaluation, a standardized canister and the waste package-compatible canister are assumed to be the same physical canister; the canister would be placed in a storage overpack to become part of the storage system or be placed in a waste package overpack to become part of the engineered barrier system in a geologic repository

2.3 Assembly Access Strategies

Assembly access strategies are defined as shifting to bare fuel[11] storage and transportation. This strategy could involve bolted, bare fuel transportation casks to move the assemblies from the reactor pools to an ISF, or it could involve individual assembly vault storage at reactor sites.

There are numerous options for this strategy, including the following:

- Size and capacity of casks
- Assembly storage system at reactors or an ISF
    - Pool
    - Vault
    - Bolted canister
- Timing of loading and implementation
    - Load bolted casks/vaults as soon as casks/vaults are available
    - Load bolted casks once storage facility is operational
    - Load bolted casks/vaults after reactor shutdown

This strategy is outside the scope of this initial evaluation and will be examined in future work. Many of these options are being considered as part of other NFST systems analysis work activities and those results will help guide the most appropriate strategies and scenarios related to bare fuel options.

2.4 Strategy Evaluation using Scenario Analyses

Most strategies[12] include the assumption that once the characteristics of a repository site are known, the corresponding WP requirements are defined, and the compatible standardized canister systems are available, SNF being unloaded from reactor spent fuel pools will be placed into repository-compatible standardized canister systems, as illustrated in Figure 1. It is also assumed that the legacy canistered SNF will be repackaged into such standardized canister systems at the repository if needed. To clarify, only the direct disposal of all existing DPCs results in no repackaging. Even if standardized canister systems were implemented today and are compatible with eventual disposal, the existing DPCs (~3,500 by 2025 (Ref. 2)) would need to be repackaged if they could not be directly disposed.

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[11] Bare fuel references non-canistered assemblies that can be loaded into a transportation cask with the intent of removing those assemblies in the near future (generally no welding or cutting would be required).

[12] The eight strategy/response to outcome scenarios that do not migrate to WP-compatible canisters once the repository becomes known are the reference scenarios (see Section 5.1.1 and Section 4.1.2).

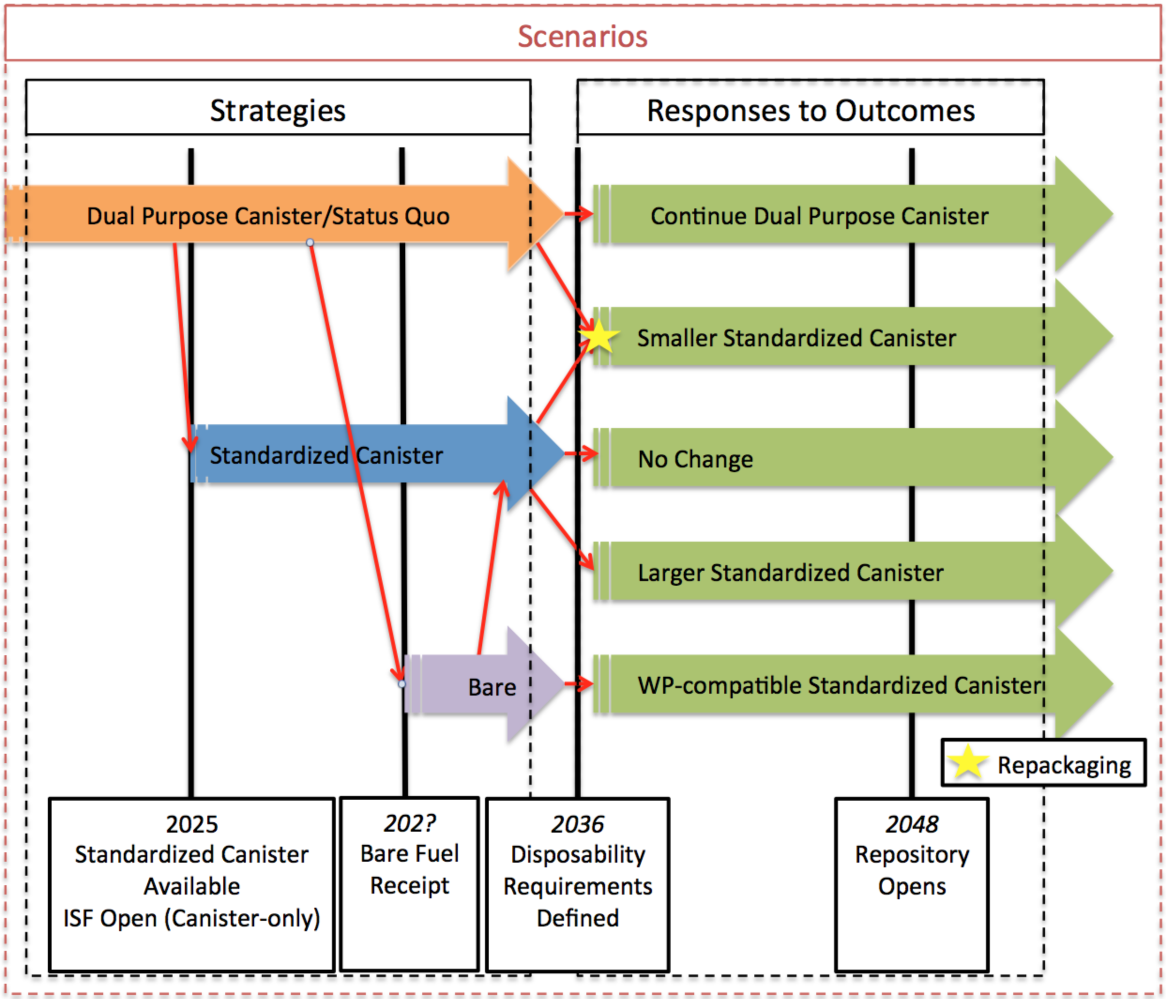

Figure 1. Three main system strategies and their potential responses to outcomes.

In Figure 1, the arrows in orange (Status Quo) and blue (Standardized Canister) are the focus of this initial FY14 evaluation. This figure does not show all options of a given scenario, but it does illustrate the high-level, near-term strategies evaluated in this initial evaluation. The red arrows show only shifts in policy (e.g., moving from loading DPCs to loading standardized canister systems) not actual repackaging operations of single assemblies. The need to repackage is indicated by the yellow star.

The selected strategy options will be analyzed using a set of scenarios that describe alternative possible evolutions of the waste management system (Section 3.2). However, all scenarios are based on the reference set of assumptions described below (Section 3.1). Sensitivity cases to test the impacts of variations in these assumptions will be evaluated as needed.

These scenarios include a large number of branching decision points, as illustrated in Figure 2. Note that timing of each branching selection varies (i.e. the ISF could begin accepting SNF in 2025, 2030, or any other time). This leads to an almost unlimited number of potential scenarios.

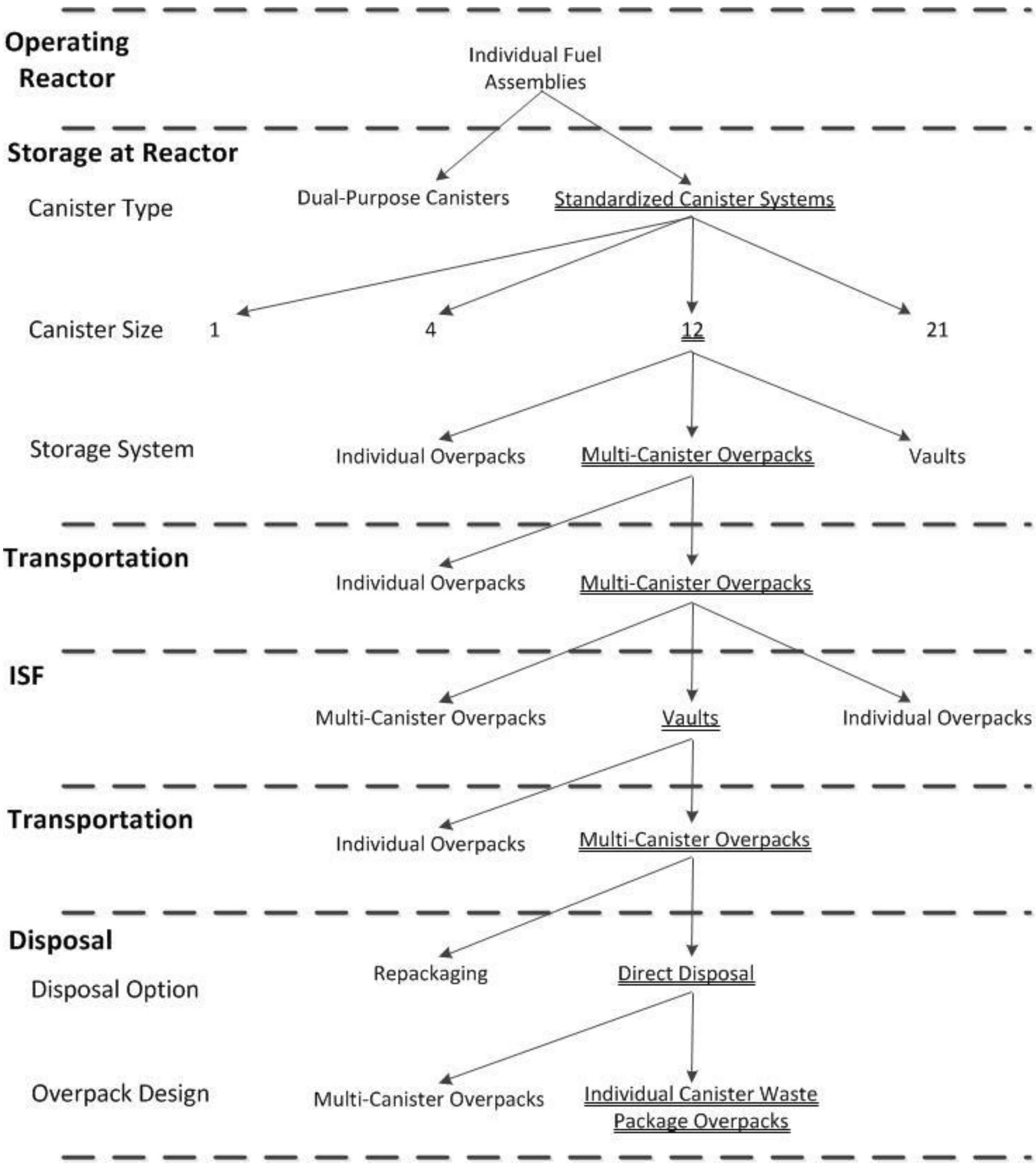

Figure 2. An example of single scenario represented as an event tree.

This example tracks a single fuel assembly out of the reactor pool, through storage and transportation, ending in final disposal.

3. ASSUMPTIONS AND INPUT SELECTIONS

In order to reduce the number of analyzed scenarios to a manageable amount, a number of assumptions and input selections were made. The reference scenario assumptions and selections (Section 3.1) were made in all scenarios in this evaluation, whereas, the scenario assumption variations (Section 3.2) were changed between different scenarios.

A detailed list of input data selections is available in Appendix C.

3.1 Reference Scenario Assumptions and Selections

As mentioned above, there are a number of assumptions selections that were held constant for all strategies and comparison scenarios. These may be reevaluated in the future with the help of sensitivity studies to quantify their system impacts.

3.1.1 All canister systems are feasible

This assumes that regardless of the number, size, or capacity of a canister system, the cask manufacturers and vendors are able to produce the needed canisters. As part of this assumption, it is assumed that material is available and that vendors have the capability to increase production to meet demand.

3.1.2 Reference spent fuel generation projections

The reference NFST SNF fuel projections are selected for all strategies and scenarios (Ref. 12). The reference inventory projection assumes that no new reactors are constructed and operated. The inventory used for all scenarios in this evaluation includes the SNF discharged from the 18 shutdown reactors[13] and the 100 currently operating reactors. Ninety-eight of the 100 currently operating reactors are assumed to have one 20 year life extension and will be decommissioned after 60 years of operations. The remaining reactors (Vermont Yankee and Oyster Creek) have utility-announced early shutdown dates of 2014 and 2019, respectively. This reference projection can be revised as needed in future analyses to take into account additional early shutdowns and new builds.

3.1.3 Reference system spent fuel acceptance assumptions

A system acceptance rate of 3,000 metric tons of heavy metal (MTHM) and a youngest fuel first (YFF) acceptance/ oldest fuel first (OFF) allocation are selected for all strategies and scenarios. All SNF is accepted in canisters (DPCs or standardized canisters). The nine existing shutdown reactor sites are de-inventoried first over a ramp-up of five years.[14] After that time, the SNF is allocated with an OFF procedure and accepted with a YFF procedure. Allocation priority determines which reactor sites ship and how much 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. An OFF allocation is used to determine the amount of SNF (MTHM) that will be accepted when SNF is transported away from reactor sites. A YFF, minimum 5-year out-of-reactor (YFF-5) fuel prioritization is used to determine the number of fuel assemblies transported within the allocated MTHM amount for each reactor site. It is assumed that reactor operators would prefer to transfer younger SNF from the spent fuel pools first and leave the generally older SNF in dry storage. This would increase the available capacity in the spent fuel pools and reduce or eliminate the need to transfer additional SNF to dry storage. This assumption is consistent with the reference system spent fuel acceptance assumption used in previous systems studies (Ref. 2). As concluded in Reference 2, acceptance priority assumptions can have a significant influence on the transportation system and the sizing of facilities. The NFST is evaluating the implications of other acceptance strategies outside of this standardization assessment, and those results may be evaluated with respect to standardization in future evaluations.

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[13] SNF at Fort St. Vrain and INL is not included because the sites are owned and operated by DOE.

[14] The nine existing shutdown sites are Big Rock Point, Haddam Neck, Humboldt Bay, LaCrosse, Maine Yankee, Rancho Seco, Trojan, Yankee Rowe, and Zion.

3.1.4 Reference storage and transportation assumptions

There are two assumptions related to storage and transportation of standardized canister systems.

- Large standardized canister systems are stored at reactors or at the ISF in the types of systems currently in use at the reactor sites (i.e., concrete overpacks for vertical canisters and horizontal modules) for DPCs and were transferred to overpacks for subsequent transportation.
- Small, standardized canister systems are stored at reactors and subsequently transported away in the multi-canister overpacks. At an ISF, they are stored in a multi-canister configuration in large concrete overpacks, consistent with at-reactor storage.

The assumed storage and transportation overpack capacities can be seen in Table 1.

Table 1. Overpack capacity as a function of canister size.

Canister Size	Storage Capacity	Transportation Capacity
4 PWR / 9 BWR	4	4
12 PWR / 32 BWR	3	1
21 PWR / 44 BWR	1	1
Ref DPC	1	1
37 PWR / 89 BWR	1	1

3.1.5 Reference ISF assumptions

The ISF assumptions have been applied consistently to all scenarios. Sensitivity studies may be conducted in this area in the future (start dates are documented in Section 3.2.2). All assumptions are based on Reference 13**.**

- Acceptance is limited at a pilot ISF to DPCs from the nine existing shutdown reactor sites.
- Operations expand to 3,000 MTHM per year canister receipt capability at a co-located, large ISF. It is assumed that there is a 3 year ramp-up to get to the full receipt capability. 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. Once the repository begins accepting SNF, all SNF from reactors goes directly to the repository. Once at-reactor SNF is unavailable for transport, the SNF at the ISF is accepted at the repository.[15]
- No packaging/repackaging for disposal is performed at the ISF. This is consistent with the status quo strategies in which DPCs are shipped directly from reactors to the repository with no ISF in the system.
- Standardized canister systems will be stored at the ISF as described above.
- The storage capacity is not constrained.

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[15] Sensitivity case(s) in which the ISF serves as a throughput facility that receives and handles all SNF on the way to the repository may be evaluated in the future to see if the observations concerning standardized containers would be affected.

3.1.6 Reference repository assumptions

- There is 3,000-MTHM/year receipt and emplacement (assuming no ramp-up for this analysis).
- The surface storage capacity for canistered SNF and for WPs prior to emplacement is not constrained.
- All packaging/repackaging for disposal is performed at the repository.
- If the 37 PWR standardized canister design is assumed to be disposable, all legacy DPCs are also assumed to be disposable.
- No capacity limits for final disposition are specified.

3.2 Scenario Assumption Variations

Along with the reference assumptions and selections, the following assumptions were varied.

3.2.1 Responses to outcomes based on repository compatibility

Scenarios were constructed by combining each strategy with a response to outcome (based on repository compatibility). Then the scenarios were analyzed using the reference scenario assumptions described above. Possible responses to outcome based on repository compatibility are described below.

- No change (compatible case): A base case in which it is determined, at the time that the repository site/design characteristics were known, that the standardized canister system/DPC used in the strategy was directly disposable in the repository. In this case, the standardized canister systems/DPCs were loaded at the repository into suitable disposal overpacks.
- Change to smaller canister or change to larger canister (incompatible case): A contingent case in which it is determined, at the time that the repository site/design characteristics were assumed to become known, that the optimal WP capacity or size was not consistent with the capacity or size of the canister used in the strategy. As described in Section 2.4, at that time all future SNF was loaded into repository-compatible standardized canister systems. The already-canistered SNF will be dispositioned depending on the specific case.
    - If the strategy involves larger standardized canister systems or DPCs and the repository is determined to be incompatible with a large capacity 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. Since the 4P/9B standardized canister system is expected to be compatible with the most restrictive disposal environments under consideration, those standardized canister systems are assumed to be disposable without repackaging.
    - If the repository is determined to be compatible with the larger standardized canister systems, the small, standardized canister systems would not be repackaged. Instead, the loaded smaller canisters would be disposed of in multi-canister disposal overpacks.[16]

3.2.2 Schedule variations

These dates are based on the Administration’s Strategy (Ref. 1) where applicable.

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

- ISF accepts DPCs from shutdown reactors – 2021
- ISF accepts DPCs/standardized canister systems at large scale[17] – 2025
- Standardized canister systems available – 2025
- Repository sited – 2026
- Disposability of canisters known with high confidence – 2036
- Repository opens – 2048

The reference date (2036) for determination of the repository WP size is based on past engineering experience. While the repository is sited in 2026, it will take some time to more fully characterize the repository to determine the appropriate WP capacity. Assuming the repository license is granted in 2042, the application would need to be submitted in the 2038 time frame. It is assumed that two years prior to submittal, the design specifications would be selected (and locked down) to prepare the application, including the specifications on the WP size.

All strategies are based on the reference dates listed above. However, to test the sensitivity of the results to changes in those dates, several combinations of changes for the various events have been identified. The intent is to start with the smallest set of schedule contingencies. This would provide important insights and would avoid the multiplication of scenario evaluations. In future evaluations, additional scenarios will be defined and evaluated if the initial analyses indicate that further refinement is needed.

3.2.3 Other variations

In future evaluations, other variations to the reference scenario assumptions may be considered, including addition of bare fuel receipt and perhaps bare fuel storage capabilities at the ISF, as well as loading of standardized canister systems at the ISF. Alternative receipt priority approaches to determine effects on different strategies might also be examined.

4. SCENARIO DESCRIPTIONS

As noted in Section 1.2, scenarios consist of an initial strategy (i.e., size of canister to load), an outcome (i.e., WP size), and a response to outcome (i.e., immediately switch to waste-package-compatible canister). Scenarios include assumptions on when and where they would be implemented. Scenarios encompass the entire time period of the system, including initial/boundary conditions (system start to finish) for an assumed outcome and the response to that outcome. In this initial evaluation, 52 scenarios were analyzed to (1) identify areas for more refined future study, (2) identify areas where input information could be improved/confirmed, and (3) provide insight into impacts related to near-term implementation of standardized canister systems.

All scenarios in the initial system evaluation have the same SNF generation projection (Section 3.1.2) and the same acceptance priority for shipment from utility sites (Section 3.1.3). All scenarios assume a 3,000 MTHM annual throughput at system steady state operation (Sections 3.1.5 and 3.1.6). If needed, the repackaging facility is assumed to be at the repository (Section 3.1.6).

Relevant waste management system future end states (outcomes) are represented by a geologic repository design that can handle a specific capacity WP (in terms of number of SNF assemblies). Representative

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[17] Assumes a 3-year ramp-up to 3,000 MTHM/year steady state.

WP capacities are chosen based on recent research on disposal concepts in the US (Refs. 5 and 9). The standardized canister system sizes considered in this evaluation match WP capacities:

- Small:	4 PWR / 9 BWR (Ref. 11)
- Medium:	12 PWR / 32 BWR (Ref. 11)
- Large:	21 PWR / 44 BWR (Ref. 10)
- Largest:	37 PWR / 89 BWR (Largest currently-licensed DPC design)

For small 4 PWR-sized canisters, a multicanister overpack with a capacity of four canisters is assumed to be used for both storage and transportation (Ref. 11). For medium canisters, a multicanister overpack with a capacity of three canisters is assumed to be used for storage only, but not for transportation (Ref. 11). SNF in DPCs or standardized canisters that is not compatible with the final repository design is repackaged into repository-compatible WPs at repository repackaging facilities (Section 3.1.6).

In this section, the scenarios are divided into two major classes based on the scenario's initial strategy: status quo and standardization. These are subdivided into multiple classes based on both the outcome and the waste management system architecture implementation assumptions (i.e., with or without an ISF).

4.1 Status Quo Major Class

All scenarios in the status quo major class include the status quo strategy, which continues use of DPC systems with no actions taken to increase the likelihood that DPCs can be used for storage, transportation, and disposal. There are 14 scenarios in the status quo major class. This major class was selected to provide a baseline for comparison to scenarios where standardized canister systems were introduced early in the waste management system. This status quo strategy is consistent with the utilities' current loading decisions (i.e. load large DPCs).

4.1.1 Status Quo Class 1 (Reference)

This class contains the following assumptions and input selections:

- All reactors load all SNF into DPCs, regardless of WP size or timing of when the WP size is known.
- The waste management system architecture implementation does not include an ISF.
- The WP size is known in 2036 (not relevant for this class) and the repository begins accepting SNF in 2048.

In this class, the outcome (size of WP) is varied, but the response to the outcome is to continue loading DPCs. Four scenarios were analyzed in this class.

1. The WP size is 4 PWR.
2. The WP size is 12 PWR.
3. The WP size is 21 PWR.
4. All DPCs are determined to be disposable.

4.1.2 Status Quo Class 2 (Reference with ISF)

This class contains the following assumptions and input selections:

- All reactors load all SNF into DPCs, regardless of WP size or timing of when the WP size is known.

- The waste management system architecture implementation includes a pilot ISF that accepts DPCs from the existing shutdown sites from 2021–2025, with a full-scale ISF that begins accepting DPCs in 2025.
- The WP size is known in 2036 (not relevant for this class) and the repository begins accepting SNF in 2048.

In this class, the outcome (size of WP) is varied, but the response to the outcome is to continue loading DPCs regardless of the size of the WP. Four scenarios were analyzed in this class.

5. The WP size is 4 PWR.
6. The WP size is 12 PWR.
7. The WP size is 21 PWR.
8. All DPCs are determined to be disposable.

4.1.3 Status Quo Class 3

This class is similar to status quo class 1 (Section 4.1.1), but the response to outcome is different.

This class contains the following assumptions and input selections:

- All reactors load SNF into DPCs until the WP capacity is determined. At that point, the reactors begin loading WP-compatible canisters.
- The waste management system architecture implementation does not include an ISF.
- The WP size is known in 2036 and the repository begins accepting SNF in 2048.

In this class, the outcome (size of WP) is varied and the response to the outcome is to begin loading WP-compatible canisters once the WP capacity is determined. Three scenarios were analyzed in this class.

9. The WP size is 4 PWR.
10. The WP size is 12 PWR.
11. The WP size is 21 PWR.

4.1.4 Status Quo Class 4

This class is similar to status quo class 3 (Section 4.1.3), except that an ISF was added to the system.

This class contains the following assumptions and input selections:

- All reactors load SNF into DPCs until the WP size is determined. At that point, the reactors begin loading WP-compatible canisters.
- The waste management system architecture implementation includes a pilot ISF that accepts DPCs from the existing shutdown sites from 2021–2025, with a full-scale ISF that begins accepting DPCs in 2025.
- The WP size is known in 2036 and the repository begins accepting SNF in 2048.

In this class, the outcome (size of WP) is varied and the response to the outcome is to begin loading WP-compatible canisters once the WP capacity is determined. Three scenarios were analyzed in this class.

12. The WP size is 4 PWR.
13. The WP size is 12 PWR.
14. The WP size is 21 PWR.

4.2 Standardized Canister Major Class

All scenarios in the standardized canister major class implement the standardized canister strategy. This implies that all reactors begin loading a standardized canister system before the disposal requirements are known (either 2025 or 2030 in all scenarios). This major class was selected to provide variations on the different standardized canister system options. These scenarios include implementation of a specific-capacity standardized canister system early in the waste management system.

4.2.1 Standardized Canister Class 1

This class contains the following assumptions and input selections:

- All reactors load SNF into DPCs until 2025, when the standardized canister systems become available. At that point, reactors begin loading the standardized canister systems.
- A pilot ISF accepts DPCs from 2021–2025 from the existing shutdown sites, and a full-scale ISF begins accepting DPCs in 2025.
- The WP capacity is known in 2036, and the repository begins accepting SNF in 2048.

In this class, the strategy (initial standardized canister size loaded in 2025) is varied, the outcome (size of WP) is varied, and the response to the outcome is to begin loading WP-compatible canisters once the WP is determined. Twelve scenarios were analyzed in this class.

15. The initial standardization canister strategy is 4 PWR (2025). The WP size is 4 PWR (2036).
16. The initial standardization canister strategy is 4 PWR (2025). The WP size is 12 PWR (2036).
17. The initial standardization canister strategy is 4 PWR (2025). The WP size is 21 PWR (2036).
18. The initial standardization canister strategy is 4 PWR (2025). The WP size is 37 PWR (2036).
19. The initial standardization canister strategy is 12 PWR (2025). The WP size is 4 PWR (2036).
20. The initial standardization canister strategy is 12 PWR (2025). The WP size is 12 PWR (2036).
21. The initial standardization canister strategy is 12 PWR (2025). The WP size is 21 PWR (2036).
22. The initial standardization canister strategy is 12 PWR (2025). The WP size is 37 PWR (2036).
23. The initial standardization canister strategy is 21 PWR (2025). The WP size is 4 PWR (2036).
24. The initial standardization canister strategy is 21 PWR (2025). The WP size is 12 PWR (2036).
25. The initial standardization canister strategy is 21 PWR (2025). The WP size is 21 PWR (2036).
26. The initial standardization canister strategy is 21 PWR (2025). The WP size is 37 PWR (2036).

4.2.2 Standardized Canister Class 2

This class is similar to the standardized canister class 1 (Section 4.2.1), but the ISF is assumed to be delayed by five years.

This class contains the following assumptions and input selections:

- All reactors load SNF into DPCs until 2025 when the standardized canister systems become available. At that point, the reactors begin loading the standardized canister systems.
- A pilot ISF accepts DPCs from 2026–2030 from the existing shutdown sites, and a full-scale ISF begins accepting DPCs in 2030.
- The WP size is known in 2036, and the repository begins accepting SNF in 2048.

In this class, the strategy (initial standardized canister size loaded in 2025) is varied, the outcome (size of WP) is varied, and the response to the outcome is to begin loading WP-compatible canisters once the WP is determined. Three scenarios were analyzed in this class.

27. The initial standardization canister strategy is 4 PWR (2025). The WP size is 4 PWR (2036).
28. The initial standardization canister strategy is 12 PWR (2025). The WP size is 12 PWR (2036).
29. The initial standardization canister strategy is 21 PWR (2025). The WP size is 21 PWR (2036).

4.2.3 Standardized Canister Class 3

This class is similar to the standardized canister class 1 (Section 4.2.1), but there is no ISF in the system.

This class contains the following assumption and input selections:

- All reactors load SNF into DPCs until 2025, when the standardized canister systems are available. At that point, reactors begin loading the standardized canister systems.
- The waste management system architecture implementation does not include an ISF.
- The WP size is known in 2036, and the repository begins accepting SNF in 2048.

In this class, the strategy (initial standardized canister size loaded in 2025) is varied, the outcome (size of WP) is varied, and the response to the outcome is to begin loading WP-compatible canisters once the WP is determined. Twelve scenarios were analyzed in this class.

30. The initial standardization canister strategy is 4 PWR (2025). The WP size is 4 PWR (2036).
31. The initial standardization canister strategy is 4 PWR (2025). The WP size is 12 PWR (2036).
32. The initial standardization canister strategy is 4 PWR (2025). The WP size is 21 PWR (2036).
33. The initial standardization canister strategy is 4 PWR (2025). The WP size is 37 PWR (2036).
34. The initial standardization canister strategy is 12 PWR (2025). The WP size is 4 PWR (2036).
35. The initial standardization canister strategy is 12 PWR (2025). The WP size is 12 PWR (2036).
36. The initial standardization canister strategy is 12 PWR (2025). The WP size is 21 PWR (2036).
37. The initial standardization canister strategy is 12 PWR (2025). The WP size is 37 PWR (2036).
38. The initial standardization canister strategy is 21 PWR (2025). The WP size is 4 PWR (2036).
39. The initial standardization canister strategy is 21 PWR (2025). The WP size is 12 PWR (2036).
40. The initial standardization canister strategy is 21 PWR (2025). The WP size is 21 PWR (2036).
41. The initial standardization canister strategy is 21 PWR (2025). The WP size is 37 PWR (2036).

4.2.4 Standardized Canister Class 4

This class is similar to the standardized canister class 2 (Section 4.2.2). The ISF and the standardized canister system are both assumed to be delayed by five years.

This class contains the following assumptions and input selections:

- All reactors load SNF into DPCs until 2030 when the standardized canister systems become available. At that point, the reactors begin loading the standardized canister systems.
- A pilot ISF accepts DPCs from 2026–2030 from the existing shutdown sites, and a full-scale ISF begins accepting DPCs in 2030.

- The WP size is known in 2036 and the repository begins accepting SNF in 2048.

In this class, the strategy (initial standardized canister size loaded in 2030) is varied, the outcome (size of WP) is varied, and the response to the outcome is to begin loading WP-compatible canisters once the WP is determined. Three scenarios were analyzed in this class.

42. The initial standardization canister strategy is 4 PWR (2030). The WP size is 4 PWR (2036).
43. The initial standardization canister strategy is 12 PWR (2030). The WP size is 12 PWR (2036).
44. The initial standardization canister strategy is 21 PWR (2030). The WP size is 21 PWR (2036).

4.2.5 Standardized Canister Class 5

This class is similar to the standardized canister class 1 (Section 4.2.1), but the WP is assumed to be known and the repository is assumed to be complete six years earlier.

This class contains the following assumptions and input selections:

- All reactors load SNF into DPCs until 2025, when the standardized canister systems become available. At that point, the reactors begin loading the standardized canister systems.
- A pilot ISF accepts DPCs from 2021–2025 from the existing shutdown sites, and a full-scale ISF begins accepting DPCs in 2025.
- The WP size is known in 2030, and the repository begins accepting SNF in 2042.

In this class, the strategy (initial standardized canister size loaded in 2025) is varied, the outcome (size of WP) is varied, and the response to the outcome is to begin loading WP-compatible canisters once the WP is determined. Four scenarios were analyzed in this class.

45. The initial standardization canister strategy is 4 PWR (2025). The WP size is 21 PWR (2030).
46. The initial standardization canister strategy is 12 PWR (2025). The WP size is 21 PWR (2030).
47. The initial standardization canister strategy is 12 PWR (2025). The WP size is 4 PWR (2030).
48. The initial standardization canister strategy is 21 PWR (2025). The WP size is 4 PWR (2030).

4.2.6 Standardized Canister Class 6

This class is similar to the standardized canister class 1 (Section 4.2.1), but the WP is assumed to be known and the repository is assumed to be complete four years later.

This class contains the following assumptions and input selections:

- All reactors load SNF into DPCs until 2025, when the standardized canister systems become available. At that point, the reactors begin loading the standardized canister systems.
- A pilot ISF accepts DPCs from 2021–2025 from the existing shutdown sites, and a full-scale ISF begins accepting DPCs in 2025.
- The WP size is known in 2040, and the repository begins accepting SNF in 2052.

In this class, the strategy (initial standardized canister size loaded in 2025) is varied, the outcome (size of WP) is varied, and the response to the outcome is to begin loading WP-compatible canisters once the WP is determined. Four scenarios were analyzed in this class.

49. The initial standardization canister strategy is 4 PWR (2025). The WP size is 21 PWR (2040).
50. The initial standardization canister strategy is 12 PWR (2025). The WP size is 21 PWR (2040).

51. The initial standardization canister strategy is 12 PWR (2025). The WP size is 4 PWR (2040).
52. The initial standardization canister strategy is 21 PWR (2025). The WP size is 4 PWR (2040).

5. SCENARIO RESULTS

This is the initial evaluation of the impact of incorporating standardized canisters into the waste management system. Therefore, one of the primary purposes of this evaluation is to understand results in the context of the system computational model inputs, boundary conditions, and assumptions. In several instances, the results were unexpected and will lead to a more critical evaluation of the data and cost inputs to ensure that appropriate values are used in future evaluations. Cost information is provided to show how management strategies and responses to outcomes affect relative costs. Application of the rough order of magnitude (ROM) cost results beyond this purpose should be avoided for several reasons.

1) Simplified assumptions are used in this evaluation and in describing the alternative SNF management strategies.
2) Significant portions of the input data assumptions related to standardized canisters (e.g., at-reactor costs, ISF design concepts) are based on limited or no operational or design experience[18].
3) Key factors such as waste management system costs for siting, characterization, and licensing for repository facilities are not included.
4) Costs associated with delay in the waste management program, which are potentially greater for some concepts than others, are not included.
5) All metrics are tabulated from 2020 forward.

The high-level results of the scenarios are presented in Table 2 and Table 3. Table 2 shows the ROM cost metrics for each scenario and Table 3 shows the logistics metrics for each scenario. Table 4 gives a description of each column for Table 2 and Table 3. Table 5 provides a quick reference for the assumptions for each scenario.

Throughout this report, different colors are used to represent groups of scenarios based on the WP size:

- 4 PWR WP size: orange
- 12 PWR WP size: light blue
- 21 PWR WP size: green
- 37 PWR (or DPC) WP size: red

This color system is used in Table 2, Table 3, Table 5, and Appendix A and Appendix B, as well as in various figures throughout the report.

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[18] Specifically, the cost to load any size canister (4 PWR through 37 PWR) is assumed to be the same. This is because all at-reactor loading operations, regardless of canister size, are assumed to be performed in same manner (i.e., serially). Future evaluations will evaluate the benefits of different loading operations.

Table 2. The ROM cost estimates for each scenario.[19]

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	At-reactor Capital Cost	At-reactor Other Costs	ISF Cask/Pad Cost	ISF Other Costs	WP/LLW Costs	Other Repackaging Costs	Fleet/Capital Transportation Costs	Other Transportation Costs	Total Cost
1	Status Quo	Class 1	DPCs loaded at-Rx; 4 PWR WPs repackaged at Repo; Repo open (2048); no ISF	SQ 1.a	$8.5	$42.4	$0.0	$0.0	$29.6	$9.9	$0.5	$4.3	$95.2
2	Status Quo	Class 1	DPCs loaded at-Rx; 12 PWR WP repackaged at Repo; Repo open (2048); no ISF	SQ 1.b	$8.5	$42.4	$0.0	$0.0	$17.5	$5.3	$0.5	$4.3	$78.5
3	Status Quo	Class 1	DPCs loaded at-Rx; 21 PWR WP repackaged at Repo; Repo open (2048); no ISF	SQ 1.c	$8.5	$42.4	$0.0	$0.0	$16.9	$5.0	$0.5	$4.3	$77.6
4	Status Quo	Class 1	DPCs loaded at-Rx; all DPCs disposable (2048); no ISF	SQ 1.d	$8.5	$42.4	$0.0	$0.0	$0.0	$0.6	$0.5	$4.3	$56.3
5	Status Quo	Class 2	DPCs loaded at-Rx; 4 PWR WP Size repackaged at Repo; Repo open (2048); Pilot ISF (2021)	SQ 2.a	$7.2	$23.3	$6.2	$2.2	$29.6	$10.0	$0.7	$5.0	$84.2
6	Status Quo	Class 2	DPCs loaded at-Rx; 12 PWR WP Size repackaged at Repo; Repo open (2048); Pilot ISF (2021)	SQ 2.b	$7.2	$23.3	$6.2	$2.2	$17.5	$5.3	$0.7	$5.0	$67.4
7	Status Quo	Class 2	DPCs loaded at-Rx; 21 PWR WP Size repackaged at Repo; Repo open (2048); Pilot ISF (2021)	SQ 2.c	$7.2	$23.3	$6.2	$2.2	$16.9	$5.0	$0.7	$5.0	$66.4
8	Status Quo	Class 2	DPCs loaded at-Rx; all DPCs disposable; Repo open (2048); Pilot ISF (2021)	SQ 2.d	$7.2	$23.3	$6.2	$2.2	$0.0	$0.6	$0.7	$5.0	$45.2
9	Status Quo	Class 3	4 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.a	$21.0	$58.8	$0.0	$0.0	$14.2	$8.1	$0.8	$5.5	$108.4
10	Status Quo	Class 3	12 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.b	$13.0	$45.8	$0.0	$0.0	$8.4	$4.2	$0.9	$6.1	$78.4
11	Status Quo	Class 3	21 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.c	$13.8	$43.5	$0.0	$0.0	$8.1	$3.9	$0.7	$4.6	$74.5
12	Status Quo	Class 4	4 PWR WPs loaded at Rx (2036); Repo open (2048); Pilot ISF (2021)	SQ 4.a	$16.9	$30.7	$7.9	$5.0	$16.9	$9.6	$1.3	$6.8	$95.2
13	Status Quo	Class 4	12 PWR WPs loaded at Rx (2036); Repo open (2048); Pilot ISF (2021)	SQ 4.b	$11.1	$23.6	$5.7	$2.8	$10.0	$5.2	$1.4	$7.6	$67.4
14	Status Quo	Class 4	21 PWR WPs loaded at Rx (2036); Repo open (2048); Pilot ISF (2021)	SQ 4.c	$11.3	$22.4	$7.1	$2.5	$9.7	$4.9	$1.1	$5.9	$64.7
15	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.4.2025.4.2036	$22.3	$34.4	$9.9	$6.4	$9.2	$8.9	$1.2	$7.7	$100.1
16	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.4.2025.12.2036	$16.7	$27.5	$7.7	$5.5	$5.5	$5.7	$1.8	$8.8	$79.2
17	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.4.2025.21.2036	$16.9	$26.3	$9.1	$5.5	$5.3	$5.5	$1.4	$7.1	$77.2
18	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.4.2025.37.2036	$13.5	$25.4	$7.7	$5.3	$0.0	$2.0	$1.3	$6.0	$61.2
19	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.12.2025.4.2036	$19.0	$31.3	$7.3	$5.3	$17.2	$9.8	$1.7	$8.6	$100.2

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[19] As mentioned in Section 3.1.6, if the 37 PWR standardized canister is assumed to be disposable, all DPCs are also assumed to be disposable.

Table 2. The ROM cost estimates for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	At-reactor Capital Cost	At-reactor Other Costs	ISF Cask/Pad Cost	ISF Other Costs	WP/LLW Costs	Other Repackaging Costs	Fleet/Capital Transportation Costs	Other Transportation Costs	Total Cost
20	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.12.2025.12.2036	$13.2	$24.4	$5.0	$3.2	$5.5	$4.6	$1.4	$8.8	$66.1
21	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.12.2025.21.2036	$13.5	$23.2	$6.4	$3.2	$5.3	$4.4	$1.6	$7.7	$65.1
22	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.12.2025.37.2036	$10.1	$22.3	$5.0	$2.9	$0.0	$0.9	$1.4	$6.6	$49.2
23	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.21.2025.4.2036	$19.0	$30.7	$9.0	$5.1	$17.2	$9.7	$1.5	$7.4	$99.5
24	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.21.2025.12.2036	$13.3	$23.8	$6.7	$3.0	$10.1	$5.2	$1.6	$8.2	$71.9
25	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.21.2025.21.2036	$13.4	$22.6	$8.1	$2.6	$5.3	$4.3	$1.0	$6.1	$63.4
26	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.21.2025.37.2036	$8.5	$21.5	$5.1	$2.0	$0.0	$0.6	$0.8	$4.5	$42.9
27	Standardized Canister	Class 2	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 2.4.2025.4.2036	$22.9	$40.9	$7.7	$5.6	$9.2	$8.9	$1.2	$7.5	$104.0
28	Standardized Canister	Class 2	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 2.12.2025.12.2036	$13.5	$29.1	$4.0	$2.8	$5.4	$4.6	$1.4	$8.6	$69.5
29	Standardized Canister	Class 2	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 2.21.2025.21.2036	$13.9	$27.1	$6.3	$2.4	$5.3	$4.3	$1.0	$6.1	$66.2
30	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.4.2025.4.2036	$25.1	$63.8	$0.0	$0.0	$9.2	$7.2	$0.9	$6.0	$112.3
31	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.12.2036	$17.0	$50.8	$0.0	$0.0	$5.4	$4.5	$1.0	$6.7	$85.4
32	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.21.2036	$17.9	$48.5	$0.0	$0.0	$5.3	$4.2	$0.8	$5.2	$81.8
33	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.37.2036	$13.1	$46.8	$0.0	$0.0	$0.0	$1.4	$0.7	$4.1	$66.1
34	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.4.2036	$22.5	$59.6	$0.0	$0.0	$14.2	$8.1	$1.0	$6.3	$111.7

Table 2. The ROM cost estimates for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	At-reactor Capital Cost	At-reactor Other Costs	ISF Cask/Pad Cost	ISF Other Costs	WP/LLW Costs	Other Repackaging Costs	Fleet/Capital Transportation Costs	Other Transportation Costs	Total Cost
35	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.12.2025.12.2036	$14.4	$46.5	$0.0	$0.0	$5.4	$3.9	$1.0	$6.7	$78.0
36	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.21.2036	$15.3	$44.3	$0.0	$0.0	$5.3	$3.6	$0.9	$5.4	$74.6
37	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.37.2036	$10.5	$42.6	$0.0	$0.0	$0.0	$0.8	$0.7	$4.3	$58.9
38	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.4.2036	$22.7	$58.8	$0.0	$0.0	$14.2	$8.1	$0.9	$5.7	$110.5
39	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.12.2036	$14.7	$45.8	$0.0	$0.0	$8.4	$4.2	$1.0	$6.4	$80.5
40	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.21.2025.21.2036	$15.5	$43.6	$0.0	$0.0	$5.3	$3.6	$0.7	$4.8	$73.4
41	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.37.2036	$10.8	$41.8	$0.0	$0.0	$0.0	$0.6	$0.6	$3.8	$57.6
42	Standardized Canister	Class 4	4 PWR STADs loaded at Rx (2030); 4 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 4.4.2030.4.2036	$21.2	$38.5	$7.7	$5.6	$11.5	$8.9	$1.2	$7.2	$101.7
43	Standardized Canister	Class 4	12 PWR STADs loaded at Rx (2030); 12 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 4.12.2030.12.2036	$12.9	$28.6	$4.0	$2.8	$6.8	$4.6	$1.3	$8.3	$69.4
44	Standardized Canister	Class 4	21 PWR STADs loaded at Rx (2030); 21 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 4.21.2030.21.2036	$13.1	$26.9	$6.3	$2.4	$6.6	$4.8	$0.9	$5.9	$66.9
45	Standardized Canister	Class 5	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2030); Repo open (2042); Pilot ISF (2021)	SCS 5.4.2025.21.2030	$15.1	$24.7	$6.6	$4.6	$5.3	$5.4	$1.4	$6.7	$69.7
46	Standardized Canister	Class 5	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2030); Repo open (2042); Pilot ISF (2021)	SCS 5.12.2025.21.2030	$13.4	$22.9	$5.4	$2.7	$5.3	$4.4	$1.5	$7.0	$62.7
47	Standardized Canister	Class 5	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2030); Repo open (2042); Pilot ISF (2021)	SCS 5.12.2025.4.2030	$20.6	$32.6	$6.5	$5.2	$13.2	$9.8	$1.7	$8.1	$97.8
48	Standardized Canister	Class 5	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2030); Repo open (2042); Pilot ISF (2021)	SCS 5.21.2025.4.2030	$20.7	$32.3	$7.2	$5.2	$13.2	$9.7	$1.4	$7.5	$97.0
49	Standardized Canister	Class 6	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2040); Repo open (2050); Pilot ISF (2021)	SCS 6.4.2025.21.2040	$18.5	$28.3	$10.7	$6.1	$5.3	$5.5	$1.5	$7.5	$83.5

Table 2. The ROM cost estimates for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	At-reactor Capital Cost	At-reactor Other Costs	ISF Cask/Pad Cost	ISF Other Costs	WP/LLW Costs	Other Repackaging Costs	Fleet/Capital Transportation Costs	Other Transportation Costs	Total Cost
50	Standardized Canister	Class 6	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2040); Repo open (2050); Pilot ISF (2021)	SCS 6.12.2025.21.2040	$13.4	$23.4	$7.0	$3.4	$5.3	$4.4	$1.7	$8.2	$67.0
51	Standardized Canister	Class 6	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2040); Repo open (2050); Pilot ISF (2021)	SCS 6.12.2025.4.2040	$17.5	$29.5	$7.7	$5.1	$20.8	$9.8	$1.8	$8.9	$101.1
52	Standardized Canister	Class 6	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2040); Repo open (2050); Pilot ISF (2021)	SCS 6.21.2025.4.2040	$17.4	$28.7	$10.0	$4.8	$20.7	$9.7	$1.5	$7.3	$100.0

Table 3. The logistics metrics for each scenario.[20]

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	Total At-rx Canisters Loaded	Max Canisters Loaded (In a Year)	Shutdown Rx-years with Fuel	ISF Receipt Bays	Max Storage Casks at ISF	Number of Canisters to Waste	m^3 of LLW	Repackaging Receiving Bays	Repackaging Opening Bays	Repackaging Closing Bays	Transportation Consist Miles	Transportation Cask Miles
1	Status Quo	Class 1	DPCs loaded at-Rx; 4 PWR WPs repackaged at Repo; Repo open (2048); no ISF	SQ 1.a	8,649	30	3,912	0	0	11,146	133,752	3	3	21	12,405,213	28,321,463
2	Status Quo	Class 1	DPCs loaded at-Rx; 12 PWR WP repackaged at Repo; Repo open (2048); no ISF	SQ 1.b	8,649	30	3,912	0	0	11,146	133,752	3	3	7	12,405,213	28,321,463
3	Status Quo	Class 1	DPCs loaded at-Rx; 21 PWR WP repackaged at Repo; Repo open (2048); no ISF	SQ 1.c	8,649	30	3,912	0	0	11,146	133,752	3	3	5	12,405,213	28,321,463
4	Status Quo	Class 1	DPCs loaded at-Rx; all DPCs disposable (2048); no ISF	SQ 1.d	8,649	30	3,912	0	0	0	0	0	0	0	12,405,213	28,321,463
5	Status Quo	Class 2	DPCs loaded at-Rx; 4 PWR WP Size repackaged at Repo; Repo open (2048); Pilot ISF (2021)	SQ 2.a	8,882	32	2,182	4	5,818	11,379	136,548	3	3	22	14,941,997	36,787,423
6	Status Quo	Class 2	DPCs loaded at-Rx; 12 PWR WP Size repackaged at Repo; Repo open (2048); Pilot ISF (2021)	SQ 2.b	8,882	32	2,182	4	5,818	11,379	136,548	3	3	7	14,941,997	36,787,423
7	Status Quo	Class 2	DPCs loaded at-Rx; 21 PWR WP Size repackaged at Repo; Repo open (2048); Pilot ISF (2021)	SQ 2.c	8,882	32	2,182	4	5,818	11,379	136,548	3	3	5	14,941,997	36,787,423
8	Status Quo	Class 2	DPCs loaded at-Rx; all DPCs disposable; Repo open (2048); Pilot ISF (2021)	SQ 2.d	8,882	32	2,182	4	5,818	0	0	0	0	0	14,941,997	36,787,423
9	Status Quo	Class 3	4 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.a	46,091	219	3,907	0	0	5,382	64,584	3	3	20	17,116,164	42,914,352
10	Status Quo	Class 3	12 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.b	16,474	66	3,907	0	0	5,382	64,584	3	3	7	19,202,582	48,413,179
11	Status Quo	Class 3	21 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.c	11,382	46	3,907	0	0	5,382	64,584	3	3	4	14,900,795	35,383,762
12	Status Quo	Class 4	4 PWR WPs loaded at Rx (2036); Repo open (2048); Pilot ISF (2021)	SQ 4.a	39,591	79	2,040	26	7,537	6,500	78,000	3	3	22	18,888,487	50,187,299
13	Status Quo	Class 4	12 PWR WPs loaded at Rx (2036); Repo open (2048); Pilot ISF (2021)	SQ 4.b	15,250	32	2,040	10	5,340	6,500	78,000	3	3	7	21,077,777	56,570,250
14	Status Quo	Class 4	21 PWR WPs loaded at Rx (2036); Repo open (2048); Pilot ISF (2021)	SQ 4.c	10,984	32	2,040	6	6,700	6,500	78,000	3	3	5	16,760,828	43,310,553
15	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.4.2025.4.2036	58,141	232	2,040	28	9,523	3,549	42,588	3	3	19	21,750,820	59,148,340
16	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.4.2025.12.2036	34,108	232	2,040	28	7,320	3,549	42,588	3	3	7	23,979,219	65,451,111
17	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.4.2025.21.2036	29,917	232	2,040	28	8,689	3,549	42,588	3	3	4	19,713,687	52,413,401
18	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.4.2025.37.2036	26,766	232	2,040	28	7,323	0	0	0	0	0	16,391,736	42,591,379
19	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.12.2025.4.2036	42,969	79	2,040	26	6,933	10,430	76,993	3	6	22	23,367,438	63,593,818

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[20] As mentioned in Section 3.1.6, if the 37 PWR standardized canister is assumed to be disposable, all DPCs are also assumed to be disposable.

Table 3. The logistics metrics for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	Total At-rx Canisters Loaded	Max Canisters Loaded (In a Year)	Shutdown Rx-years with Fuel	ISF Receipt Bays	Max Storage Casks at ISF	Number of Canisters to Waste	m^3 of LLW	Repackaging Receiving Bays	Repackaging Opening Bays	Repackaging Closing Bays	Transportation Consist Miles	Transportation Cask Miles
20	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.12.2025.12.2036	18,994	70	2,040	10	4,735	3,549	42,588	3	3	7	25,454,047	69,877,602
21	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.12.2025.21.2036	14,812	70	2,040	10	6,096	3,549	42,588	3	3	4	21,258,626	56,855,260
22	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.12.2025.37.2036	11,671	70	2,040	10	4,733	0	0	0	0	0	17,936,605	47,061,972
23	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.21.2025.4.2036	40,399	80	2,040	26	8,566	7,891	94,692	3	4	22	20,366,283	54,593,013
24	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.21.2025.12.2036	16,444	48	2,040	10	6,368	7,891	94,692	3	4	7	22,502,128	60,881,711
25	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.21.2025.21.2036	12,264	48	2,040	6	7,734	3,549	42,588	3	3	4	18,185,936	47,859,641
26	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); Pilot ISF (2021)	SCS 1.21.2025.37.2036	7,522	24	2,040	4	4,765	0	0	0	0	0	12,935,611	31,976,441
27	Standardized Canister	Class 2	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 2.4.2025.4.2036	58,141	232	2,415	28	7,356	3,549	42,588	3	3	19	21,000,523	56,515,624
28	Standardized Canister	Class 2	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 2.12.2025.12.2036	18,994	70	2,415	10	3,768	3,549	42,588	3	3	7	24,444,490	66,334,979
29	Standardized Canister	Class 2	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 2.21.2025.21.2036	12,264	33	2,415	6	6,014	3,549	42,588	3	3	4	17,657,205	45,563,874
30	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.4.2025.4.2036	58,141	237	3,873	0	0	3,549	42,588	3	3	18	18,611,827	47,723,228
31	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.12.2036	28,378	85	3,873	0	0	3,549	42,588	3	3	6	20,609,851	53,209,960
32	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.21.2036	23,263	85	3,873	0	0	3,549	42,588	3	3	4	16,410,449	40,123,329
33	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.37.2036	19,347	85	3,873	0	0	0	0	0	0	0	13,063,975	30,051,813
34	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.4.2036	48,697	237	3,873	0	0	7,869	64,188	3	4	20	19,263,005	49,415,432
35	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.12.2025.12.2036	18,994	71	3,873	0	0	3,549	42,588	3	3	6	21,188,266	54,874,632

Table 3. The logistics metrics for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	Total At-rx Canisters Loaded	Max Canisters Loaded (In a Year)	Shutdown Rx-years with Fuel	ISF Receipt Bays	Max Storage Casks at ISF	Number of Canisters to Waste	m^3 of LLW	Repackaging Receiving Bays	Repackaging Opening Bays	Repackaging Closing Bays	Transportation Consist Miles	Transportation Cask Miles
36	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.21.2036	13,889	48	3,873	0	0	3,549	42,588	3	3	4	17,021,185	41,812,315
37	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.37.2036	9,985	25	3,873	0	0	0	0	0	0	0	13,695,527	31,768,426
38	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.4.2036	47,011	237	3,873	0	0	6,259	75,108	3	3	20	17,876,271	45,234,241
39	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.12.2036	17,360	71	3,873	0	0	6,259	75,108	3	3	7	19,795,728	50,695,140
40	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.21.2025.21.2036	12,264	48	3,873	0	0	3,549	42,588	3	3	4	15,579,158	37,657,790
41	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.37.2036	8,365	25	3,873	0	0	0	0	0	0	0	12,270,790	27,626,208
42	Standardized Canister	Class 4	4 PWR STADs loaded at Rx (2030); 4 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 4.4.2030.4.2036	52,640	232	2,415	28	7,343	4,385	52,620	3	3	19	20,320,896	54,339,898
43	Standardized Canister	Class 4	12 PWR STADs loaded at Rx (2030); 12 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 4.12.2030.12.2036	17,849	70	2,415	10	3,771	4,385	52,620	3	3	7	23,420,879	63,380,666
44	Standardized Canister	Class 4	21 PWR STADs loaded at Rx (2030); 21 PWR WP confirmed (2036); Repo open (2048); Pilot ISF (2026)	SCS 4.21.2030.21.2036	11,862	48	2,415	6	6,007	4,385	52,620	3	3	4	17,286,016	44,528,378
45	Standardized Canister	Class 5	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2030); Repo open (2042); Pilot ISF (2021)	SCS 5.4.2025.21.2030	21,020	232	2,040	28	6,306	3,549	42,588	3	3	4	18,279,717	47,466,639
46	Standardized Canister	Class 5	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2030); Repo open (2042); Pilot ISF (2021)	SCS 5.12.2025.21.2030	13,510	70	2,040	10	5,185	3,549	42,588	3	3	4	19,008,194	49,504,099
47	Standardized Canister	Class 5	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2030); Repo open (2042); Pilot ISF (2021)	SCS 5.12.2025.4.2030	50,577	89	2,040	27	6,210	6,960	59,643	3	6	22	21,742,490	58,320,679
48	Standardized Canister	Class 5	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2030); Repo open (2042); Pilot ISF (2021)	SCS 5.21.2025.4.2030	49,290	89	2,040	27	6,926	5,722	68,664	3	4	22	20,378,432	54,204,265
49	Standardized Canister	Class 6	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2040); Repo open (2050); Pilot ISF (2021)	SCS 6.4.2025.21.2040	37,792	232	2,040	28	10,210	3,549	42,588	3	3	4	20,660,283	55,891,212
50	Standardized Canister	Class 6	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2040); Repo open (2050); Pilot ISF (2021)	SCS 6.12.2025.21.2040	15,925	70	2,040	10	6,637	3,549	42,588	3	3	4	22,876,826	62,240,497
51	Standardized Canister	Class 6	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2040); Repo open (2050); Pilot ISF (2021)	SCS 6.12.2025.4.2040	36,215	77	2,040	22	7,279	13,479	92,238	3	6	22	24,481,661	67,203,096
52	Standardized Canister	Class 6	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2040); Repo open (2050); Pilot ISF (2021)	SCS 6.21.2025.4.2040	32,523	77	2,040	22	9,526	9,830	117,960	3	4	22	20,151,268	54,321,079

Table 4. A description of each column in Table 2 and Table 3.

Scenario #	The scenario number (1–52) as described in Section 4
Major Class	The major class of the scenario that is either "status quo" or "standardized canister"—as described in Section 4
Scenario Class	The scenario class, including the common assumptions described in Section 4
Scenario Description	A brief description of a scenario containing the initial standardized canister loading strategy, the initial standardized canister system procurement date, the WP canisters, and the date when the WP size will be known
Scenario Description Number	Shorthand information in alpha-numeric form about the scenario, including the initial standardized canister loading strategy, the initial standardized canister system procurement date, the WP canisters, and the date when the WP size will be known
At-reactor Capital Cost	The capital costs at all reactors, including the cost to purchase standardized canisters, DPCs, and associated storage overpacks, as well as costs associated with building additional independent spent fuel storage installations (ISFSIs) after 2020
At-reactor Other Costs	Operational costs at the reactor, including ISFSI maintenance and monitoring costs, as well as loading/unloading costs (i.e., [1] loading from a pool into dry storage, [2] loading directly into a canister/cask for off-site shipment from a pool, and [3] loading from dry storage for off-site shipment)
ISF Cask/Pad Cost	The cask/pad costs at an ISF, including storage overpacks and associated concrete pad costs
ISF Other Costs	Other ISF costs, including cask/canister handling bays, loading/unloading, and other operational costs
WP/LLW Costs	The cost of disposing of the LLW generated from various equipment and canisters, as well as the cost to purchase WP-compatible canisters
Other Repackaging Costs	All other costs associated with repackaging, such as cutting, loading, unloading, etc.
Fleet/Capital Transportation Costs	Costs accumulated during the purchase of the cask, the buffer, and the escort railcars, as well as cask trailers, escort trucks, and transportation overpacks
Other Transportation Costs	The costs associated with transportation other than the fleet and capital transportation cost, specifically the operational and maintenance costs
Total At-Rx Canisters Loaded	The sum of all the canisters loaded at reactors

Max Canisters Loaded in a Year	The maximum number of canisters loaded at a single operating reactor site in a given year
Shutdown Rx-Years with SNF	The cumulative number of years that any reactor has SNF on site post-shutdown
ISF Cask/Canister Handling Bays	The required number of bays at the ISF for receiving and shipping casks
Max Storage Casks at ISF	The maximum number of casks in storage at the ISF at any time
Number of Canisters to Waste	The number of canisters that must be disposed of as waste due to repackaging
m^3 of LLW	Cubic meters of the LLW generated by repackaging used DPCs and standardized canisters that cannot be used for disposal
Repackaging Receiving Bays	Number of bays needed at the repackaging facility to receive the incoming casks
Repackaging Opening Bays	Number of bays needed at the repackaging facility to open the received canisters
Repackaging Closing Bays	Number of bays needed at the repackaging facility to close the WP-compatible canisters
Transportation Consist Miles	The sum of the total distance all consists travel. A consist may include multiple cask cars, multiple buffer cars, and multiple locomotives, along with other cars
Transportation Cask Miles	The sum of the total distance that all casks travel

Table 5. Reference table for each scenario and its assumptions.[21]

		At-reactor											Pilot Interim Storage Facilty			Interim Storage Facilty		Repository			Initial Standardization Canister Size			Waste Package Size				
Class	Code	Only DPC	DPC to 2024	DPC to 2029	DPC to 2035	Standardized Canister 2025 - 2035	Standardized Canister 2025 - 2029	Standardized Canister 2025 - 2039	Standardized Canister 2030 - 2035	WP 2030+	WP 2036+	WP 2040+	None	2021 to 2025	2026 to 2030	2025+	2030+	2042	2048	2052	4 PWR	12 PWR	21 PWR	4 PWR	12 PWR	21 PWR	37 PWR	DPC
SQ Class 1	SQ1.a	x											x						x					x				
	SQ1.b	x											x						x						x			
	SQ1.c	x											x						x							x		
	SQ1.d	x											x						x									x
SQ Class 2	SQ2.a	x												x		x			x					x				
	SQ2.b	x												x		x			x						x			
	SQ2.c	x												x		x			x							x		
	SQ2.d	x												x		x			x									x
SQ Class 3	SQ3.a				x						x		x						x					x				
	SQ3.b				x						x		x						x						x			
	SQ3.c				x						x		x						x							x		
SQ Class 4	SQ4.a				x						x			x		x			x					x				
	SQ4.b				x						x			x		x			x						x			
	SQ4.c				x						x			x		x			x							x		
SC Class 1	SCS 1.4.2025.4.2036		x			x					x			x		x			x		x			x				
	SCS 1.4.2025.12.2036		x			x					x			x		x			x		x				x			
	SCS 1.4.2025.21.2036		x			x					x			x		x			x		x					x		
	SCS 1.4.2025.37.2036		x			x					x			x		x			x		x						x	x
	SCS 1.12.2025.4.2036		x			x					x			x		x			x			x		x				
	SCS 1.12.2025.12.2036		x			x					x			x		x			x			x			x			
	SCS 1.12.2025.21.2036		x			x					x			x		x			x			x				x		
	SCS 1.12.2025.37.2036		x			x					x			x		x			x			x					x	x
	SCS 1.21.2025.4.2036		x			x					x			x		x			x				x	x				
	SCS 1.21.2025.12.2036		x			x					x			x		x			x				x		x			
	SCS 1.21.2025.21.2036		x			x					x			x		x			x				x			x		
	SCS 1.21.2025.37.2036		x			x					x			x		x			x				x				x	x
SC Class 2	SCS 2.4.2025.4.2036		x			x					x				x		x		x		x			x				
	SCS 2.12.202512.2036		x			x					x				x		x		x			x			x			
	SCS 2.21.2025.21.2036		x			x					x				x		x		x				x			x		
SC Class 3	SCS 3.4.2025.4.2036		x			x					x		x						x		x			x				
	SCS 3.4.2025.12.2036		x			x					x		x						x		x				x			
	SCS 3.4.2025.21.2036		x			x					x		x						x		x					x		
	SCS 3.4.2025.37.2036		x			x					x		x						x		x						x	x
	SCS 3.12.2025.4.2036		x			x					x		x						x			x		x				
	SCS 3.12.2025.12.2036		x			x					x		x						x			x			x			
	SCS 3.12.2025.21.2036		x			x					x		x						x			x				x		
	SCS 3.12.2025.37.2036		x			x					x		x						x			x					x	x
	SCS 3.21.2025.4.2036		x			x					x		x						x				x	x				
	SCS 3.21.2025.12.2036		x			x					x		x						x				x		x			
	SCS 3.21.2025.21.2036		x			x					x		x						x				x			x		
	SCS 3.21.2025.37.2036		x			x					x		x						x				x				x	x

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[21] As mentioned in Section 3.1.6, if the 37 PWR standardized canister is assumed to be disposable, all DPCs are also assumed to be disposable.

Table 5. Reference table for each scenario and its assumptions (Continued)

		At-reactor											Pilot Interim Storage Facilty			Interim Storage Facilty		Repository			Initial Standardization Canister Size			Waste Package Size				
Class	Code	Only DPC	DPC to 2024	DPC to 2029	DPC to 2035	Standardized Canister 2025 - 2035	Standardized Canister 2025 - 2029	Standardized Canister 2025 - 2039	Standardized Canister 2030 - 2035	WP 2030+	WP 2036+	WP 2040+	None	2021 to 2025	2026 to 2030	2025+	2030+	2042	2048	2052	4 PWR	12 PWR	21 PWR	4 PWR	12 PWR	21 PWR	37 PWR	DPC
SC Class 4	SCS 4.4.2030.4.2036			x					x		x				x		x		x		x			x				
	SCS 4.12.2030.12.2036			x					x		x				x		x		x			x			x			
	SCS 4.21.2030.21.2036			x					x		x				x		x		x				x			x		
SC Class 5	SCS 5.4.2025.21.2030		x				x			x					x		x	x			x					x		
	SCS 5.12.2025.21.2030		x				x			x					x		x	x				x				x		
	SCS 5.12.2025.4.2030		x				x			x					x		x	x				x		x				
	SCS 5.21.2025.4.2030		x				x			x					x		x	x					x	x				
SC Class 6	SCS 6.4.2025.21.2040		x					x				x		x		x				x	x					x		
	SCS 6.12.2025.21.2040		x					x				x		x		x				x		x				x		
	SCS 6.12.2025.4.2040		x					x				x		x		x				x		x		x				
	SCS 6.21.2025.4.2040		x					x				x		x		x				x			x	x				

Due to the large amount of information, the results and analyses have been broken down into the complete system information and then into four sub-categories: (1) at-reactor, (2) transportation, (3) ISF, and (4) repackaging.

The major takeaway points are as follows:

- The current models show the ROM cost of repackaging SNF to be lower than that of the initial loading and storage of SNF at reactors for 4 PWR scenarios.
- Loading 4 PWR canisters at reactors is the most expensive option, even when the final WP size is a 4 PWR.
- From a system-wide cost perspective, loading 12 PWR standardized canisters or 21 PWR standardized canisters or continuing to load DPCs has a negligible impact on relative system ROM cost regardless of the final WP size. However, the location where those costs are incurred (e.g., at-reactors, ISF, repackaging) does change.
- The number of canisters that have to be loaded at the reactors is the largest with 4 PWR-sized canisters (~58,000). The fewest canisters are loaded in the scenario when loading 21 PWR sized canisters from 2025 to 2035 and then 37 PWR-sized canisters after that point (~7500).
- Standardized canisters have a relatively minor impact on the number of years that the sites store SNF after the reactor has shut down for the 3,000 MTHM/year receipt rate and the OFF acceptance priority assumed in this evaluation.
- Incorporating an ISF that handles only canistered fuel does not change the standardization trends.
- Unless direct disposal of DPCs is feasible, a major repackaging effort will be needed regardless of future standardization options.
- The number of opening bays is higher for scenarios with an initial canister loading strategy of 12 PWR- and 21 PWR-sized canisters than those scenarios with DPCs or 4 PWR-sized canisters when the WP is determined to be smaller than the initial strategy.
- The repackaging facility number of closing bays is highly dependent on WP size and is relatively insensitive to the initial canister selection (i.e., 2025 canister size).
- Transportation miles (both consist and cask) are highest for the 12 PWR-sized canister scenarios since these scenarios have a smaller transportation cask capacity than all other scenarios.
- Transportation ROM costs are highest for small canister scenarios, though the total range of transportation costs is only ~$4.4B to ~$10.7B (as compared to relative system ROM costs of ~$43B to ~$112B).

5.1 Complete System Results and Analysis

This section describes the complete system-level results and provides insight into the major observations from a system-level perspective. All metrics are tabulated from 2020 forward to provide a common basis for all comparisons.

5.1.1 Complete system logistics analysis

At a high level, the scenarios confirm the obvious: switching to smaller canisters requires more at-reactor loading, transportation, and storage operations than maintaining the status quo of large DPCs. The detailed logistics are described by subcategory below.

5.1.2 Complete system ROM cost estimates

From a system-wide perspective, the most appropriate manner of analysis is based on the WP size. This section will step through each WP size in separate subsections.

5.1.2.1 4 PWR waste package

The ROM cost estimates for the scenarios with an ISF and without an ISF are seen in Figure 3 and Figure 4.

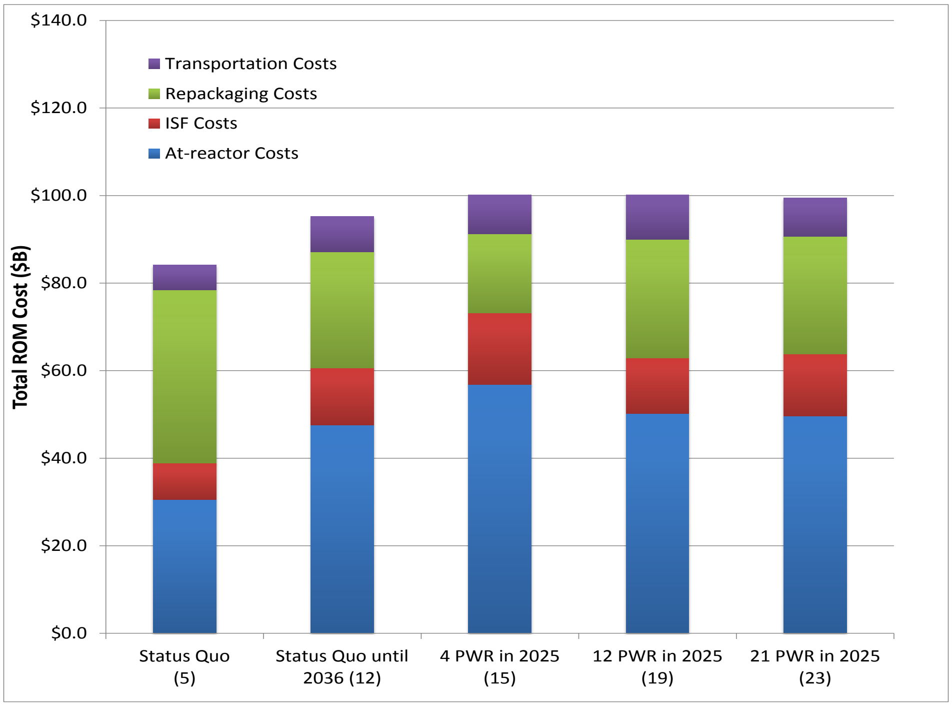

Figure 3. Total ROM cost of different initial canister loading strategies for disposing of a 4 PWR canister with an ISF (scenario IDs: 5, 12, 15, 19, and 23).

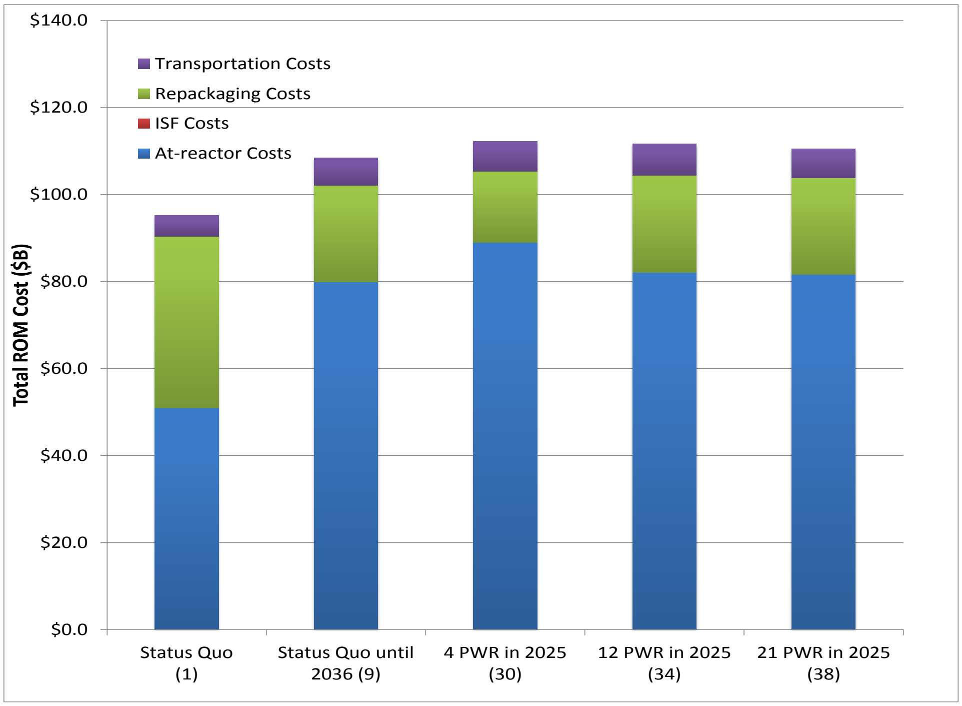

Figure 4. Total ROM cost of different initial canister loading strategies for disposing of a 4 PWR canister without an ISF (scenario IDs: 1, 9, 30, 34, and 38).

In the 4 PWR scenario, continuing to load DPCs for shipment to the ISF or repository even after the WP size is known is the most cost effective option and the most expensive option is to load the 4 PWR canister as an initial guess. Given the current cost assumptions, this indicates that it is more expensive to load and store small canisters at the reactor, potentially transport them to and from the ISF and store them at the ISF, and then transport them to the repository than it would be to load DPCs at the reactors, potentially transport them to and from the ISF and store them at the ISF, and then repackage the DPCs into the small canisters at the repository. The reasons for this result will be explored further in the next evaluation.

The results also show that continuing to load DPCs until 2036 is slightly more cost effective than switching to a medium or large standardized canister in 2025. (All three scenarios switch to loading 4 PWR waste-compatible canisters at reactors in 2036.) However, the difference between scenarios is relatively small when compared to the relative system ROM costs (~$4-5B out of ~$96B to ~108B, depending on whether an ISF is in the system). The benefit of moving to a 12 PWR or 21 PWR canister in 2025 is that there is a higher likelihood of avoiding repackaging; however, these scenarios would require that utilities adopt a new canister system, with the potential to change again once the WP size is known.

5.1.2.2 12 PWR waste package

The cost estimates for strategies with the 12 PWR WP are shown in Figure 5 and Figure 6.

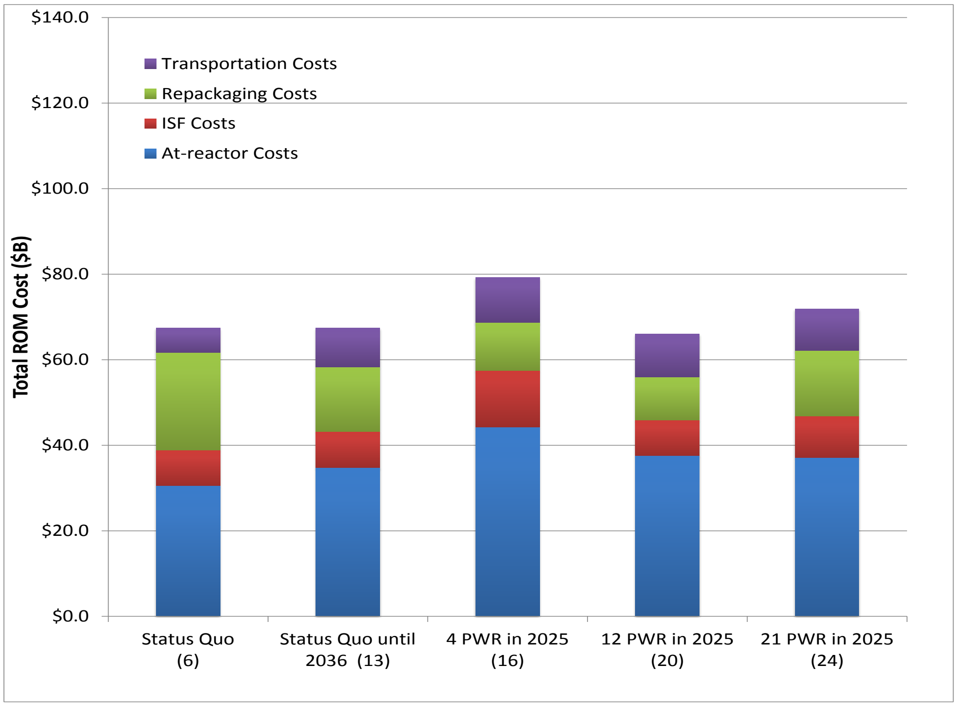

Figure 5. Total ROM cost of different initial canister loading strategies for disposing of a 12 PWR canister with an ISF (scenario IDs: 6, 13, 20, and 24).

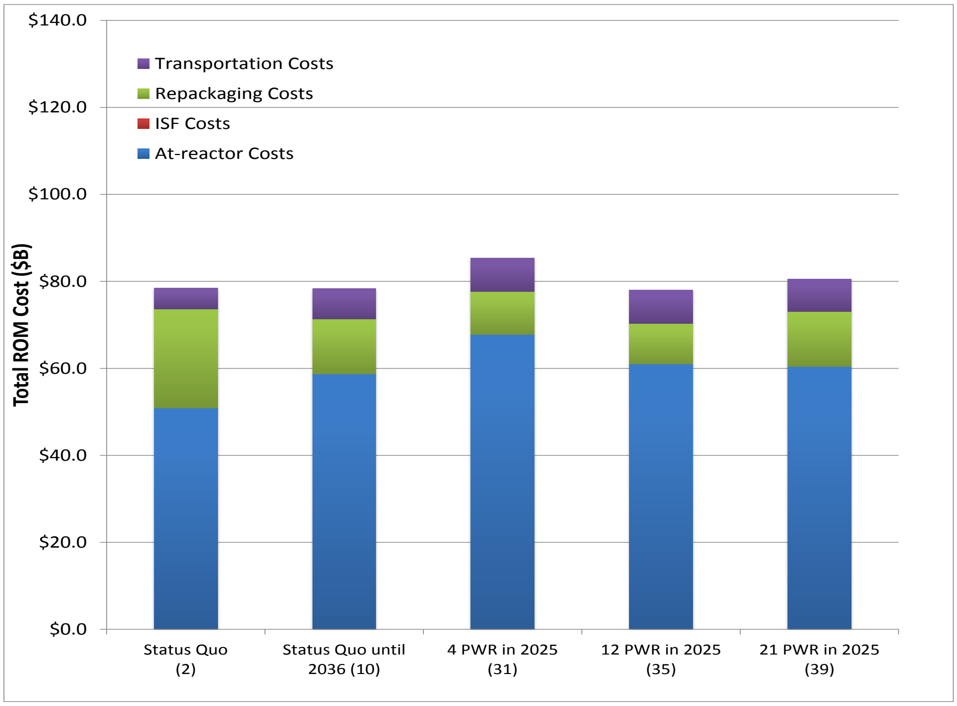

Figure 6. Total ROM cost of different initial canister loading strategies for disposing of a 12 PWR canister without an ISF (scenario IDs: 2, 10, 31, 35, and 39).

In these scenarios, loading 4 PWR canisters in 2025 is the most expensive strategy. In this scenario, the other four strategies showed similar relative system ROM costs.

The 12 PWR WPs scenarios show that all strategies (with the exception of loading 4 PWR in 2025) are similar in total ROM cost. However, loading 12 PWR canisters in 2025 (i.e. the initial strategy is compatible with WP) is slightly more economical than the status quo scenario, which is not true for the 4 PWR WP compatible scenarios.

5.1.2.3 21 PWR waste package

The cost estimates for strategies with the 21 PWR WP are shown in Figure 7 and Figure 8.

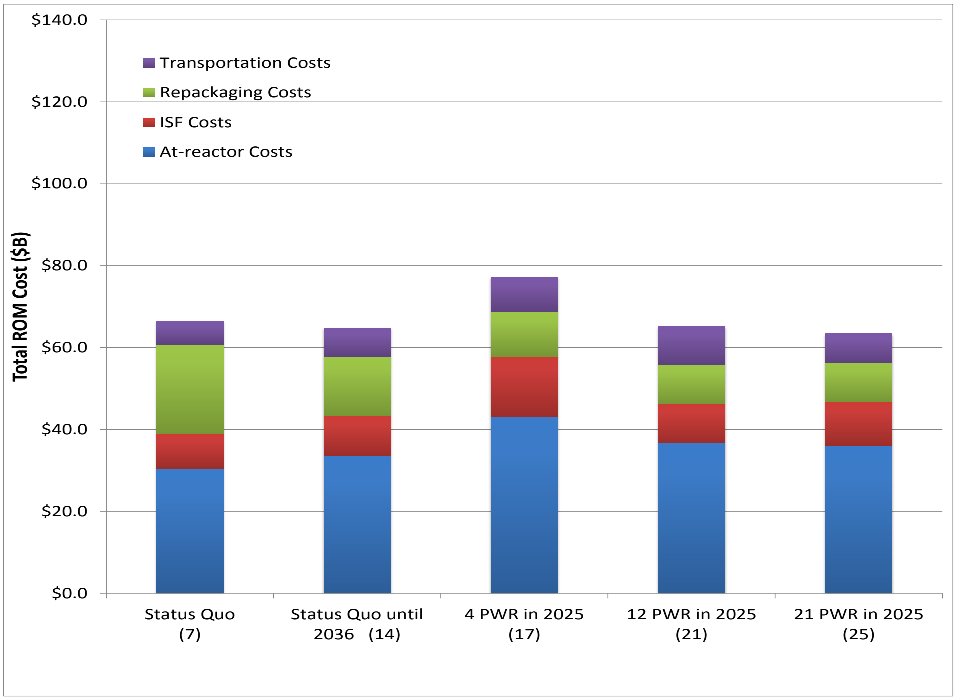

Figure 7. Total ROM cost of different initial canister loading strategies for disposing of a 21 PWR canister with an ISF (scenario IDs: 7, 14, 17, 21, and 25).

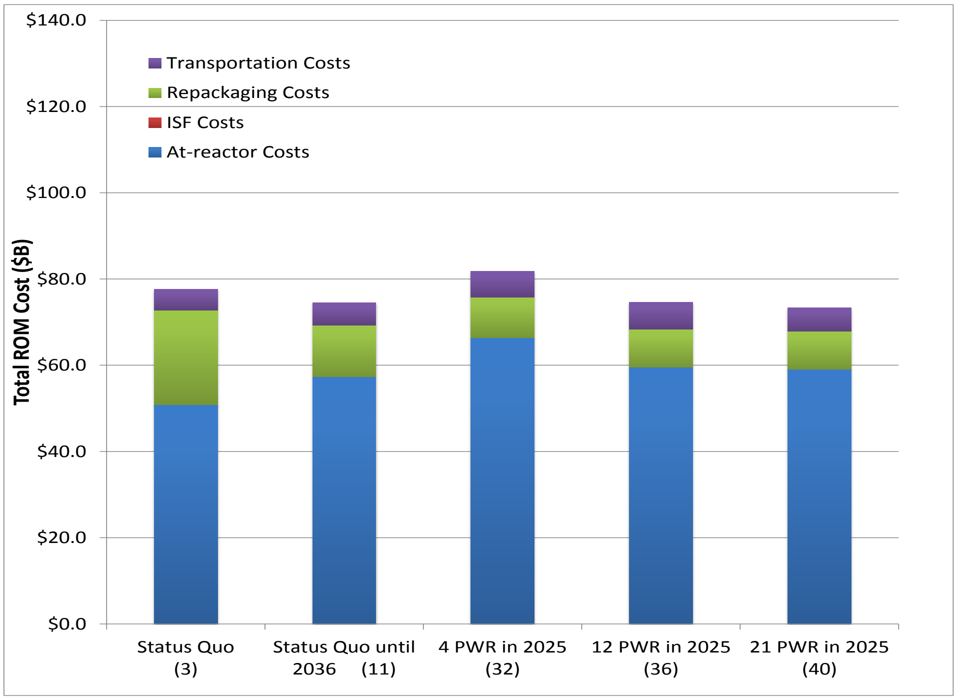

Figure 8. Total ROM cost of different initial canister loading strategies for disposing of a 21 PWR canister without an ISF (scenario IDs: 3, 11, 32, 36, and 40).

The figures illustrates that the 12 PWR, 21 PWR, and status quo with changing to the 21 PWR WP-compatible canister in 2036 are fairly equivalent from a relative system ROM cost perspective. Again the 12 PWR scenario would have the most flexibility, but the status quo scenario that changes to a 21 PWR WP-compatible canister in 2036 would also be an attractive option.

5.1.2.4 37 PWR waste package (all DPCs are disposable)

In this scenario, maintaining the status quo, loading 12 PWR canisters, and loading 21 PWR canisters are fairly equivalent from a ROM cost perspective, as illustrated in Figure 9 and Figure 10.

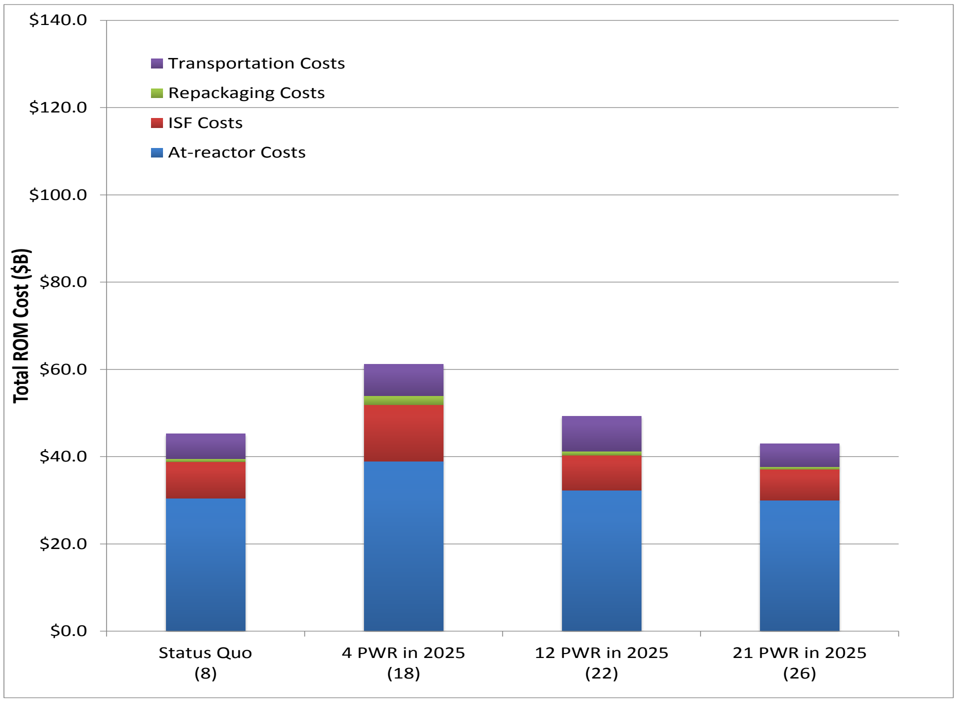

Figure 9. Total ROM cost of different initial canister loading strategies for disposing of a 37 PWR canister with an ISF (scenario IDs: 8, 18, 22, and 26).

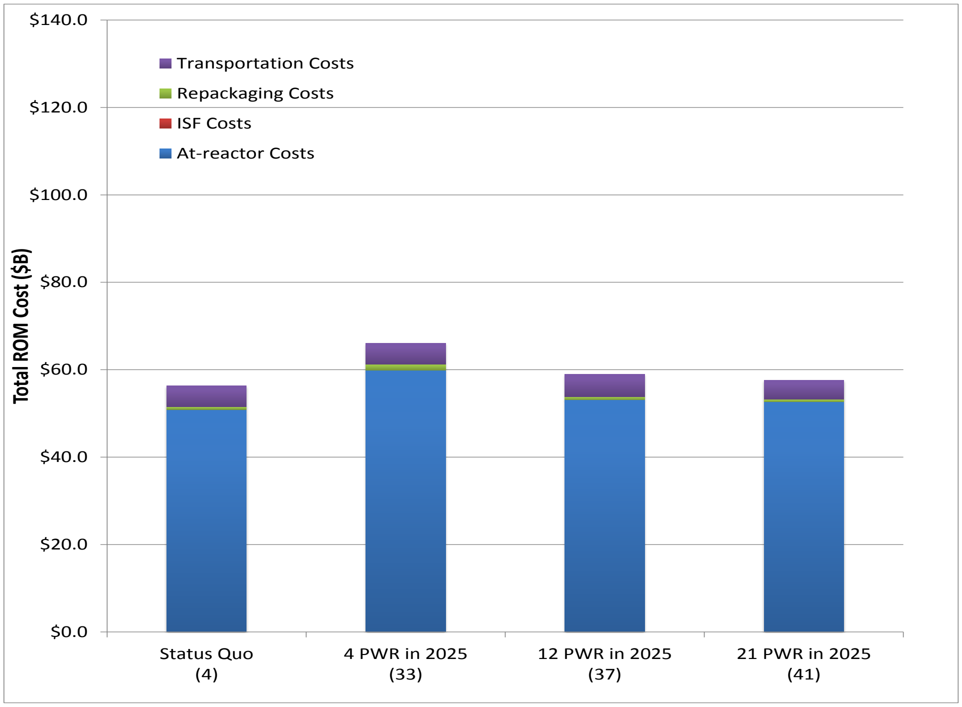

Figure 10. Total ROM cost of different initial canister loading strategies for disposing of a 37 PWR canister without an ISF (scenario IDs: 4, 33, 37, and 41).

These scenarios again show that the 4 PWR scenario is the most expensive selection. However, there is almost no difference in relative system ROM costs of the other scenarios (continuing to load DPCs or switching to 12 PWR or 21 PWR canisters in 2025). This implies there is not a significant cost advantage related to any strategy (except that 4 PWR canisters are at an economic disadvantage).

5.1.2.5 Accelerated or delayed waste package/repository selection impact

In four scenarios, the WP size was assumed to be known in 2030 instead of 2036, with the repository similarly accelerated to 2042. The relative system ROM cost impacts of this can be seen in Figure 11.

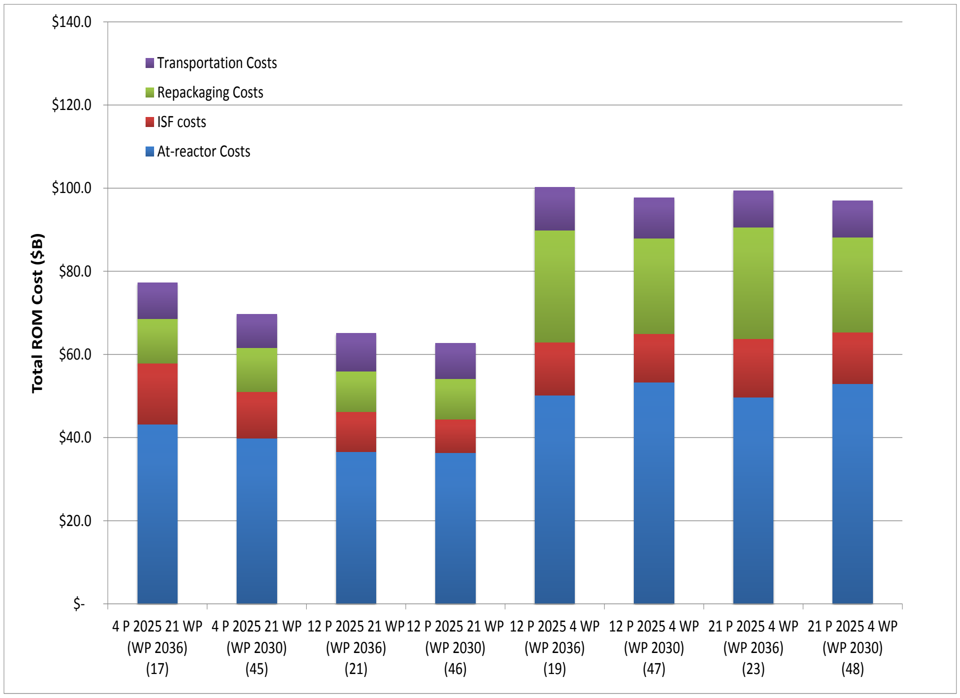

Figure 11. Total ROM costs for scenarios in which the WP size is assumed to be known in 2030 or 2036 (scenario IDs: 17, 45, 21, 46, 19, 47, 23, and 48).

As shown above, if the WP is known earlier, the relative system ROM cost decreases in all scenarios. This is due to two main drivers: (1) if repackaging is required in the scenario, the earlier implementation of WP-compatible canisters will reduce the total repackaging ROM costs, and (2) an earlier repository start date decreases the ROM cost of the ISF because it does not have to store as much SNF. The largest impact is when 4 PWR canisters are initially implemented but the final WP size is determined to be 21 PWR (~$7.4B savings); whereas the other scenarios have similar smaller, savings (~$2.4B in all scenarios). This is another indication that loading 4 PWR at reactors is expensive when compared to loading other canister sizes (12 PWR, 21 PWR, DPCs, or 37 PWR).

In four scenarios, the WP size was assumed to be known in 2040 instead of 2036, with the repository similarly delayed to 2052. The relative system ROM cost impact of this assumption can be seen in Figure 12.

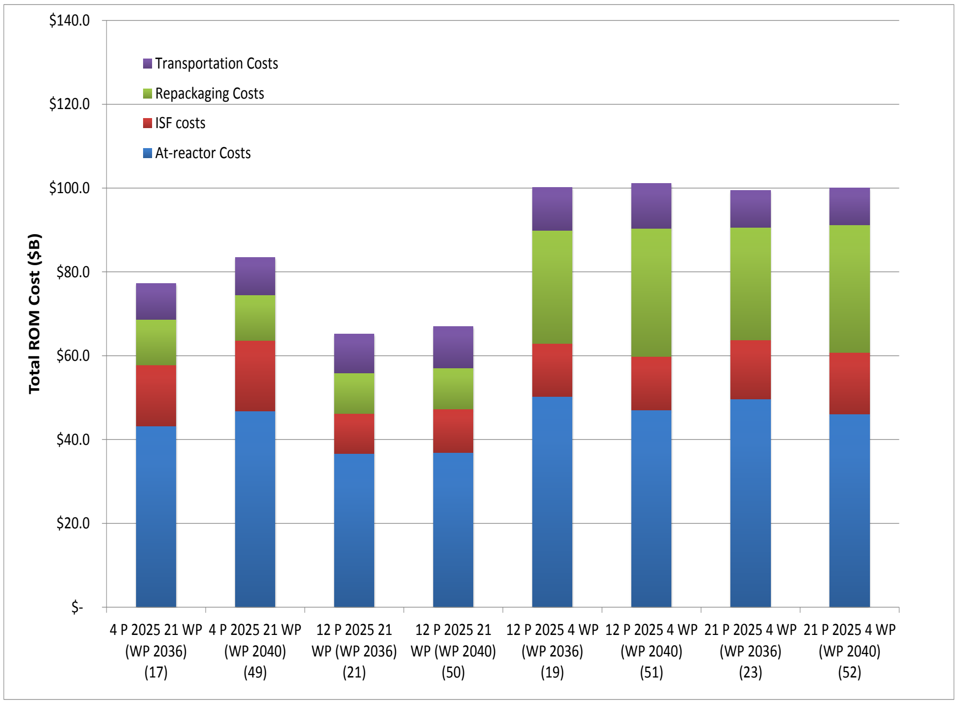

Figure 12. Total ROM costs for scenarios in which the WP size is assumed to be known in 2036 or 2040 (scenario IDs: 17, 49, 21, 50, 19, 51, 23, and 52).

As shown above, if the WP is known later, the relative system ROM cost increases in all scenarios. Similar to the accelerated repository scenarios, this is due to two main drivers: (1) if repackaging is required in the scenario, the later implementation of WP-compatible canisters will increase the total repackaging ROM costs, and (2) a later repository start date increases the ROM cost of the ISF because it has to store more SNF. However, because this evaluation shows that it is more expensive to load small, 4 PWR canisters, the delay in loading small canisters, even if they were the appropriate WP size, actually decreases at-reactor ROM costs for the scenarios that begin with larger canister sizes. The largest impact is when 4 PWR canisters are initially implemented and the final WP is larger (~$6.2B increase); whereas the other scenarios have negligible impacts (~$0.6–1.7B).

5.2 At-reactor Results and Analysis

The at-reactor results are broken down into the logistics analysis and the ROM cost estimates.

5.2.1 At-reactor logistics analysis

5.2.1.1 Total canisters loaded at reactors

One of the objectives of the larger standardization assessment is to quantify the impacts of standardized canister systems on nuclear power plant operations. The specific metric that will be studied is the number of heavy-load-handling operations. As part of this evaluation, this is assumed to be directly proportional to the total number of canisters loaded at reactors. If future advanced/innovative operational concepts are developed in regards to different sized canisters, this metric will need to be updated accordingly.

As expected, the scenarios that involve loading 4 PWR canisters either initially (2025 or 2030) or once the WP size is known have the most canisters loaded. The maximum number of canisters loaded at reactors is 58,141 in scenario 15. In this scenario, 4 PWR canisters are loaded initially, the ISF start date is delayed until 2030, and 4 PWR waste-compatible canisters are loaded in 2036. Interestingly, because a number of reactor sites currently load DPCs with capacity less than 37 PWR, the smallest number of canisters loaded at reactors is 7,522. This occurs when the 21 PWR canister is loaded starting in 2025 and then the 37 PWR waste-compatible canister is loaded beginning in 2036.

The number of canisters loaded at-reactors in scenarios in which the WP size is confirmed (scenarios 8, 15, 20, 25) with an ISF is shown in Table 6.

Table 6. Number of canisters loaded at reactors for scenarios with an ISF in which the initial canister size was compatible with the repository.

Scenario ID	Canister Size	Number of canisters loaded at reactors
15	4 PWR	58,141
20	12 PWR	18,994
25	21 PWR	12,264
8	DPC	8,882

5.2.1.2 Maximum canisters loaded at a single operating reactor in a given year

This metric is tracked to determine how large an impact there is at a reactor in a given year. Even though in reality there is an upper bound to the number of canisters that can be loaded at a reactor in a given year, the TSL-CALVIN (Ref. 14) simulation tool does not limit the number of canisters that can be loaded. All decisions in CALVIN are controlled by acceptance rates, without regard to an individual reactor's ability to load large numbers of canisters. As shown in the Figure 13 and Figure 14, the maximum number of canisters loaded at an operating reactor goes up significantly in scenarios with a 4 PWR canister. Because of this, DOE has recently released a statement of work to determine (1) more realistic impacts of small canisters on reactors, and (2) innovations that could be applied at reactors to minimize this impact.

Note that there is little difference between an ISF and a no-ISF scenario when the at-reactor canister size does not change. As illustrated in Figure 15 and Figure 16, this behavior is different when the initial canister selection is not compatible with the WP size due to more initial size canisters being loaded earlier for transport than are loaded in scenarios where an ISF is not in the system.

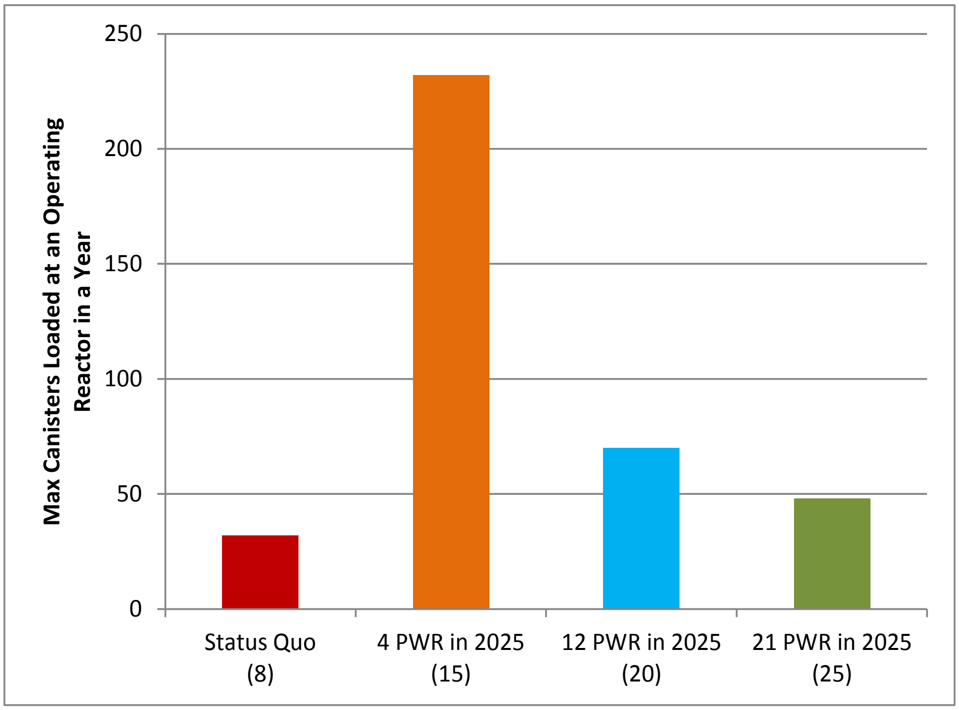

Figure 13. The maximum number of canisters loaded at any operating reactor in a given year for scenarios with correct initial canister size (initial guess = WP size) with an ISF (scenario IDs: 4, 30, 35, and 40).

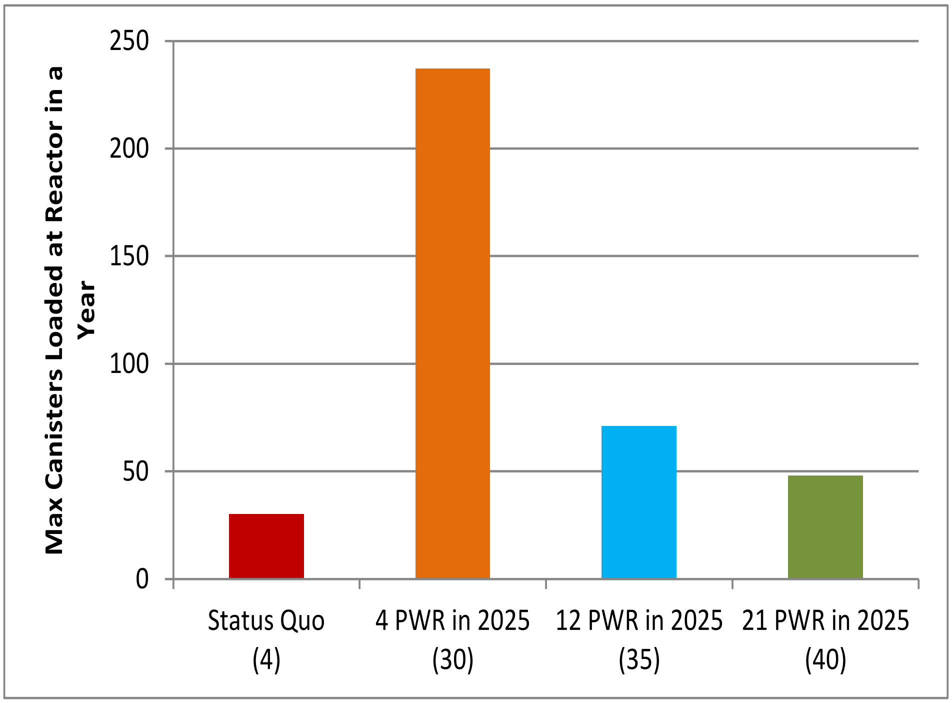

Figure 14. The maximum number of canisters loaded at any operating reactor site in a given year for scenarios with correct initial canister size (initial guess = WP size) without an ISF (scenario IDs: 4, 30, 35, and 40).

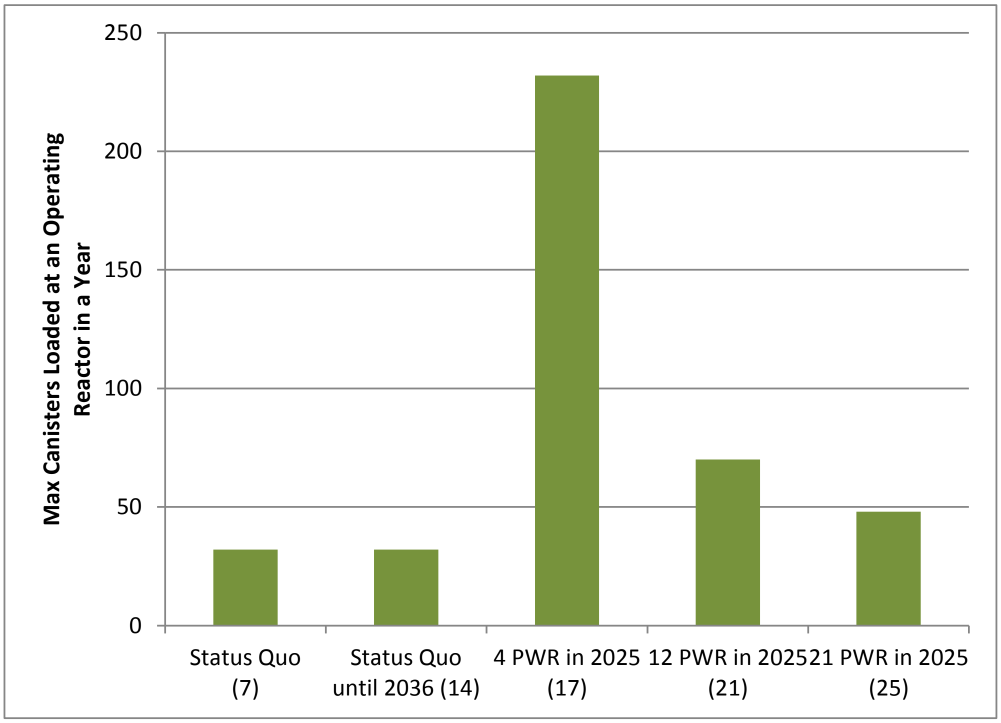

Figure 15. The maximum number of canisters loaded at any operating reactor site in a given year when disposing of a 21 PWR canister with an ISF as a function of initial canister loading strategies (scenario IDs: 7, 14, 17, 21, and 25).

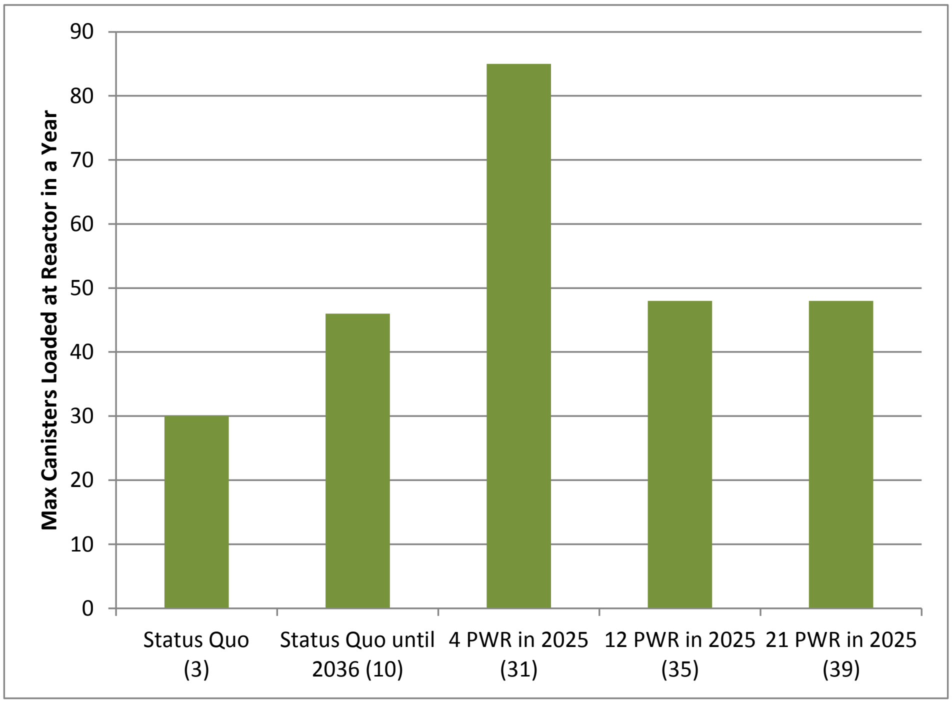

Figure 16. The maximum number of canisters loaded at any operating reactor site in a given year when disposing of a 21 PWR canister without an ISF as a function of initial canister loading strategies (scenario IDs: 3, 10, 31, 35, and 39).

5.2.1.3 Total shutdown reactor years

One objective of this evaluation (and the larger standardization assessment) is to quantify the non-productive use of reactor sites. Once the reactors have shutdown at a site, the site cannot be repurposed until the SNF is off the site. As such, the number of years after the reactor shuts down until all of the SNF is offsite is quantified in all scenarios. However, this evaluation showed that the effects of standardization were negligible when compared with the effect of opening an ISF. As evident in Table 7, in all scenarios without an ISF, the shutdown reactor years ranged from 3,868 to 3,907 years; in the scenarios with an ISF open in 2025, the shutdown reactor years ranged from 2,035 to 2,177; and in the scenarios with an ISF open in 2030, the shutdown reactor years were 2,410.

Table 7. Minimum and maximum number of shutdown reactor years as a function of ISF start date.

ISF Start Date	**Shutdown Reactor Years**	
	Min	Max
2025	2,035	2,177
2030	2,410	2,410
Never	3,868	3,907

This result implies that the DPC transportation limits rarely limit the ability to remove SNF from the reactor sites when using a 3000 MTHM/year throughput rate and OFF/YFF acceptance strategy (Section 3.1.3). Because the standardized canisters do not have a thermal transportation limit, they are similar to the bare fuel options documented in Reference 15.

5.2.1.4 Total Canisters in at-reactor storage

As expected, loading smaller canisters (instead of large DPCs) at reactor sites results in a higher maximum number of canisters in dry storage at reactor sites. Figures showing the total canisters in storage for different canister types can be found in Appendix A. It should be noted that because the 4PWR/9BWR and the 12PWR/32BWR canisters are loaded in multicanister storage overpacks holding four and three3 canisters respectively, the number of storage overpacks in storage at reactor sites does not directly scale with the number of canisters loaded for these canister sizes. Further study is needed to determine how implementing standardization at reactor sites would necessitate ISFSI expansion or modification.

5.2.2 At-reactor ROM cost estimates

This section specifically investigates the at-reactor capital ROM costs and the at-reactor operational ROM costs. As at-reactor costs are only a single piece of the relative system-wide ROM costs, any observations in this section should be considered in the context of the whole system. There will be many situations where lowering at-reactor costs will in turn increase other costs (and vice versa). This section will be broken down into two sub-sections: at-reactor capital (canister) costs and at-reactor operational costs.

5.2.2.1 At-reactor capital ROM cost estimates

Capital costs at the reactor include canisters and cask/overpack costs, as well as ISFSI costs. However, because cost is only tabulated after 2020, and most of the ISFSIs are already built at that point, the majority of the capital costs are canisters and casks. For this reason, this evaluation will refer to at-reactor capital costs as at-reactor canister costs. Figure 17 and Figure 18 show the at-reactor ROM costs with and without an ISF when the final WP size is 4 PWR.

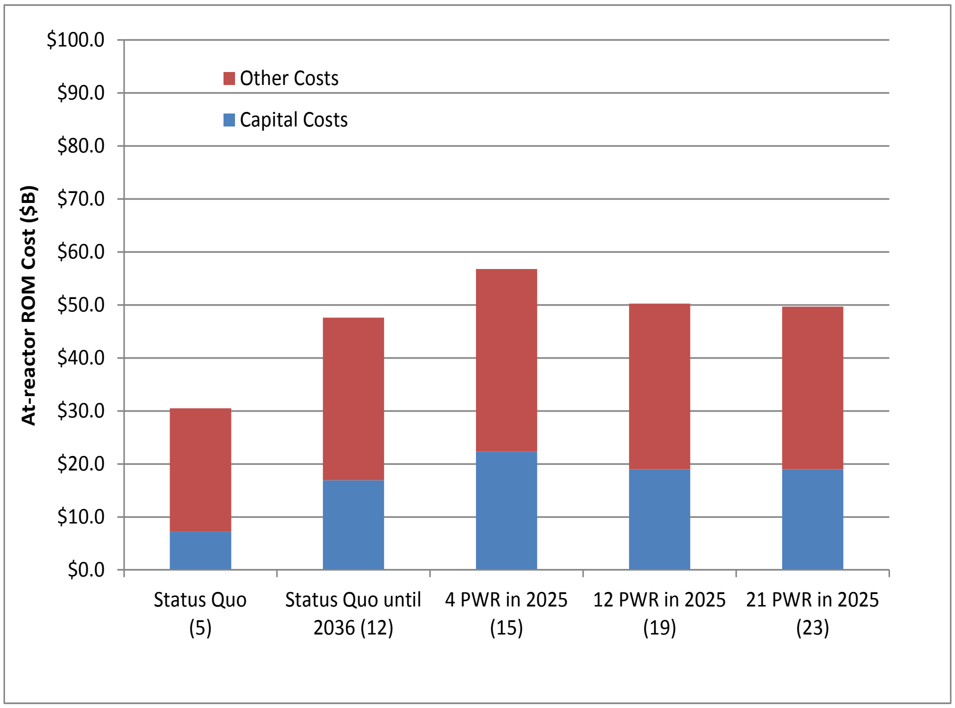

Figure 17. Breakdown of at-reactor ROM costs into other costs and capital costs for disposing of a 4 PWR WP using different initial canister loading strategies with an ISF (scenario IDs: 5, 12, 15, 19, and 23).

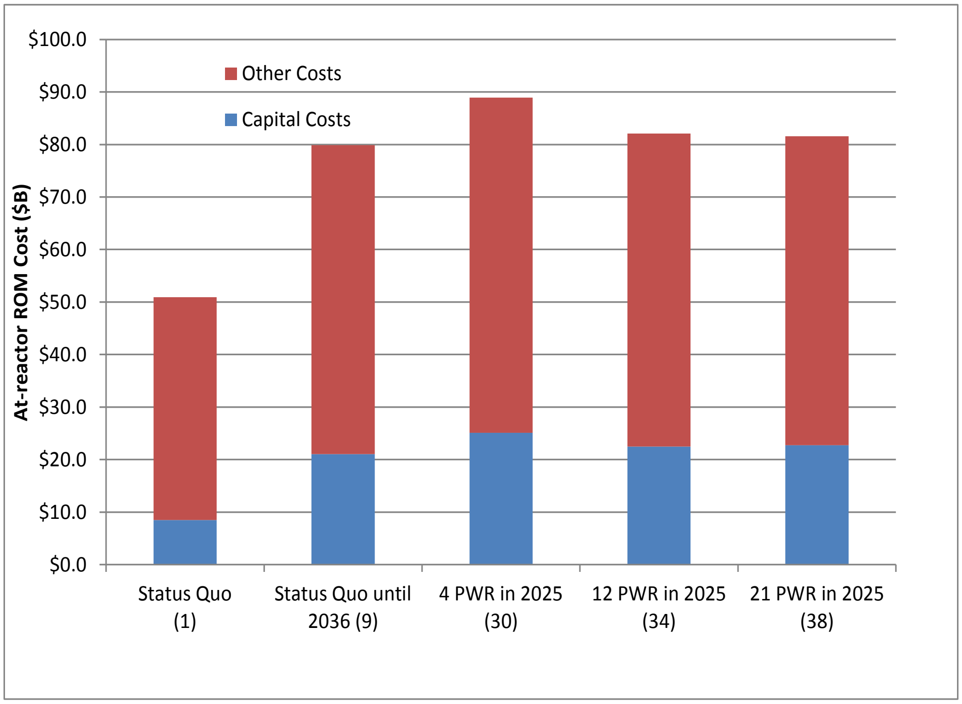

Figure 18. Breakdown of at-reactor ROM costs into other costs and capital costs for disposing of a 4 PWR WP using different initial canister loading strategies without an ISF (scenario IDs: 1, 9, 30, 34, and 38).

As evident in the above figures, adding an ISF to the system insignificantly impacts the standardization trends. Essentially, the ISF reduces the at-reactor other (operational) cost by a fairly constant amount in all scenarios.

The detailed at-reactor capital costs can be seen in Appendix B based on the WP. These figures illustrate the result that regardless of the final WP size, the at-reactor capital costs are minimized by continuing to load DPCs. The minimum at-reactor other (operational) cost is on the order of $7B, whereas the maximum at-reactor other cost is on the order of $25B, which occurs when loading 4 PWRs from 2025 until all SNF is out of the pool.

Therefore, the initial canister costs range from ~$7B to ~$25B, depending on the scenario selected.

5.2.2.2 At-reactor other ROM cost estimates

The at-reactor other costs include the cost to operate (maintenance, surveillance, etc.) an ISFSI or pool and the cost associated with canister loading/unloading. The total number of shutdown reactor years can be directly correlated to at-reactor other costs, as seen in Figure 19. These operational cost values were calculated by taking the average over the different scenarios. The costs to keep ISFSIs open after reactor sites are shutdown represent a majority of the operational costs at reactors. A pie chart showing the average breakdown of other ROM costs between ISFSI costs, pool costs, and loading/unloading costs is shown in Figure 20 through Figure 23. It should be noted that only pool costs occurring beyond 5 years after reactor shutdown are included in the pool costs.

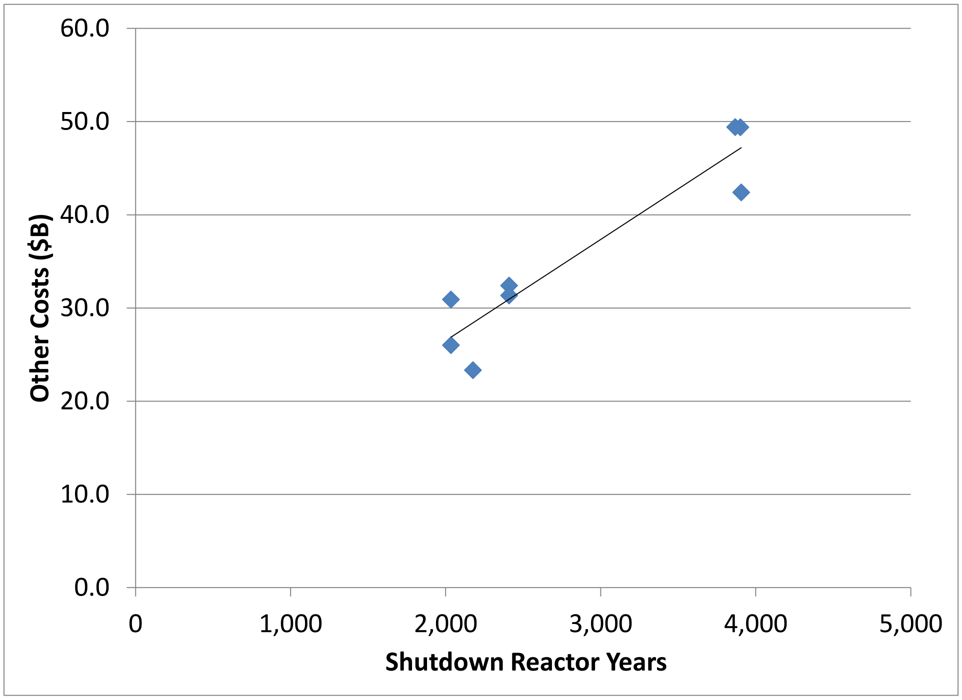

Figure 19. Total at-reactor other ROM costs versus the total number of shutdown reactor years.

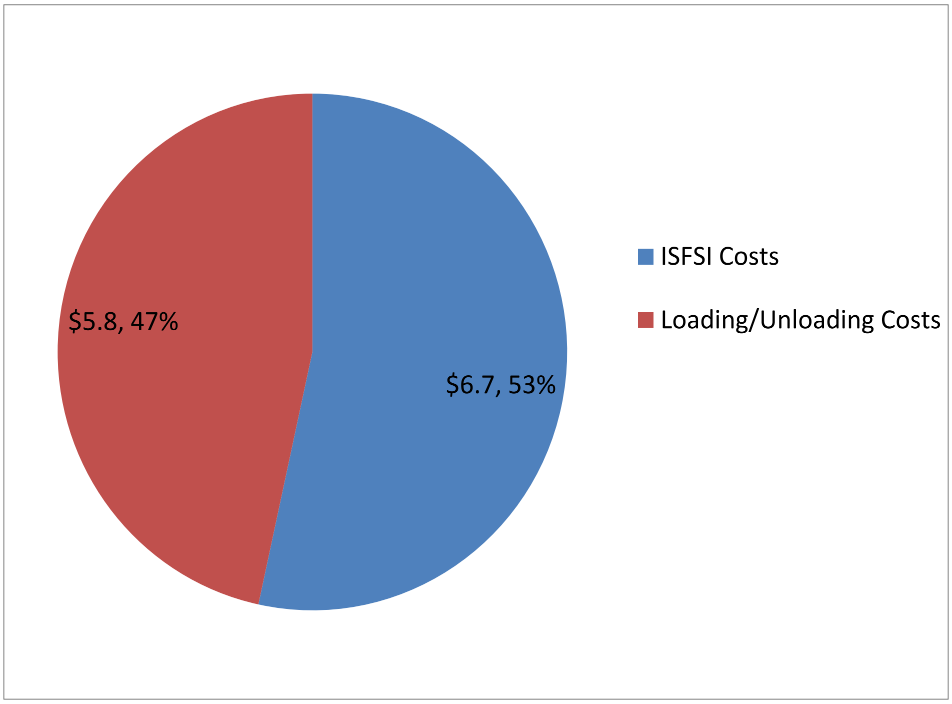

Figure 20. Breakdown of the at-reactor other ROM costs for the status quo scenario loading 21 PWR WP-compatible canisters in 2036 with an ISF (scenario ID: 14).

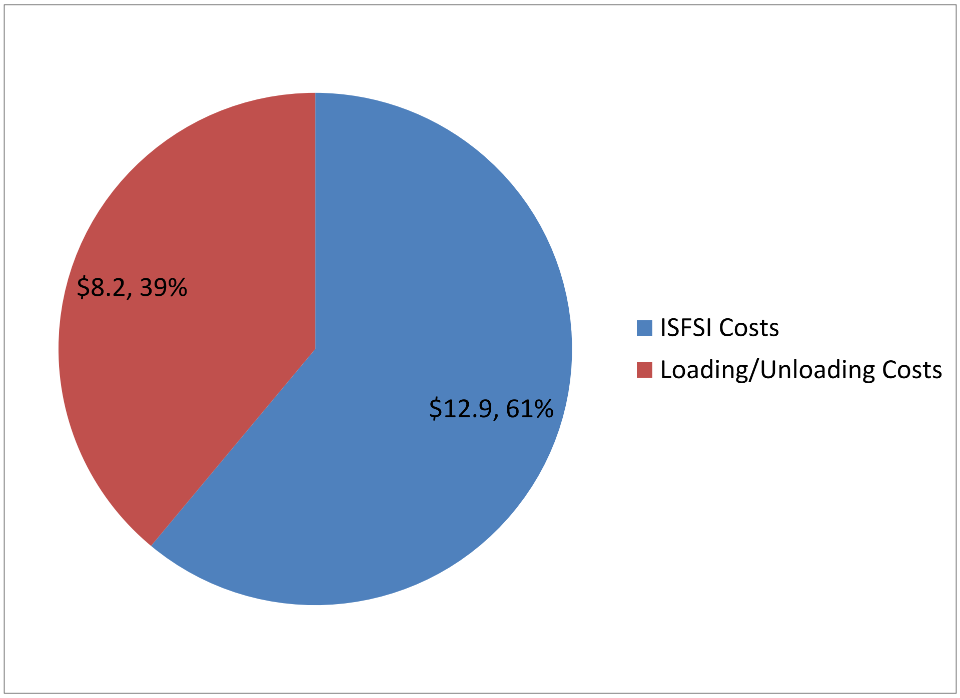

Figure 21. Breakdown of the at-reactor other ROM costs for the status quo scenario loading 21 PWR WP-compatible canisters in 2036 without an ISF (scenario ID: 11).

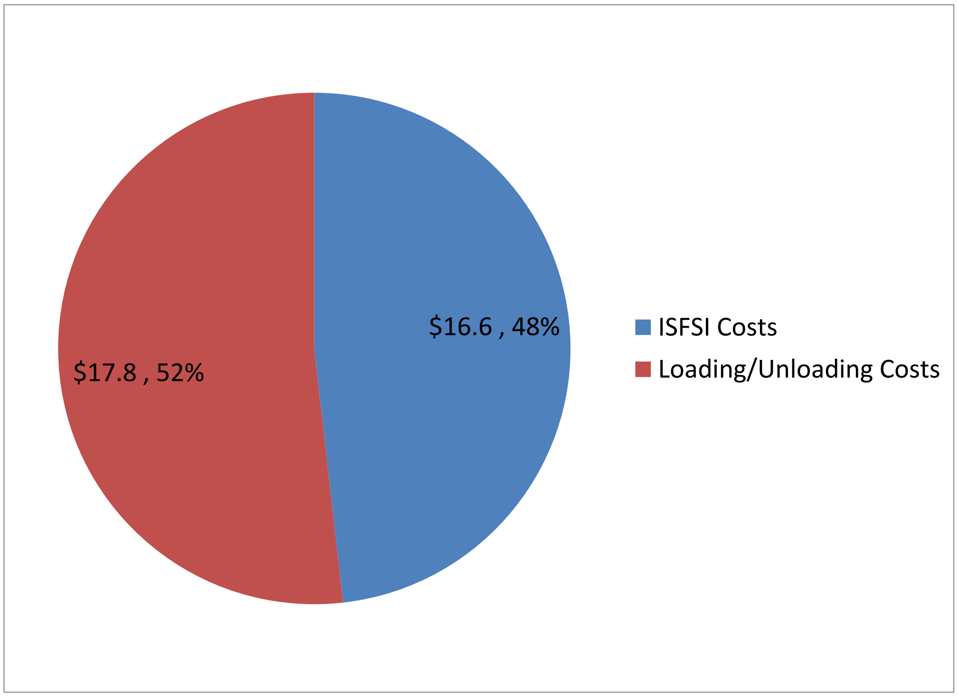

Figure 22. Breakdown of the at-reactor other ROM costs for the 4 PWR standardized canister loading strategy beginning in 2025 when the WP size is also 4 PWR with an ISF (scenario ID: 15).

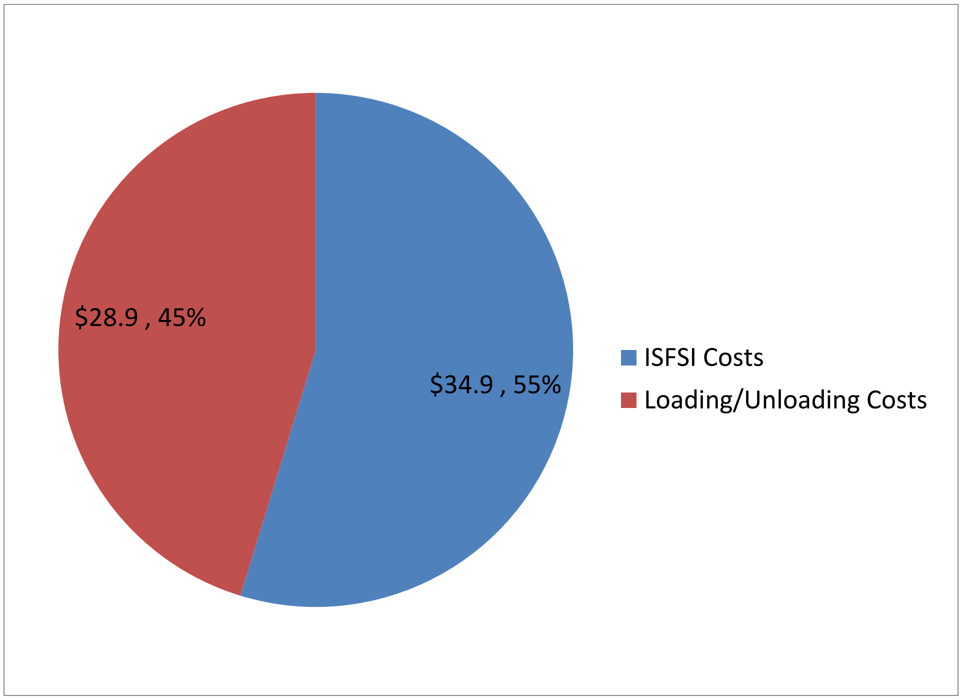

Figure 23. Breakdown of the at-reactor other ROM costs for the 4 PWR standardized canister loading strategy beginning in 2025 when the WP size is also 4 PWR without an ISF (scenario ID: 30).

By comparing Figure 20 and Figure 22 or Figure 21 and Figure 23, it is clear that the small canisters drive the operational loading costs up as a percentage of the total at-reactor operation costs.

5.2.2.3 Total at-reactor ROM cost estimates

Breakdowns of the nominal split of total at-reactor ROM costs are shown Figure 24 through Figure 27. By comparing Figure 24 and Figure 26 or Figure 25 and Figure 27, it is clear that small canisters increase the total capital cost and total other costs. In fact the capital costs increase at proportionally more than the other costs when 4 PWR canisters are introduced to the system.

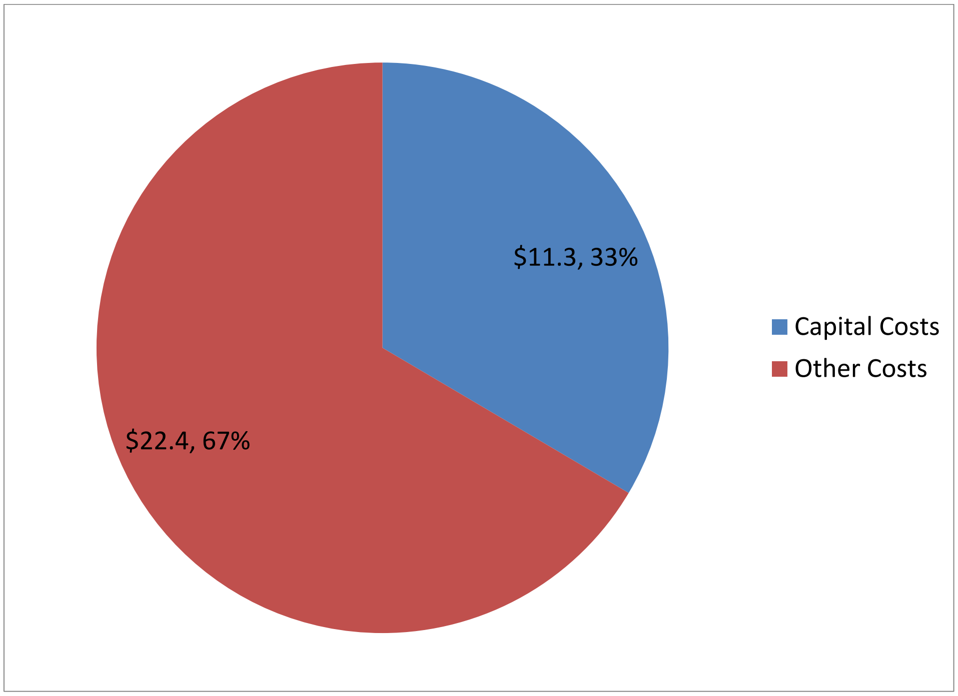

Figure 24. Breakdown of at-reactor other ROM costs and capital ROM costs for the status quo scenario that begins loading WP-compatible 21 PWR canisters in 2036 with an ISF (scenario ID: 14).

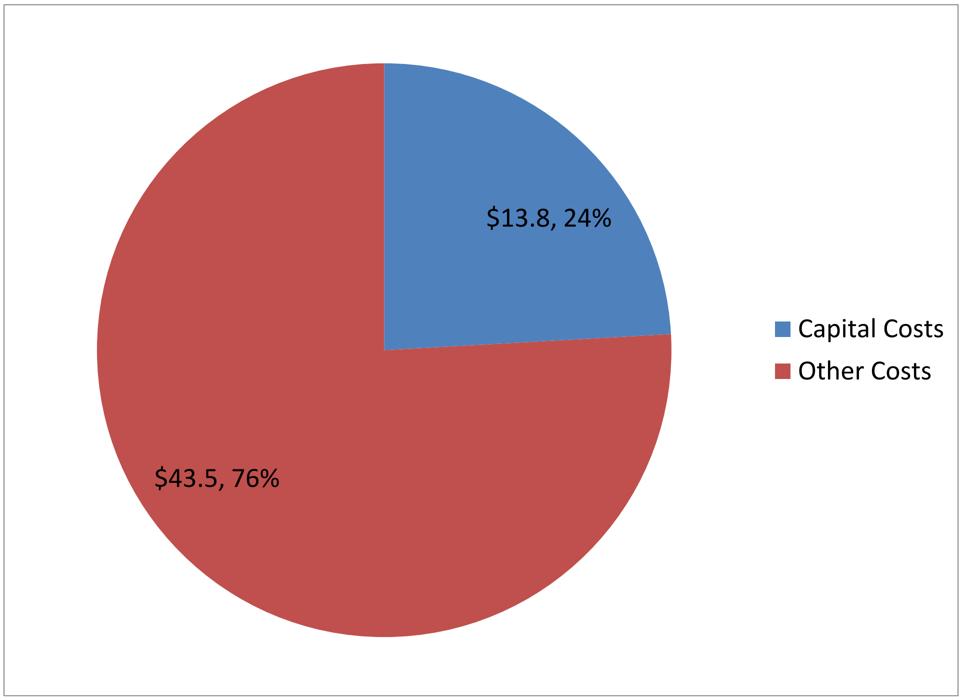

Figure 25. Breakdown of at-reactor other ROM costs and capital ROM costs for the status quo scenario that begins loading WP-compatible 21 PWR canisters in 2036 without an ISF (scenario ID: 11).

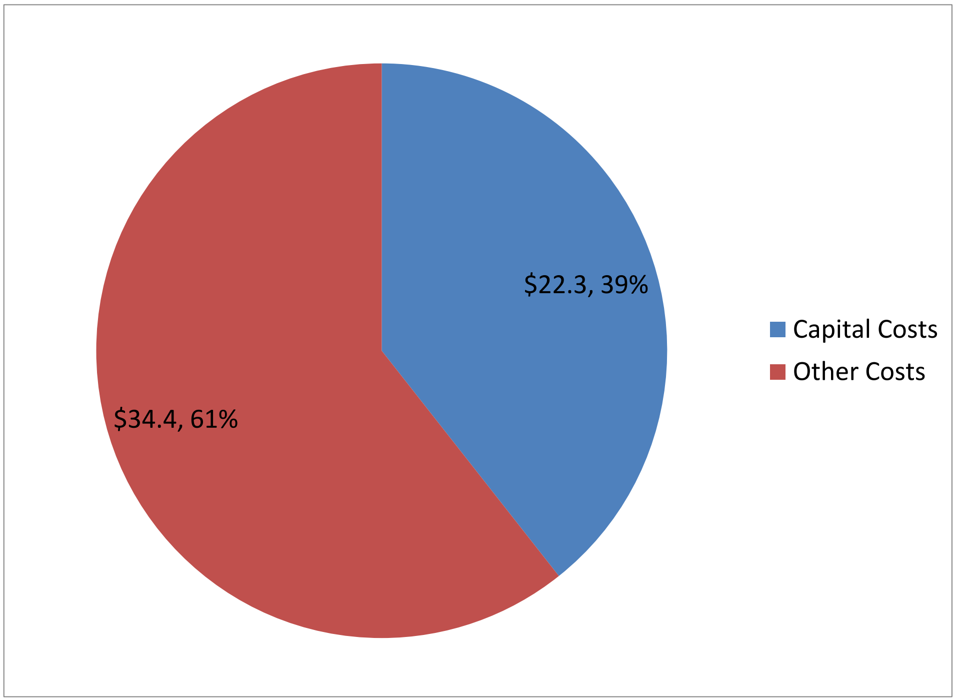

Figure 26. Breakdown of at-reactor other ROM costs and capital ROM costs for the 4 PWR standardized canister loading strategy beginning in 2025 when the WP size is also 4 PWR with an ISF (scenario ID: 15).

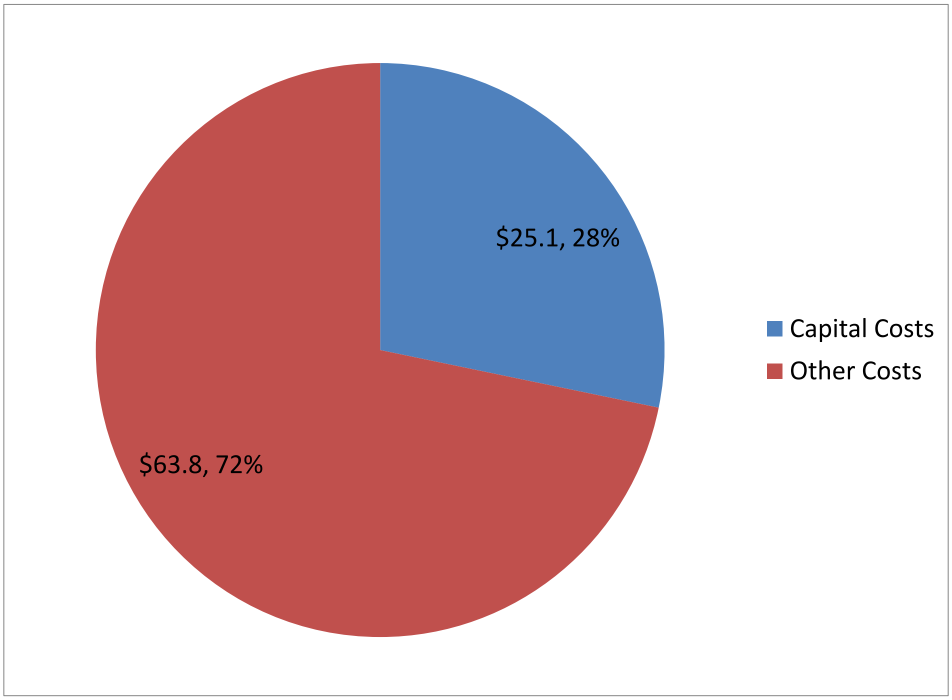

Figure 27. Breakdown of at-reactor other ROM costs and capital ROM costs for the 4 PWR standardized canister loading strategy beginning in 2025 when the WP size is also 4 PWR without an ISF (scenario ID: 30).

5.3 ISF Results and Analysis

The ISF results are broken down into the logistics analysis and the ROM cost estimates.

5.3.1 ISF logistics analysis

The ISF logistics are broken down into two main areas: the number of ISF receipt bays and the maximum number of casks stored. These metrics were chosen because they were assumed to be proportional to the operational impacts and costs at an ISF. The number of receipt bays indicates (1) the size of the facility and (2) the staffing requirements at the facility. The number of casks stored at the facility indicates the (1) number of dry storage operations (e.g., loading, lifts) and (2) the footprint of the dry storage pad.

5.3.1.1 ISF Receipt Bays

The number of ISF receipt bays goes up fairly proportionally with the total number of canisters that have to be accepted annually. This ensures that the 3000 MTHM/year throughput is achievable when the amount of SNF in each canister is smaller. Therefore the scenarios that load 4 PWR canisters at any time at the reactor sites require significantly more receipt bays. The unloading time for a small canister is assumed to be the same as that of a larger canister; therefore, a multicanister transportation cask with 4 4PWR canisters inside will take 4 times as long to unload as a transportation cask with a single DPC. Figure 28 illustrates the impact on the number of receipt bays at an ISF if WP-compatible canisters are loaded at the reactors once the WP size is known in 2036.

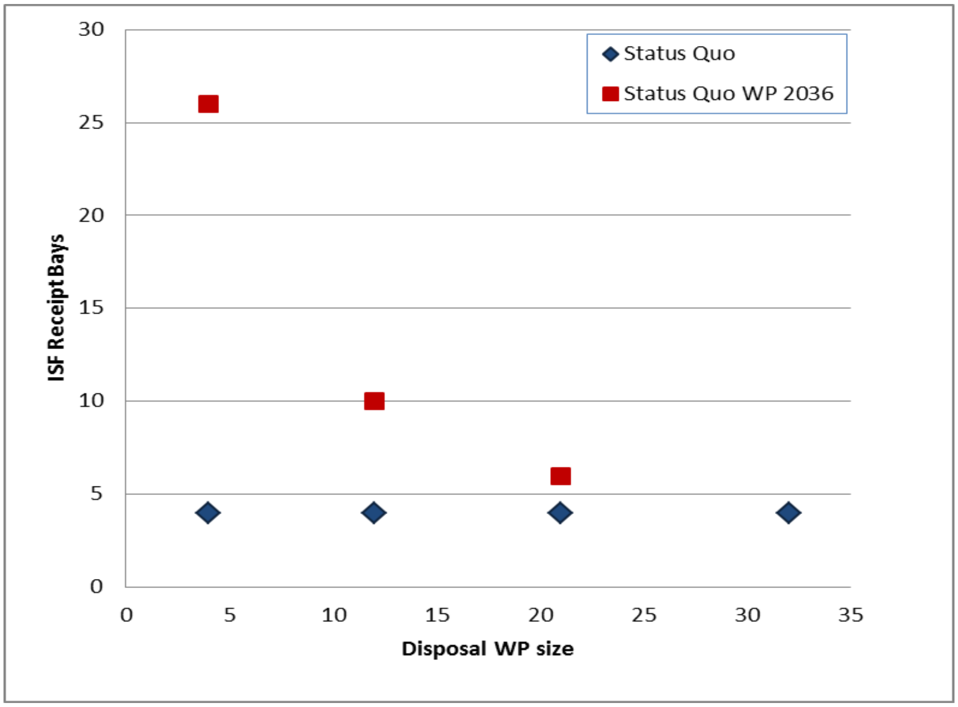

Figure 28. ISF receipt bays as a function of disposal WP size in the status quo scenario and in the status quo scenario when a WP is loaded in 2036 (scenario IDs: 5, 6, 7, 8, 12, 13, and 14).

5.3.1.2 Maximum casks in ISF storage

The amount of overpacks (not canisters), also referred to as casks, is used as an estimate of the total space requirements of an ISF. As expected, the smaller the canister size the more casks must be stored at the ISF.

The multicanister storage overpack concept allows the 4 PWR canisters to be stored 16 assemblies per cask and the 12 PWR canisters to be stored 36 PWR canisters per cask, whereas the other, larger canister concepts are stored in single overpacks. This leads to the total number of casks being minimized by using the medium-sized 12 PWR canisters. The ISF cask numbers range from ~3,800 (12 PWR scenario with delayed ISF to 2030) to more than 10,000 (4 PWR in 2025 switching to 12 PWR in 2040).

An illustration of the effect of the multicanister overpack can be seen in Figure 29 through Figure 32. These figures are combined into a single figure as illustrated in Figure 33. Each figure shows the maximum number of casks at the ISF as a function of final WP size. The different strategies illustrated are status quo, status quo moving to WP compatible canisters in 2036, the 4 PWR canisters in 2025 moving to WP-compatible canisters in 2036, the 12 PWR canisters in 2025 moving to WP-compatible canisters in 2036, and the 21 PWR canisters in 2025 moving to WP-compatible canisters in 2036.

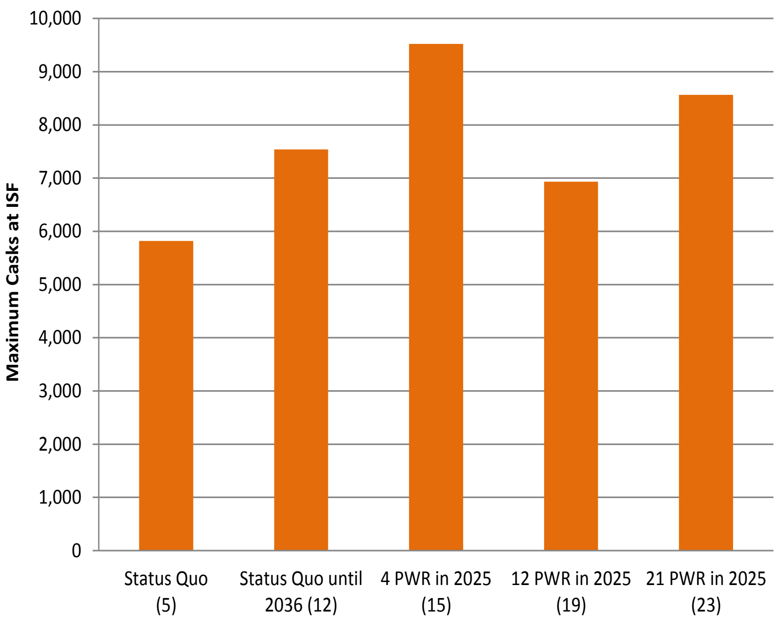

Figure 29. The maximum number of casks in storage at the ISF using different initial canister loading strategies when the final WP size is determined to be a 4 PWR (scenario IDs: 5, 12, 15, 19, and 23).

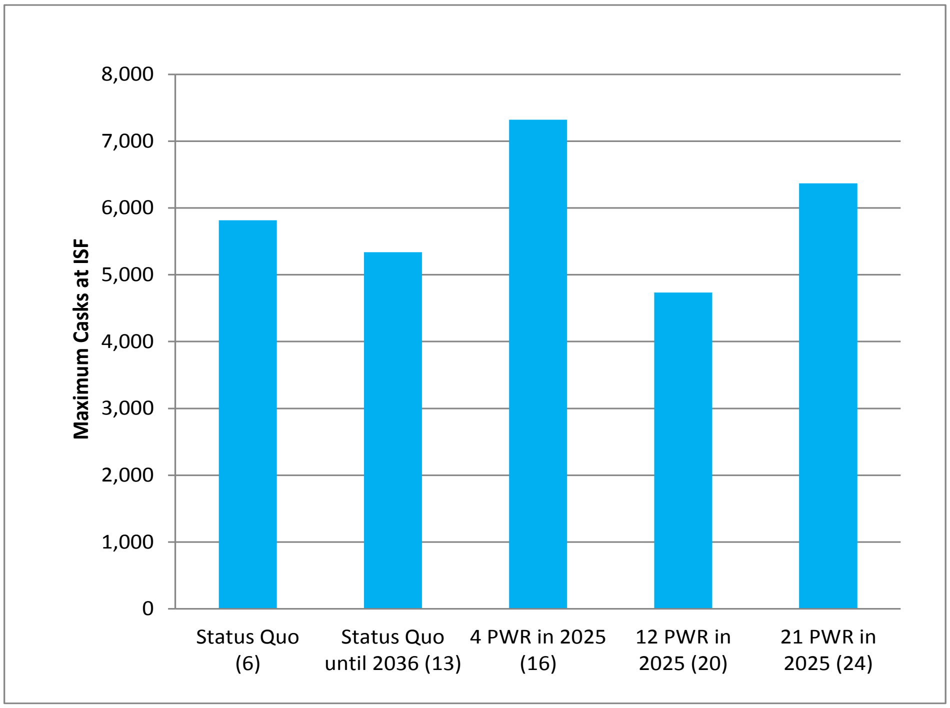

Figure 30. The maximum number of casks in storage at the ISF using different initial canister loading strategies when the final WP size is determined to be a 12 PWR (scenario IDs: 6, 13, 16, 20, and 24).

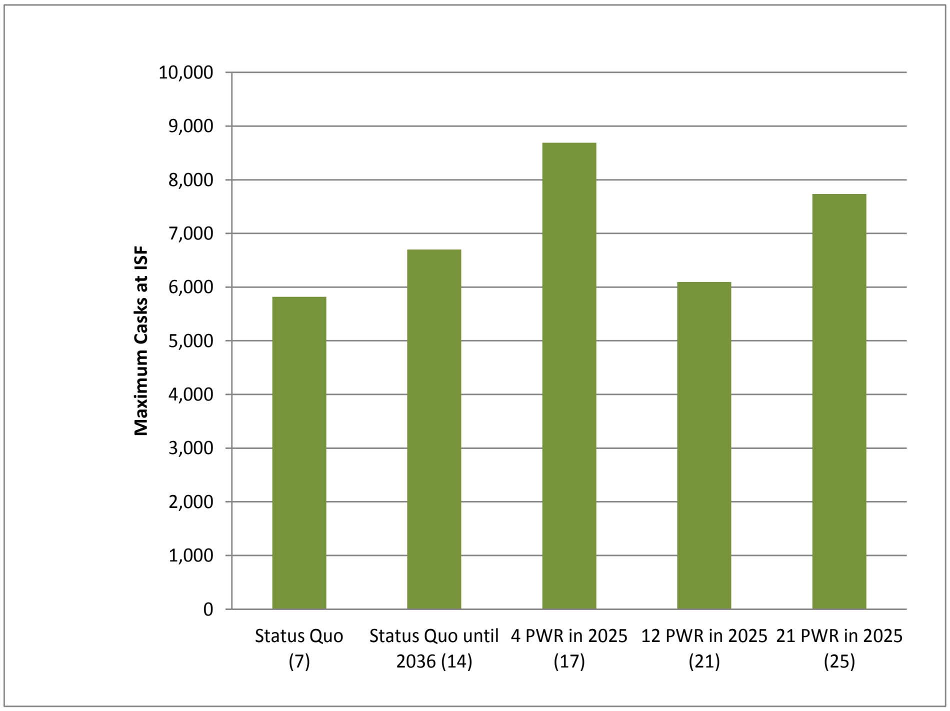

Figure 31. The maximum number of casks in storage at the ISF using different initial canister loading strategies when the final WP size is determined to be a 21 PWR (scenario IDs: 7, 14, 17, 21, and 25).

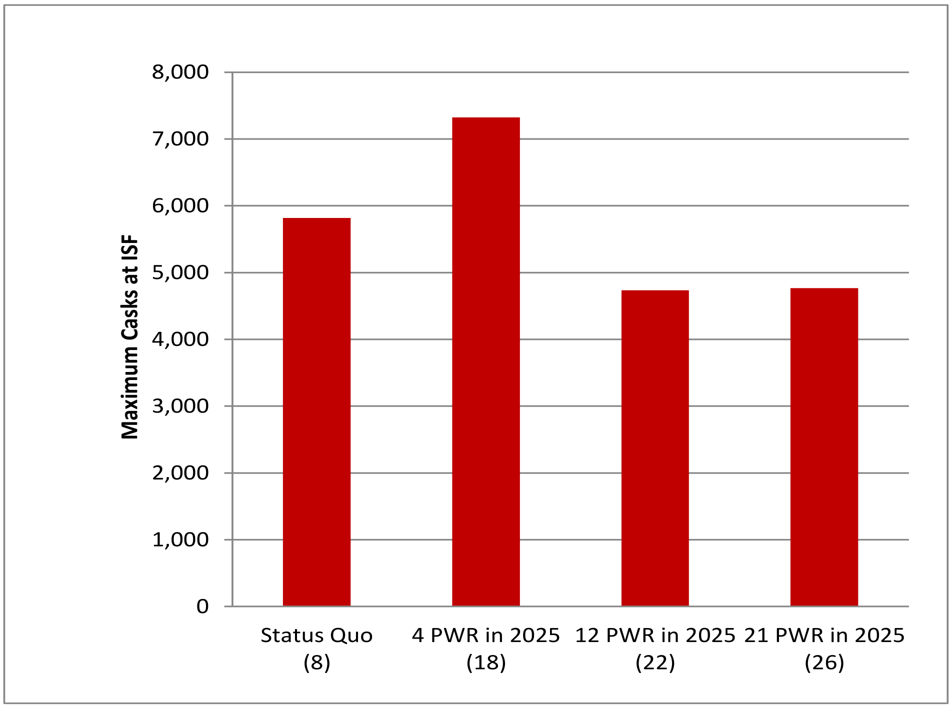

Figure 32. The maximum number of casks in storage at the ISF using different initial canister loading strategies when the final WP size is determined to be a 37 PWR (scenario IDs: 8, 18, 22, and 26).

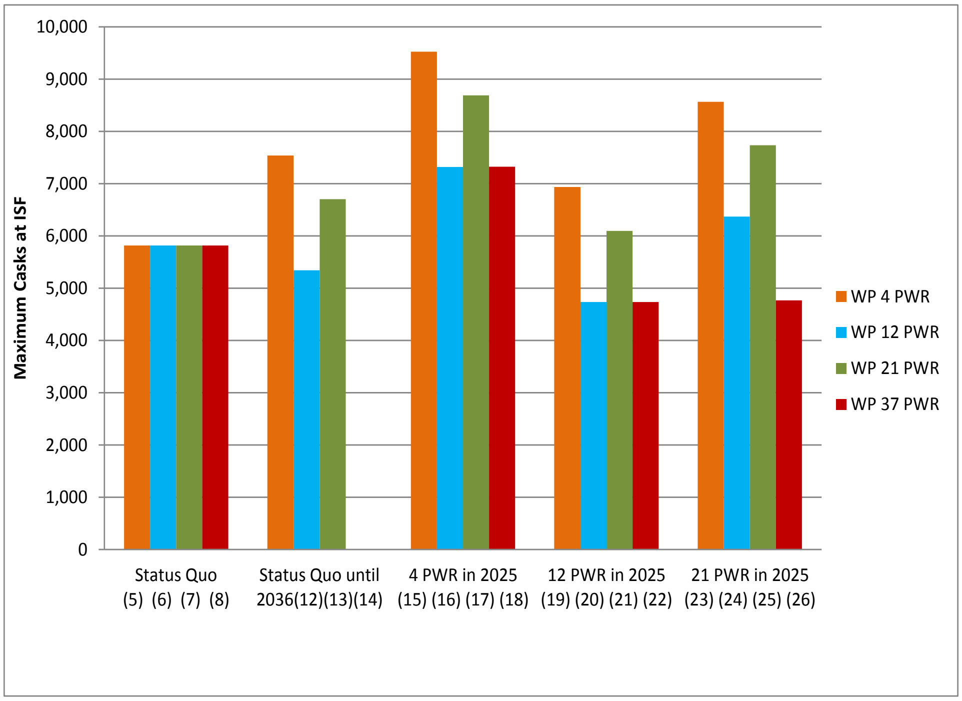

Figure 33. The maximum number of casks in storage at the ISF as a function of initial canister selection strategy when the WP size is determined to be 4 PWR (orange), 12 PWR (blue), 21 PWR (green), 37 PWR (red) (scenario IDs: 5, 6, 7, 8, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, and 26).

5.3.2 ISF ROM cost estimates

The ISF ROM cost estimates are broken down into two categories: cask and pad costs and operational costs. The cask and storage pad cost estimates include the overpacks/casks and storage pad costs; while the operational costs include costs related to general operations. Note that there are no operational costs associated with LLW or fuel handling because all repackaging is performed at the repository.

Figure 34 through Figure 38 show the ISF total ROM costs for each WP size. The ISF costs range from ~$7B to ~$17B. The most dramatic cost driver is the number of canisters received annually, which drives up the number of receipt bays and the number of casks in storage. Note that in each scenario, the relative ISF costs track very closely with the maximum number of casks (Figure 29 through Figure 32) as illustrated in Figure 39.

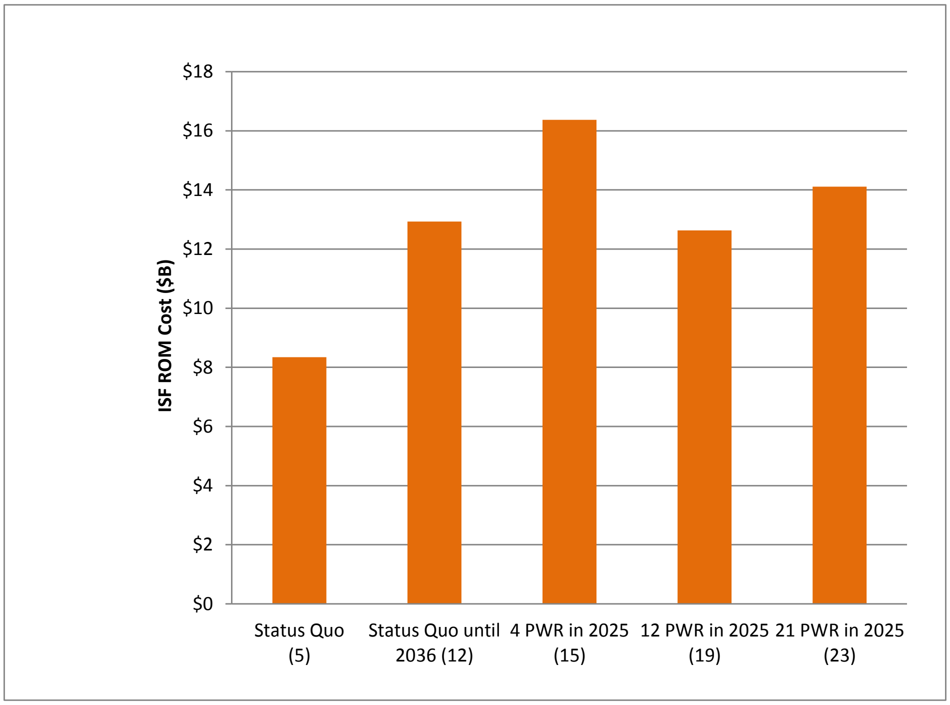

Figure 34. The total ROM cost of the ISF using different initial canister loading strategies when the final WP size is determined to be a 4 PWR (scenario IDs: 5, 12, 15, 19, and 23).

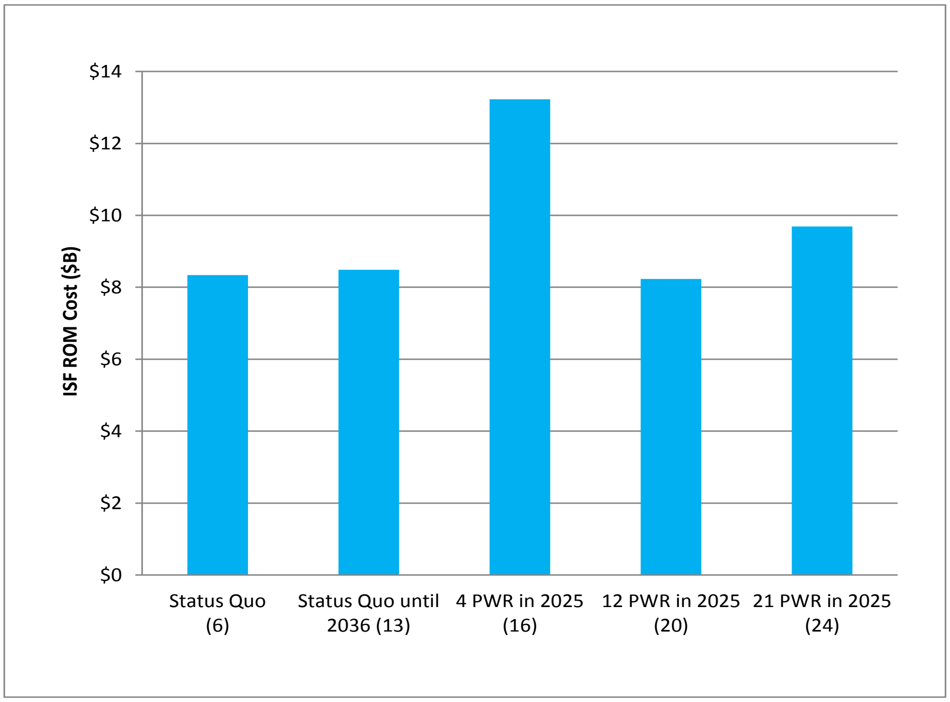

Figure 35. The total ROM cost of the ISF using different initial canister loading strategies when the final WP size is determined to be a 12 PWR (scenario IDs: 6, 13, 16, 20, and 24).

Figure 36. The total ROM cost of the ISF using different initial canister loading strategies when the final WP size is determined to be a 21 PWR (scenario IDs: 7, 14, 17, 21, and 25).

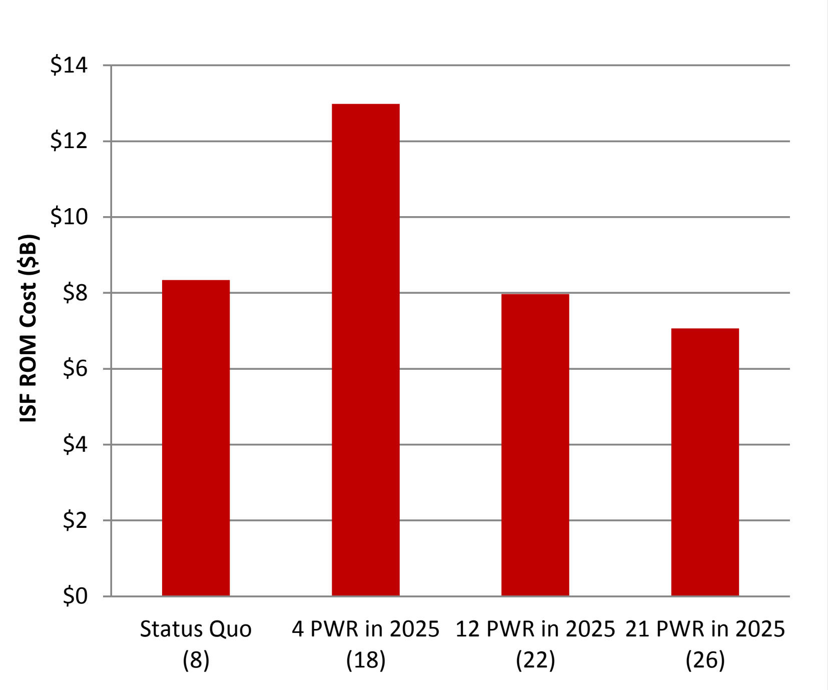

Figure 37. The total ROM cost of the ISF using different initial canister loading strategies when the final WP size is determined to be a 37 PWR (scenario IDs: 8, 18, 22, and 26).

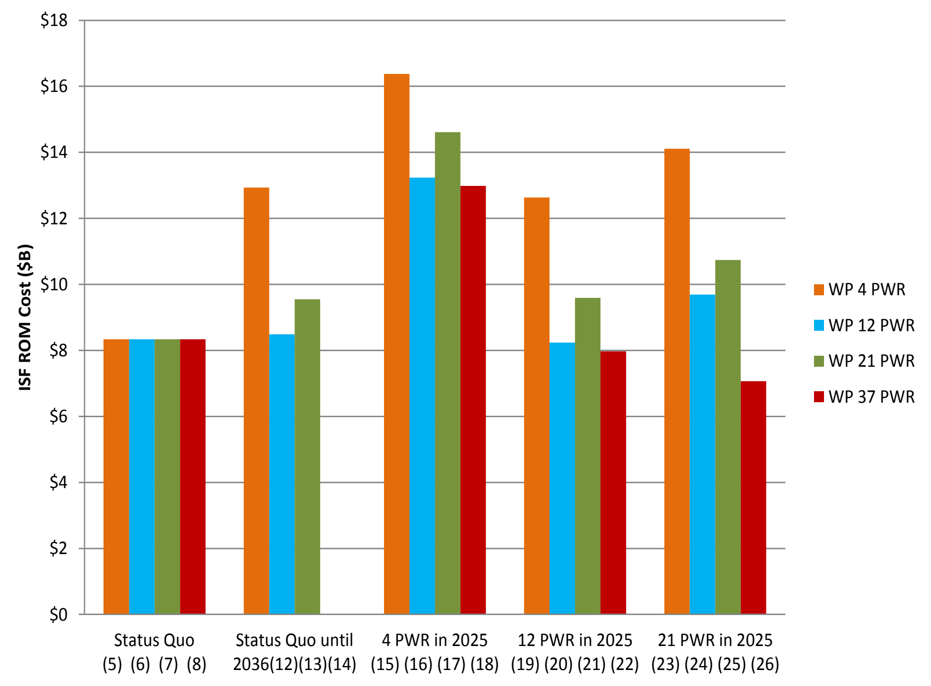

Figure 38. The total ROM cost of the ISF as a function of initial canister selection strategy when the WP size is determined to be 4 PWR (orange), 12 PWR (blue), 21 PWR (green), 37 PWR (red) (scenario IDs: 5, 6, 7, 8, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, and 26).

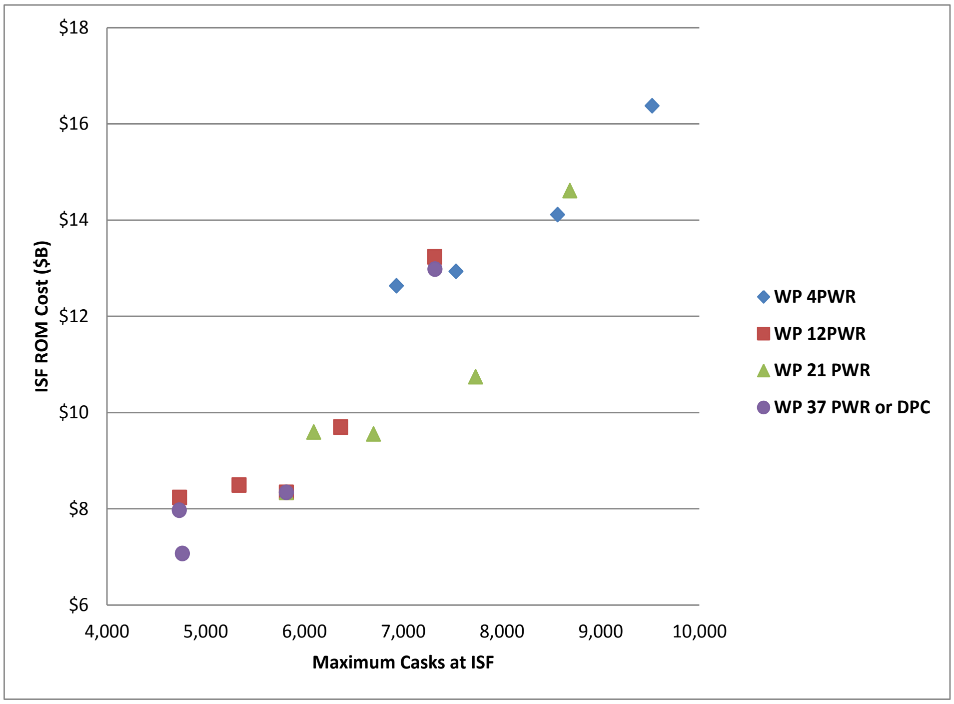

Figure 39. The ISF ROM cost as a function of maximum casks in storage at an ISF, where each symbol represents a final WP size (e.g., 4 PWR WP, 12 PWR WP) (scenario IDs: 5, 6, 7, 8, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, and 26).

As the figures illustrates, the scenarios involving 4 PWR canisters have the highest ISF cost because they have the most receipt bays and the greatest number of casks that must be stored. The least expensive ISF occurs when the ISF is delayed and thus does not store as many casks.

5.4 Repackaging Results and Analysis

The repackaging results are broken down into the logistics analysis and the ROM cost estimates.

5.4.1 Repackaging logistics analysis

The repackaging facility logistics analysis is broken down in two main areas: LLW (number of canisters and total cubic meters) and repackaging facility receiving, opening, and closing bays. The LLW indicates the waste material generated in the process and the costs associated with this waste. The number of bays at the repackaging facility indicates the size and cost of the facility and the staffing requirements at the facility.

5.4.1.1 LLW

The amount of LLW generated in different scenarios is a key metric, as it represents the amount of material no longer useful and is directly proportional to the cost of LLW disposal. Figure 40 through Figure 47 illustrate that repackaging is minimized by using 4 PWR canisters, which are assumed to be compatible with any repository concept. As expected, the total amount of waste generated is highest when all SNF is loaded into DPCs at reactors (status quo cases). By 2025 the total volume of loaded DPCs is projected to be 42,588 m^3 (3,549 canisters), which would have to be repackaged in all scenarios in which direct disposal of DPCs was found to be unfeasible. There is the possibility to decontaminate and then recycle and repurpose some of this material. The current DOE commitment is to dispose of DPCs as LLW, but that could be re-evaluated in the future.

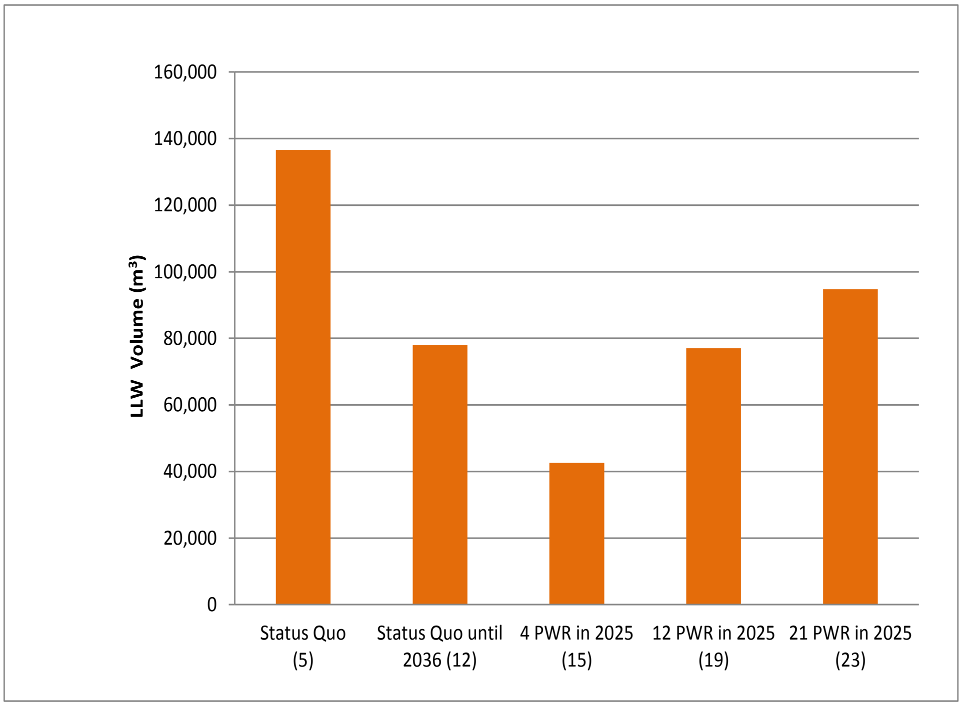

Figure 40. Cubic meters of LLW using different initial canister loading strategies when the WP size is determined to be a 4 PWR (scenario IDs: 5, 12, 15, 19, and 23).

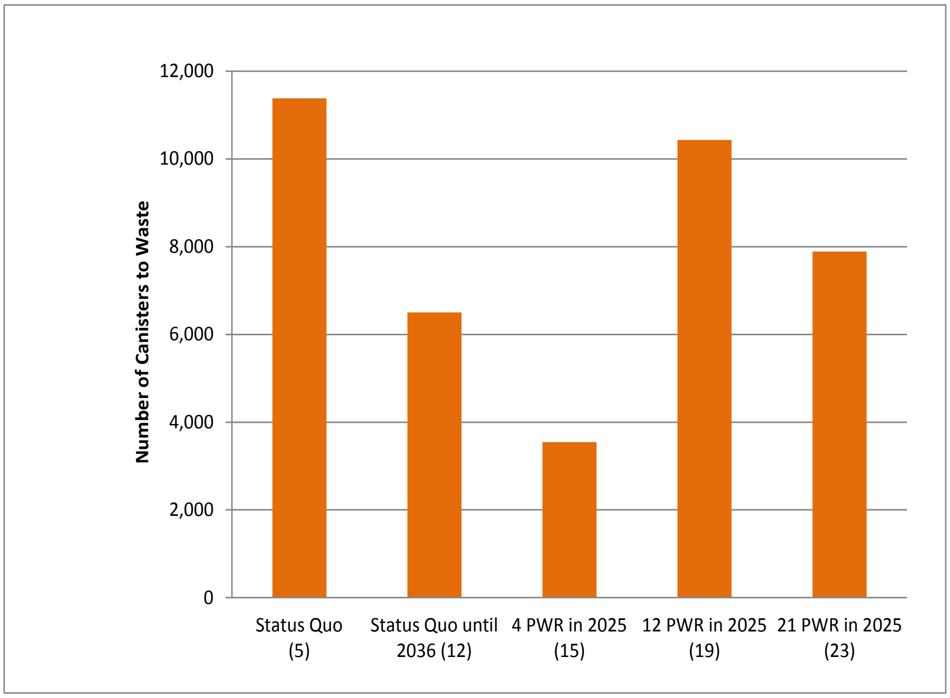

Figure 41. Number of canisters to waste using different initial canister loading strategies when the WP size is determined to be a 4 PWR (scenario IDs: 5, 12, 15, 19, and 23).

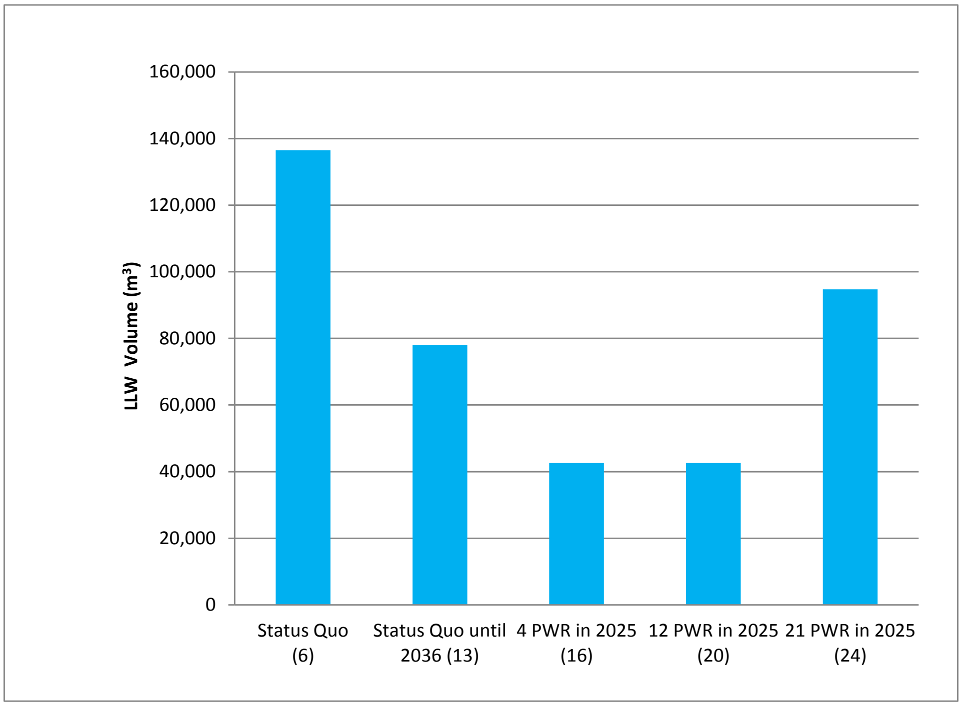

Figure 42. Cubic meters of LLW using different initial canister loading strategies when the WP size is determined to be a 12 PWR (scenario IDs: 6, 13, 16, 20, and 24).

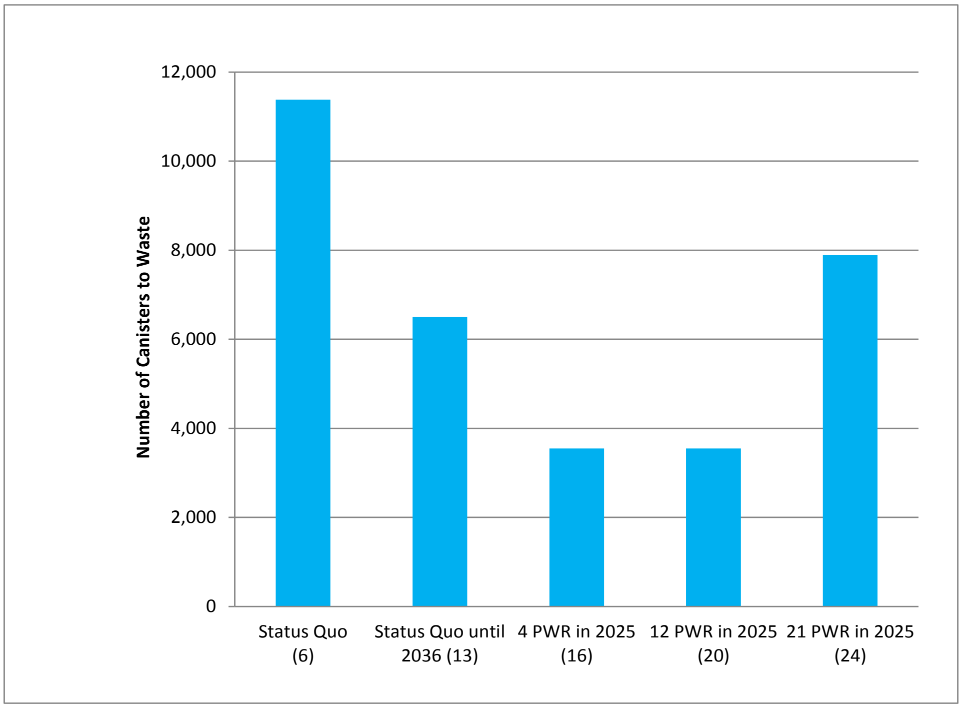

Figure 43. Number of canisters to waste using different initial canister loading strategies when the WP size is determined to be a 12 PWR (scenario IDs: 6, 13, 16, 20, and 24).

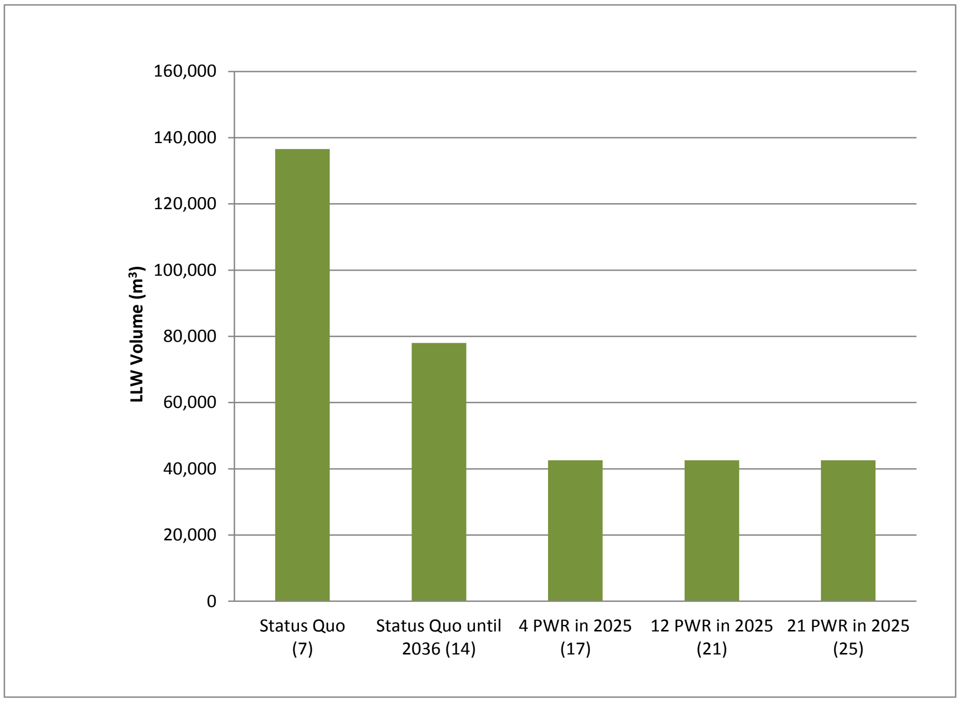

Figure 44. Cubic meters of LLW using different initial canister loading strategies when the WP size is determined to be a 21 PWR (scenario IDs: 7, 14, 17, 21, and 25).

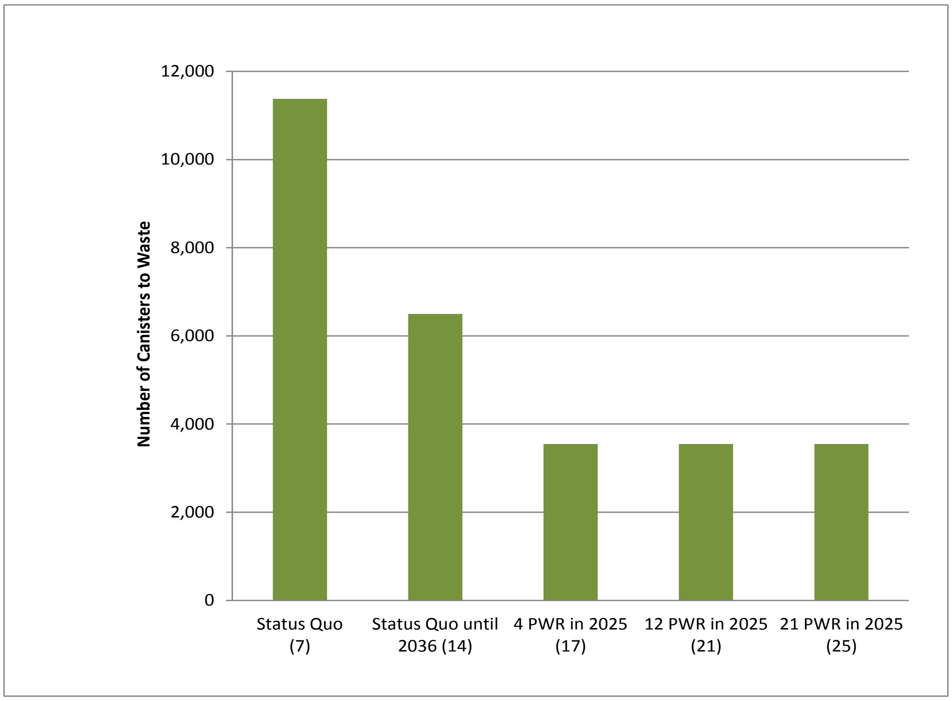

Figure 45. Number of canisters to waste using different initial canister loading strategies when the WP size is determined to be a 21 PWR (scenario IDs: 7, 14, 17, 21, and 25).

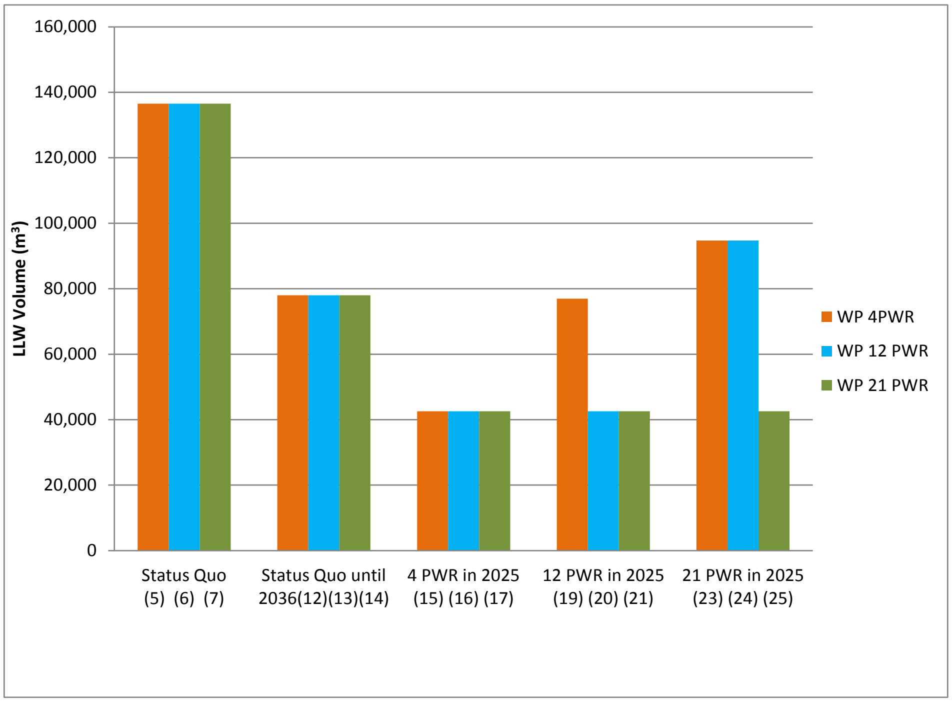

Figure 46. Cubic meters of LLW using different initial canister loading strategies with different the WP sizes (scenario IDs: 5, 6, 7, 12, 13, 14, 15, 16, 17, 19, 20, 21, 23, 24, and 25).

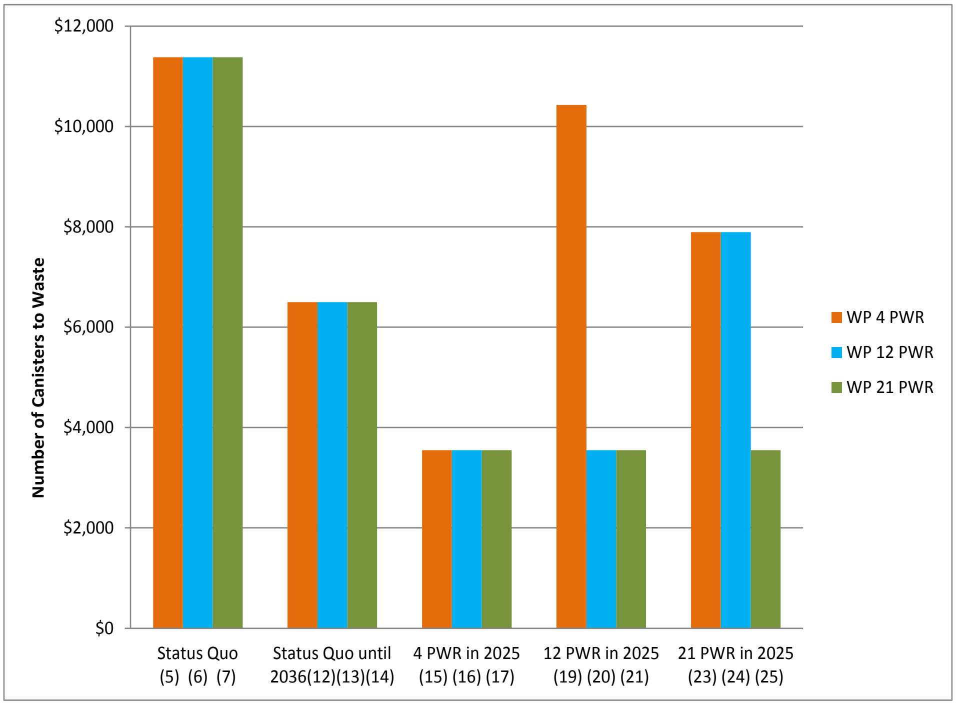

Figure 47. Number of canisters to waste using different initial canister loading strategies with different the WP sizes (scenario IDs: 5, 6, 7, 12, 13, 14, 15, 16, 17, 19, 20, 21, 23, 24, and 25).

5.4.1.2 Repackaging bays

The number of bays at the repackaging facility is a direct indicator of ROM cost. The bays that were tracked were the receiving bay, the canister-opening bay, and the canister-closing bay. There was a total of three receiving bays for all scenarios in which repackaging was determined to be necessary.

However, the number of opening bays increased from three (DPC scenarios) to a maximum of six (12 PWR canister scenarios) when repackaging was required, as is shown in Table 8. Note that if the WP size is 37 PWR, then no repackaging is necessary.

Table 8. Number of opening bays at the repackaging facility as a function of initial canister loading strategy.

Initial Canister Loading Strategy	Number of Opening Bays
DPC	3
21 PWR	3–4
12 PWR	3–6
4 PWR	3

The scenarios that create the largest number of canisters that require repackaging are those in which the initial canisters loaded are not compatible with the final WP, as it is assumed that small canisters would not have to be repackaged into larger ones.

The number of closing bays is proportional to the number of WP-compatible canisters that must be loaded. The 4 PWR WP scenarios have the most closing bays, while no closing bays are required if 37 PWR or DPCs are accepted as shown in Table 9.

Table 9. Number of closing bays as a function of WP size.

WP Size	Number of Closing Bays
37 PWR / DPC	0
21 PWR	4–5
12 PWR	6–7
4 PWR	18–22

5.4.2 Repackaging ROM cost estimates

The repackaging ROM cost estimates are broken down into LLW/WP costs and other costs.

The LLW and WP costs include disposing of the LLW from the initial canisters, as well as the WP costs for purchasing the WP compatible canisters. Note that no WP overpack costs have been assumed. The other costs include the repackaging facility and operation costs.

The repackaging ROM costs can be seen in Figure 48 and illustrates that the repackaging facility costs are driven more by the ultimate WP size needed for the repository than by the initial canister loading strategy.

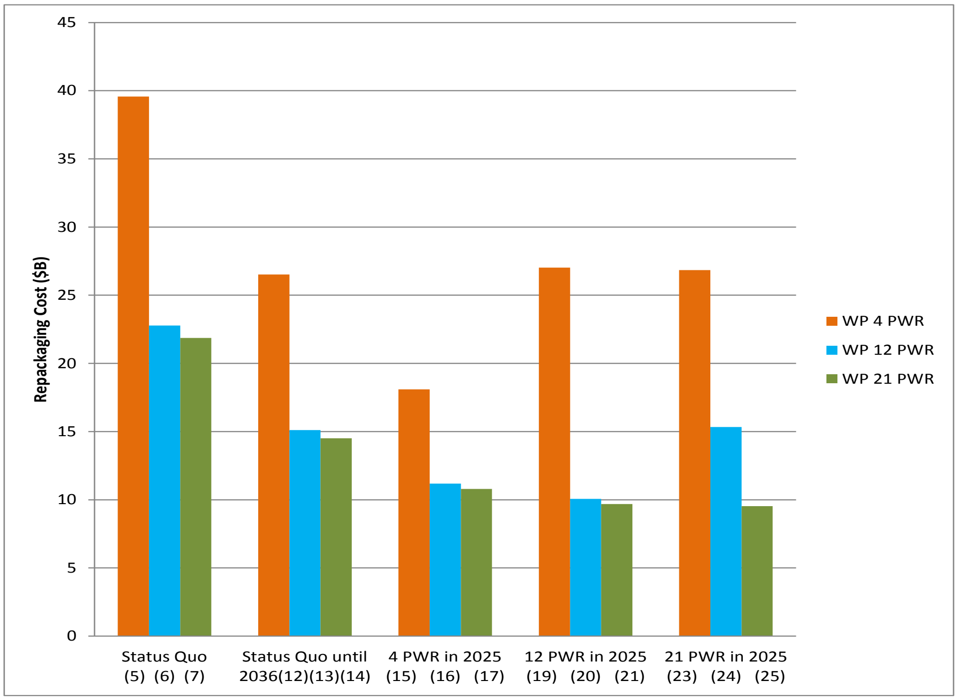

Figure 48. Repackaging ROM costs as a function of initial canister selection strategy when the WP size is determined to be 4 PWR (orange), 12 PWR (blue), 21 PWR (green) (scenario IDs: 5, 6, 7, 12, 13, 14, 15, 16, 17, 19, 20, 21, 23, 24, and 25).

For these ROM costs, there is a strong trend towards decreasing cost with larger WP size and only a weak trend favoring smaller initial canister choice. The advantage of the large WP is that there is less repackaging for any initial canister choice (assuming smaller canisters are compatible with the WP). The weak trend with initial canister choice is due to the fact that the DPCs need to be repackaged for all scenarios where the WP is less than 37 PWR, and choosing a small initial canister causes a larger number of handling and opening operations.

5.5 Transportation Results and Analysis

The transportation results are broken down into the logistics analysis and the ROM cost estimates.

5.5.1 Transportation logistics analysis

The two key areas related to transportation are transportation cask miles (total number of miles that all casks travel) and transportation consist miles (total number of miles that each consist travels). Because the three-car consist was defined as the preferable consist size in all the scenarios, the cask miles are highly correlated with the consist miles. A three-car consist was used in most shipments and smaller consists were used in only a few shipments, which is reflected in the average consist size of 2.56. Consequently, either cask miles or consist miles can be used as a transportation metric. The cask miles are directly proportional to the number of casks to be transported, and as a result, the 12 PWR canisters scenarios have the largest cask miles as illustrated in Figure 49 and Figure 50.

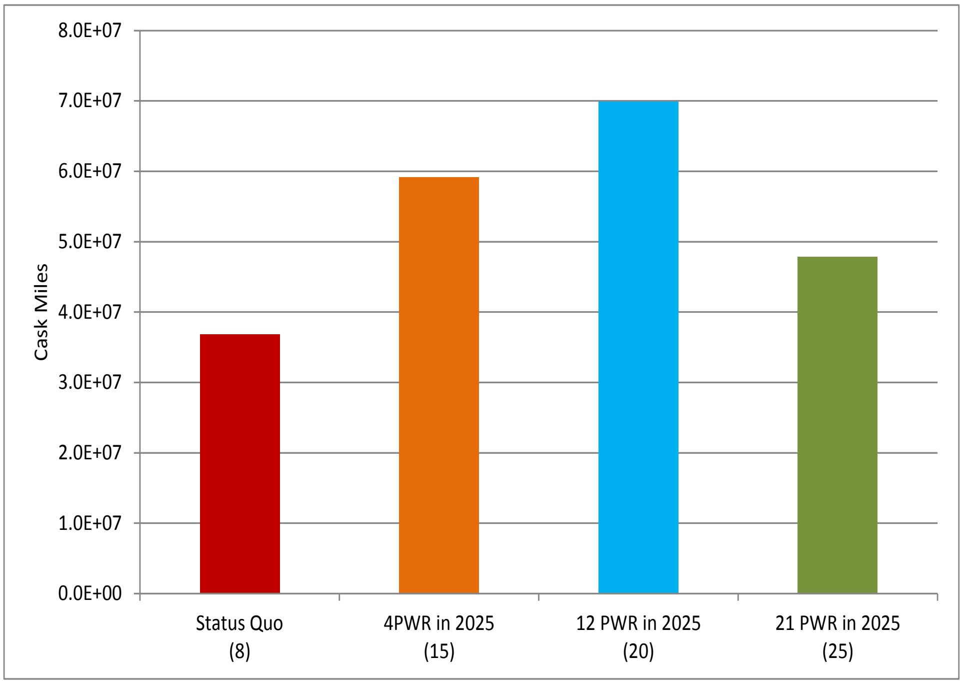

Figure 49. Cask miles for scenarios with correct initial canister size (initial guess = WP size) with an ISF (scenario IDs: 8, 15, 20, and 25).

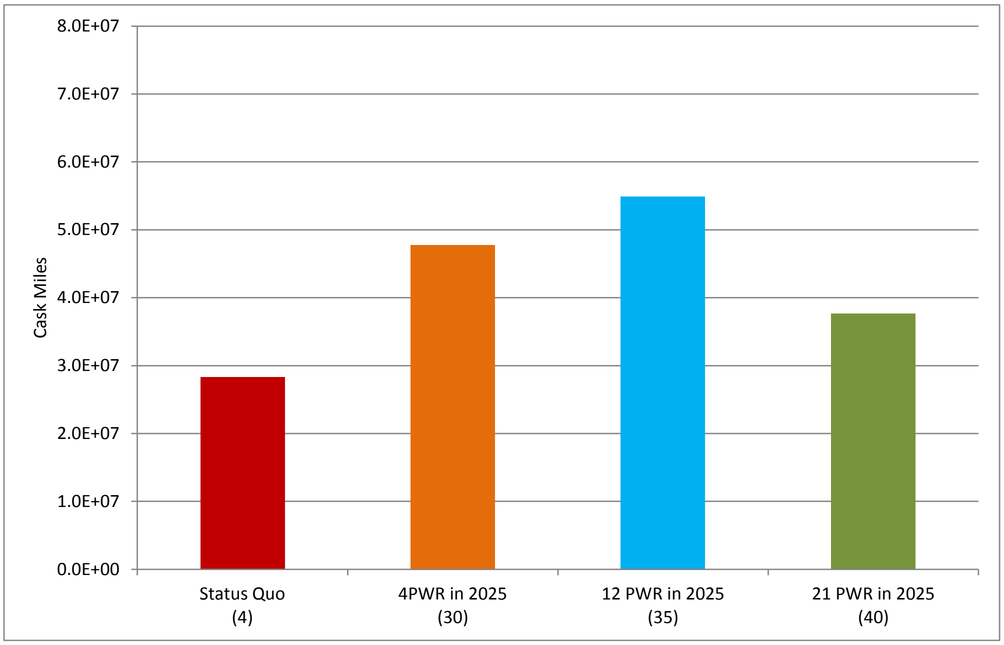

Figure 50. Cask miles for scenarios with correct initial canister size (initial guess = WP size) without an ISF (scenario IDs: 4, 30, 35, and 40).

Besides the status quo scenario where only DPCs are transported, the specific selection of initial canister selection has a minor effect, as illustrated in Figure 51 and Figure 52.

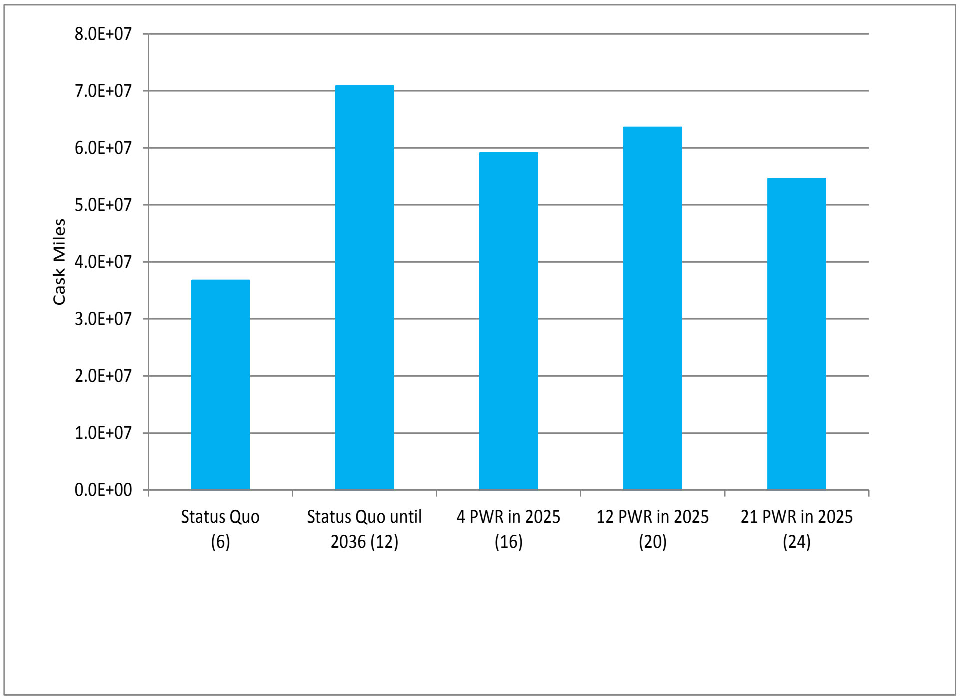

Figure 51. Cask miles when disposing of a 12 PWR WP using different initial canister loading strategies with an ISF (scenario IDs: 6, 12, 16, 20, and and 24).

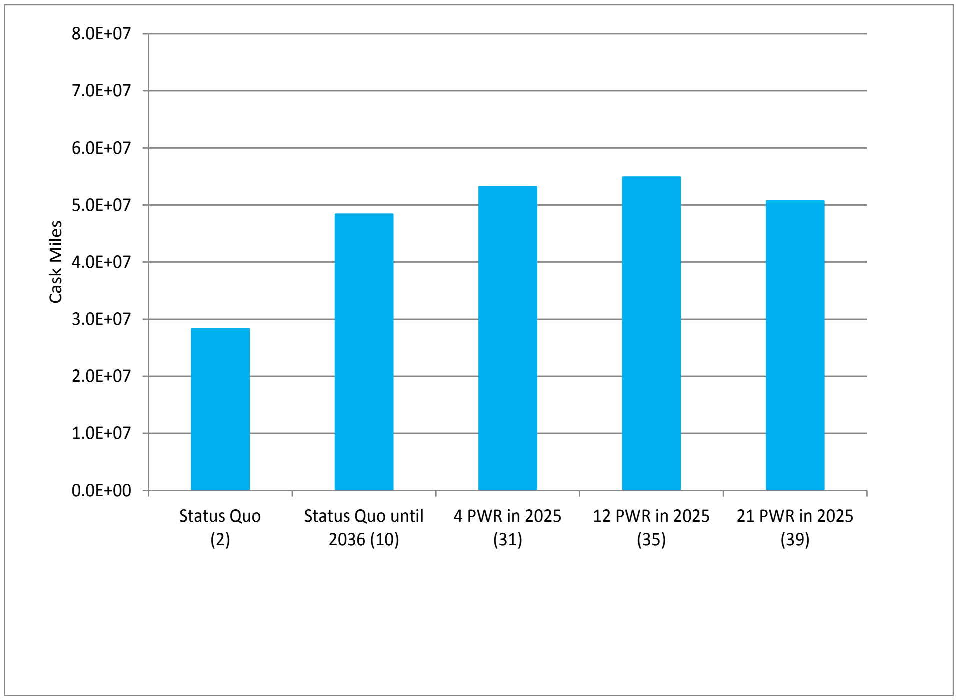

Figure 52. Cask miles when disposing of a 12 PWR WP using different initial canister loading strategies without an ISF (scenario IDs: 2, 10, 31, 35, and 39).

Due to the high correlation between consist and cask miles, the consist miles produce similar trends, as illustrated in Figure 53 through Figure 56.

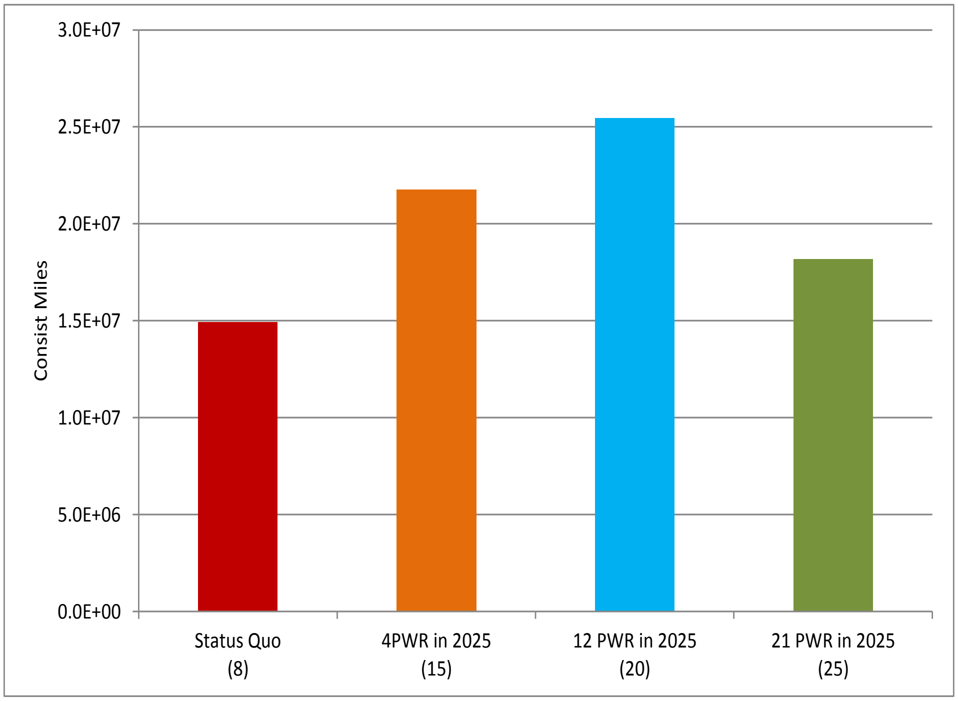

Figure 53. Consist miles for scenarios with correct initial canister size (initial guess = WP size) with ISF (scenario IDs: 8, 15, 20, and 25).

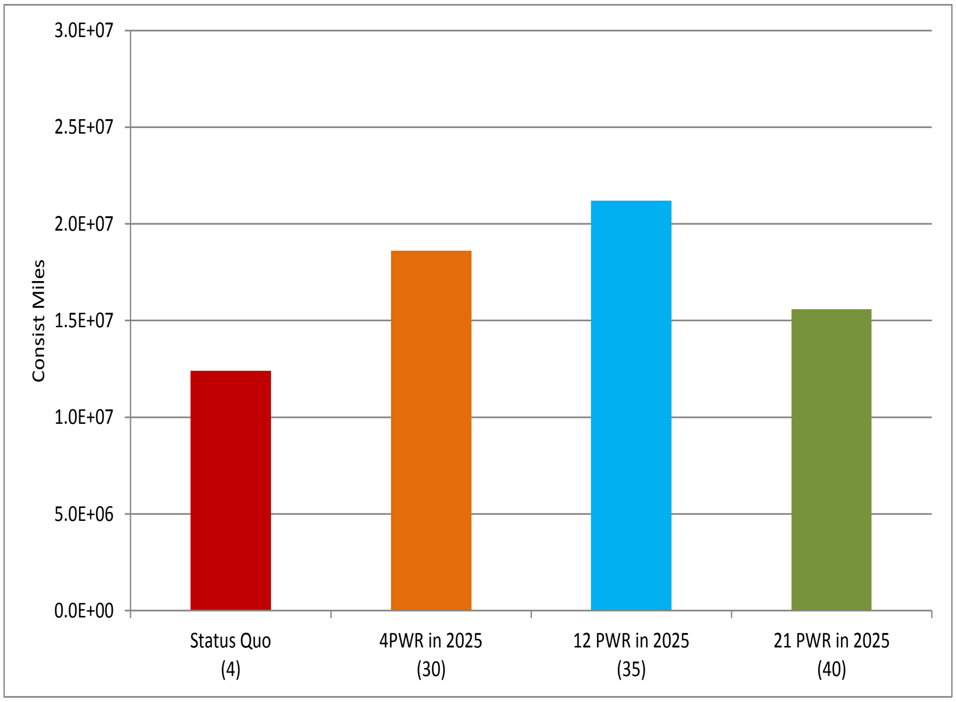

Figure 54. Consist miles for scenarios with correct initial canister size (initial guess = WP size) without ISF (scenario IDs: 4, 30, 35, and 40).

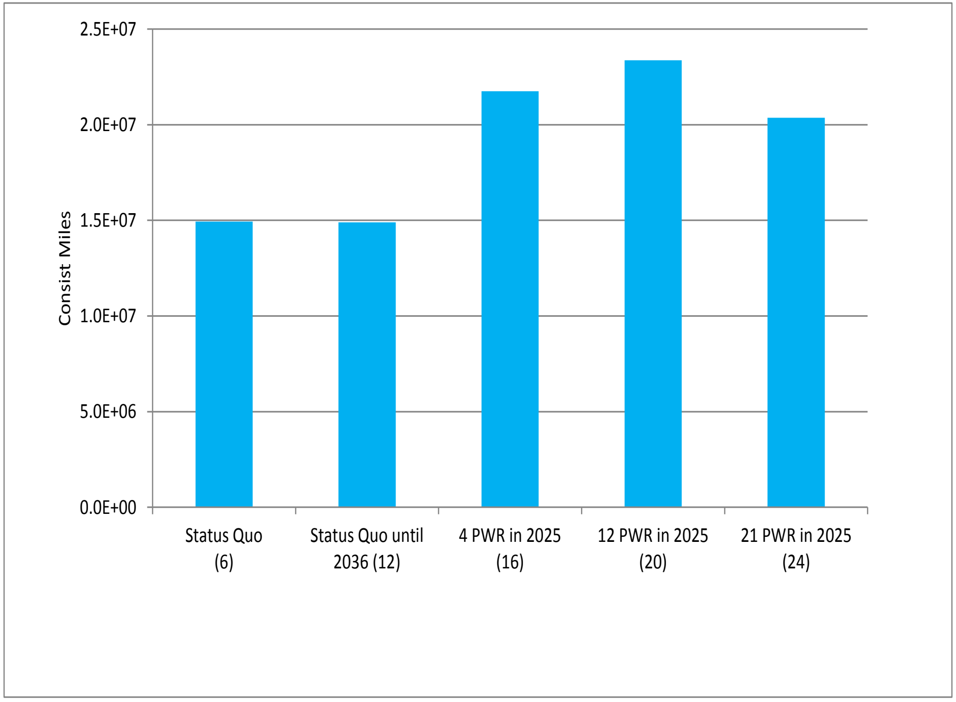

Figure 55. Consist miles when disposing of a 12 PWR WP using different initial canister loading strategies with an ISF (scenario IDs: 6, 12, 16, 20, and 24).

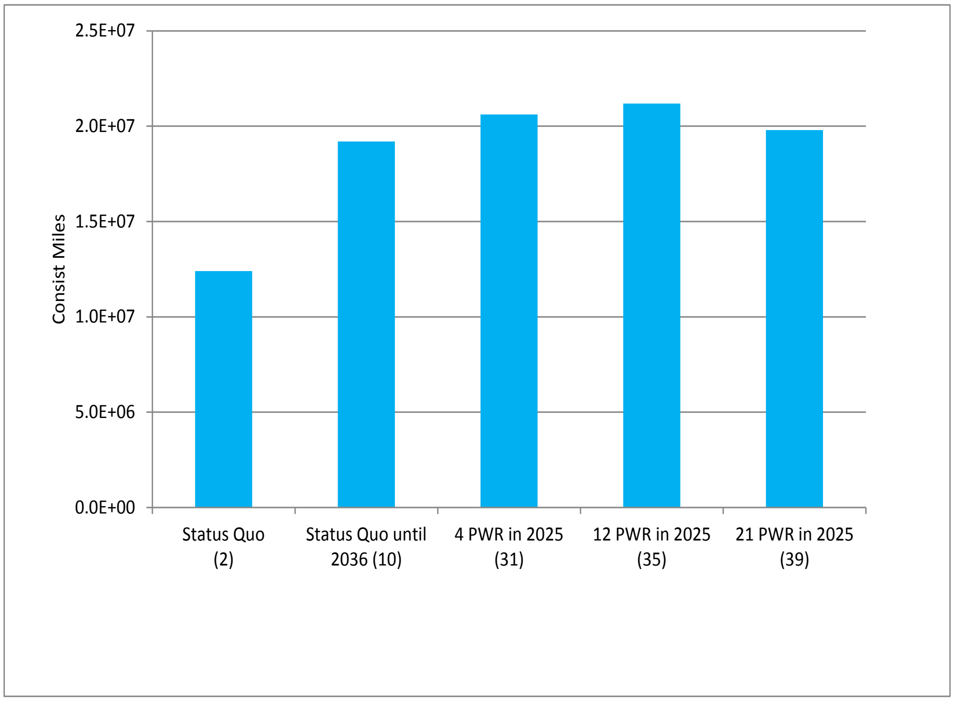

Figure 56. Consist miles when disposing of a 12 PWR WP using different initial canister loading strategies without an ISF (scenario IDs: 2, 10, 31, 35, and 39).

5.5.2 Transportation ROM cost estimates

The total transportation ROM costs range from $4.4B to $10.7B and are fairly proportional to the number of cask miles. While the fleet/capital transportation ROM costs range from 12% to 22% (17% average) of the total transportation ROM costs, the other costs (including operations) are the majority of the transportation costs, as illustrated in Figure 57 through Figure 60.

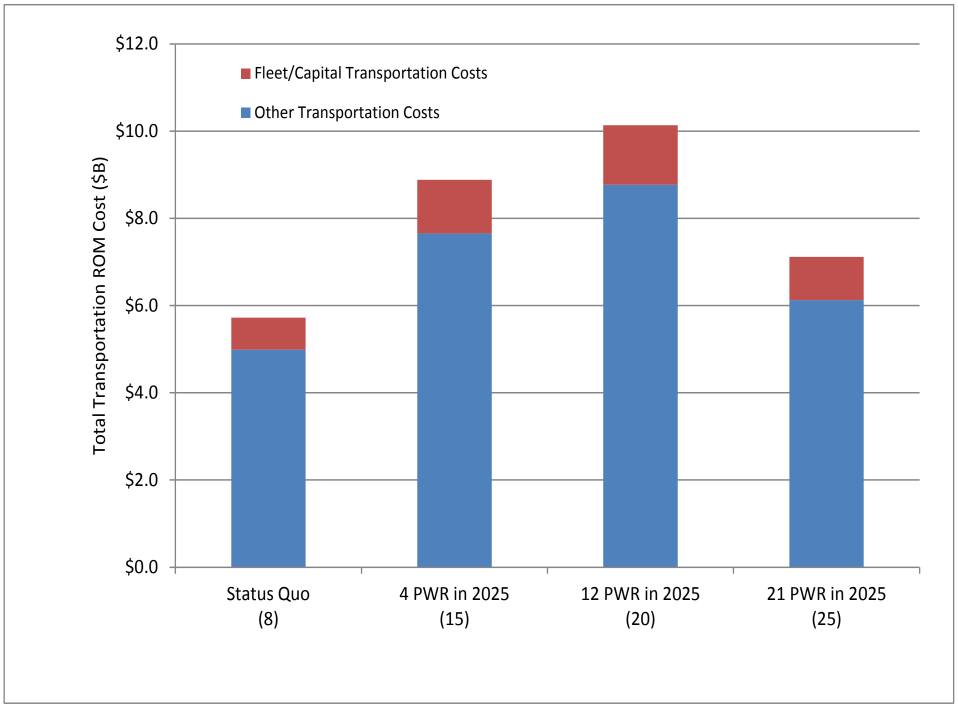

Figure 57. Comparing transportation ROM cost for scenarios with correct initial canister size (initial guess = WP size) with an ISF (scenario IDs: 8, 15, 20, and 25).

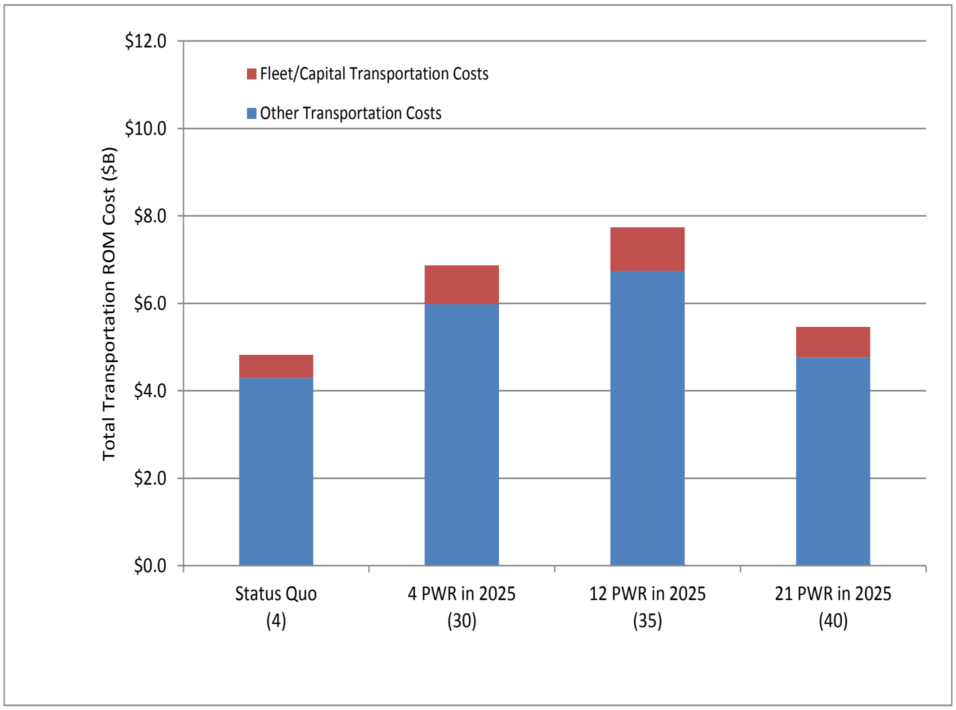

Figure 58. Comparing transportation ROM cost for scenarios with correct initial canister size (initial guess = WP size) without an ISF (scenario IDs: 4, 30, 35, and 40).

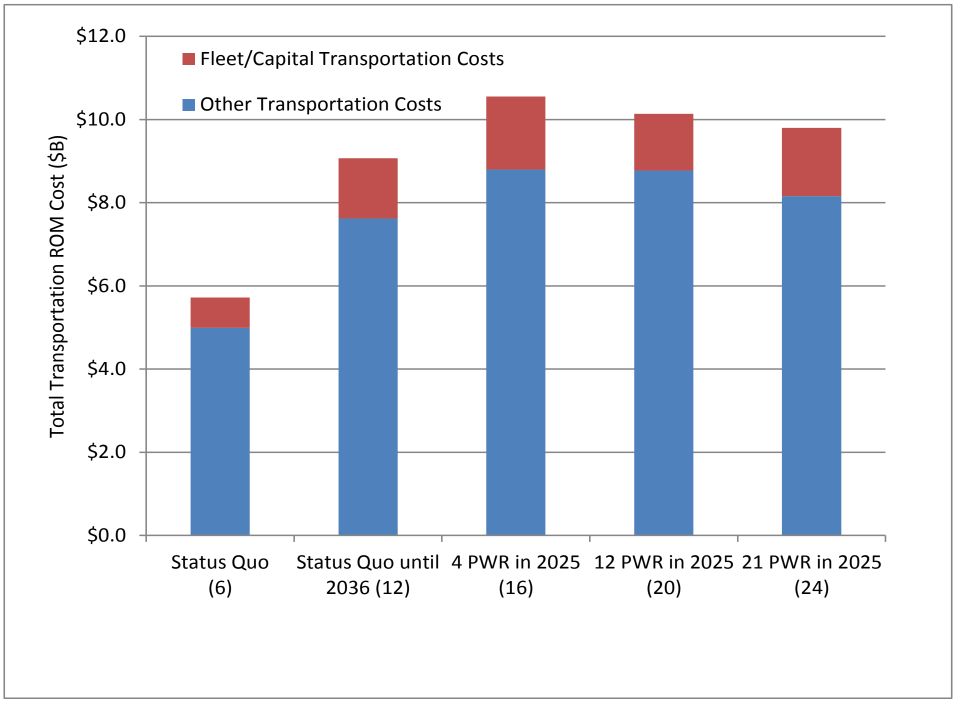

Figure 59. Transportation ROM costs when disposing of a 12 PWR WP using different initial canister loading strategies with an ISF (scenario IDs: 6, 12, 16, 20, and 24).

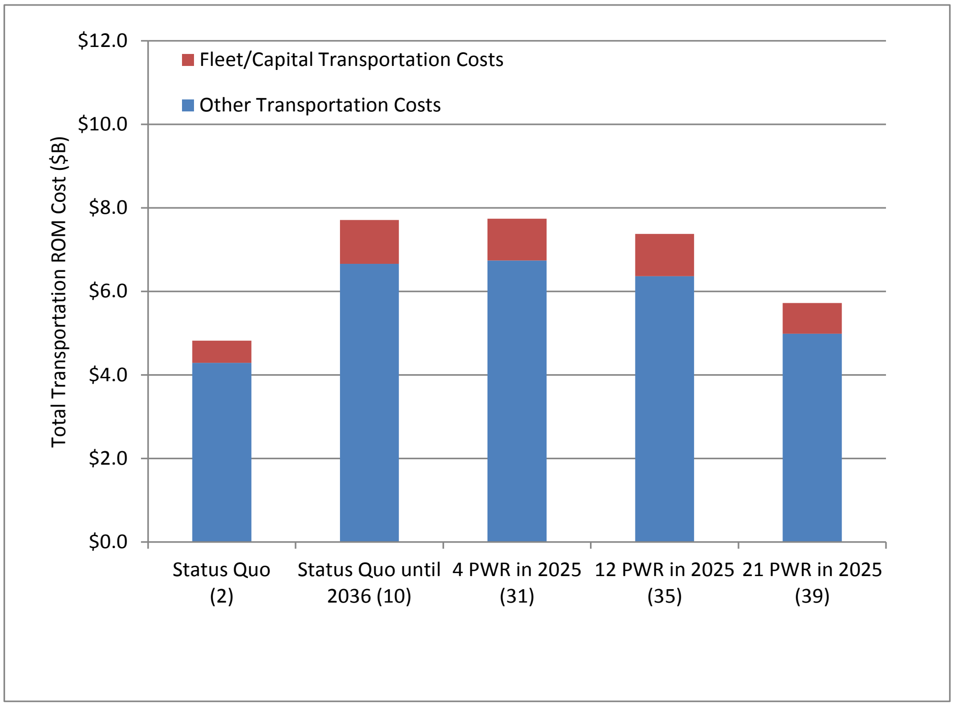

Figure 60. Transportation ROM costs when disposing of a 12 PWR WP using different initial canister loading strategies without an ISF (scenario IDs: 2, 10, 31, 35, and 39).

The other transportation costs (including operational costs) are proportional to the number of cask (or consist) miles as illustrated in Figure 61.

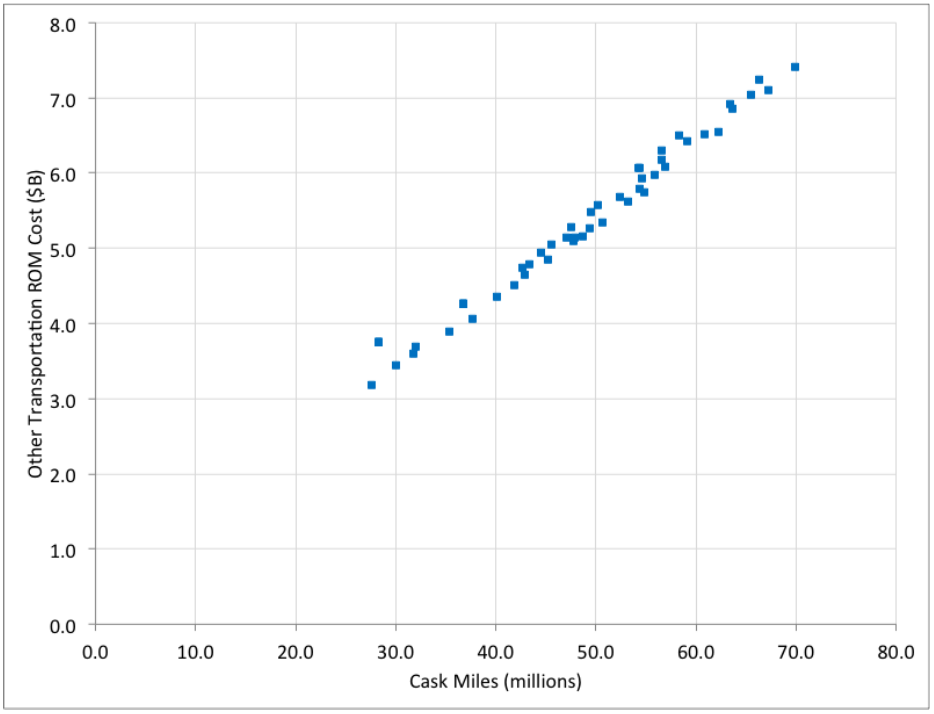

Figure 61. Operational Transportation ROM costs as a function of cask miles for all scenarios.

5.6 Qualitative Scenario Discussion

While the cost and logistics of the different scenarios can be quantitatively compared, a number of metrics are qualitative. These metrics may always be qualitative (e.g., licensing complexity, research and development [R&D] costs), or the metrics may require additional information to become quantitative (e.g., dose, SNF loading times). The qualitative metrics discussed briefly below are R&D costs, waste handling complexity, SNF loading times, organizational impacts, worker dose, licensing complexity, and system performance uncertainties and risk.

The R&D costs are going to be higher for those scenarios where innovative or advanced activities are required. This is a scenario differentiator when SNF may be stored in a manner that has not previously been implemented (e.g., large-scale bare fuel wet and/or vault storage) or new operations at facilities (e.g., reactors, repackaging facility). The scenarios that require repackaging or utilize multicanister overpacks for storage and/or transportation will most likely have a higher R&D cost than those scenarios without.

Waste handling complexity increases for bare fuel and repackaging operations. Bare fuel transportation and storage will require additional fuel handling of individual assemblies, which increases the complexity of structures and systems deployed at an ISF or a geologic repository operations area (Ref. 16). Any time bare fuel is handled there is increased potential for off-normal conditions (e.g., fuel damage) (Ref. 17). Repackaging requires handling individual assemblies and carries all of the associated complexities plus the additional complexity of opening DPCs and dealing with the associated LLW (Refs. 18, 19, and 20). Recognizing that some repackaging operations may be necessary at some point in the future, a waste management system that includes scenarios with standardized canisters offers the potential to reduce waste handling complexity system-wide and is within the state-of-the-art (Refs. 8, 5, and 21).

The SNF loading times and worker dose associated with loading and repackaging are metrics that cannot currently be estimated without large uncertainty because there is little available historic perspective. DOE is actively issuing SOWs to industry contractors to generate/estimate this data.

Organization impact includes the staffing needs of the facilities in different scenarios. Without more detailed concepts of operations, it would be premature to quantify this metric. However, it is realistic to assume that as more canisters are handled (and facilities become larger) facility staffing needs will increase. Therefore, those scenarios with the largest number of canisters and casks (generally 4 PWR scenarios) would have the largest impact on the staffing of those facilities.

Regulatory complexity includes the challenges associated with certification of the canisters and licensing the facilities in the scenario. In this current evaluation, all canisters are assumed to be right circular welded cylinders made of stainless steel. Certification of the canisters (at least for the storage and transportation functions) is assumed to have little complexity. However, certification of the multicanister overpacks (4 PWR and 12 PWR scenarios) may be more complex. The repackaging facility also has licensing risk.

Finally, the system performance uncertainties and risk pertain to the ability to adapt to future changes. The flexibility from a disposal perspective of smaller canisters is greater than that of the larger canisters, since smaller canister concepts are compatible with a wider range of geologic disposal concepts(Refs. 5 and 9). However, as observed in this initial assessment (see preliminary observations below), this additional flexibility may come with additional cost.

6. PRELIMINARY OBSERVATIONS

There are several observations regarding the results of this initial evaluation.

4 PWR canisters may be the most expensive and most challenging option from a waste management system operations perspective. Even if the WP is determined to be a 4 PWR-sized canister, the system analysis tools (based on current assumptions and input selections) suggest that it might be more cost effective to continue loading any larger canister concept. The results are highly dependent on and sensitive to the assumptions for at-reactor loading operations and associated costs, as well as the repackaging assumptions and associated cost. Results are also dependent on the assumptions about the receipt rate and acceptance priorities. Therefore, it will be important to refine the technical bases and data associated with at-reactor loading operations and repackaging facility concepts in future systems studies, design studies, concept of operations, and process flows, and to consider a wider range of receipt rates and acceptance priorities. The logistical challenges associated with managing (loading, storing, and transporting, etc.) up to eight times more canisters than the current DPC strategy can be inferred from the results in Section 6 and Appendix A. These logistical challenges and their associated increases in system operational complexity will be further investigated and quantified as repository concepts and costs are assimilated into the standardized canister system evaluation.

The 12 PWR, 21 PWR, and current DPC strategy have fairly equivalent relative system ROM costs regardless of the WP size. The 12 PWR canisters show some attraction due the higher likelihood for direct disposal without repackaging. However, the wait–and-see approach (i.e., continuing to load DPCs until the WP size is known) shows similar cost estimates and would avoid impacting utility operations until additional repository details are known. This observation is driven by the modest repackaging ROM costs when compared to at-reactor storage and loading ROM costs. This further supports the need to refine the technical bases and data associated with at-reactor loading operations and repackaging facility concepts in future systems studies, design studies, concept of operations, and process flows.

Standardization strategies incorporated into the scenarios examined do not significantly influence the ability to remove SNF from shutdown reactors for a given acceptance rate. The opening date of an ISF has a much stronger effect on the ability to remove all of the SNF from a shutdown reactor site. However, if higher acceptance rates and/or acceptance priorities aimed at clearing shutdown sites as quickly as possible were assumed, standardized canisters may be able to clear sites faster due to their lack of transportation limitations (some DPCs are not immediately transportable due to thermal and dose constraints). The assumption that thermal loads would not limit transportation would need to be confirmed once more detailed standardized canister designs are known. It may be useful to examine such scenarios to explore this possibility.

The addition of an ISF that accepts only canisters to the system does not change the relative impacts of standardization. The benefits of such an ISF are separate from those of standardization in this evaluation. However, this evaluation did not address strategies that involve the acceptance of bare fuel from the reactor sites even though bare fuel is the only acceptable waste form for acceptance under the Standard Contract,.

From a relative system ROM cost perspective, the at-reactor costs were the bulk of the system costs as they ranged from 36% to 91% of the total cost. The ISF was never more than 21% of the relative system cost, and if repackaging was required, it ranged between 12% and 41% of the total. The transportation costs made up less than 16% of the total costs in all scenarios. Note that the repository ROM costs (excluded in this initial evaluation) are expected to be a substantial portion of the total system costs for all scenarios. Multiple repository design concepts for different geologic media have been developed (Ref. 5). Therefore, it is important to include consideration of these concepts in future system evaluations.

7. FUTURE ACTIVITIES

One of the goals of the larger standardization assessment is to quantify the potential system benefits associated with:

- Increased flexibility and/or reduced sensitivity to future decisions and changes to waste management requirements
- Simplified handling and licensing at an interim storage, repackaging, or reprocessing facility and/or repository (Ref. 8)
- Simplified transportation hardware and operations
- Simplified ISF design and operations
- Reduced uncertainties associated with waste acceptance and system performance

In order to accurately quantify these benefits and to gain confidence in the evaluation observations, some questions need to be addressed.

- How accurate are the at-reactor loading costs for small canisters and how sensitive are the observations to uncertainties in this parameter?
- How accurate are the capital costs for smaller canisters and how sensitive are the observations to uncertainties in this parameter?
- Are the multi-canister concepts used in this evaluation realistic? Are there other concepts that should be evaluated?
- What are the cost and operational impacts of repackaging standardized canisters (e.g., 12 PWR, 21 PWR) into smaller (e.g., 4 PWR) canisters?

As these questions are answered, the fidelity of the evaluations will improve. Along with improved assumptions and evaluation parameters, the following scenarios will be explored in the next evaluation:

- Bare fuel movement from reactors to an ISF and subsequent implementation of standardization at the ISF
- Accelerated acceptance rates and/or alternative acceptance priority rankings based on conclusions from systems architecture studies (Refs. 2 and 15)
- Repository concepts specifically including the ROM costs to dispose different sized canisters in different geologic media
- Additional scenarios related to those analyzed in this evaluation

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Appendix A: Total Canisters in Storage At-Reactors By Year for Various Scenarios

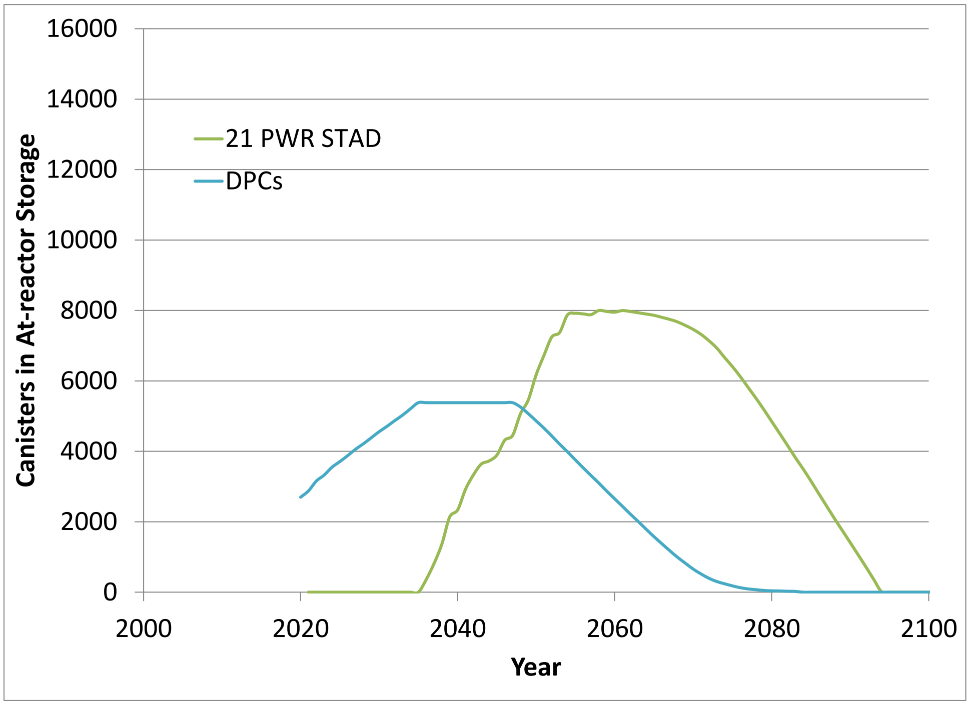

Figure A-1. Total canisters in storage at reactors for a scenario when 21-sized WPs begin being loaded at reactors in 2036 and where no ISF is incorporated into the system in 2025 (scenario ID: 11).

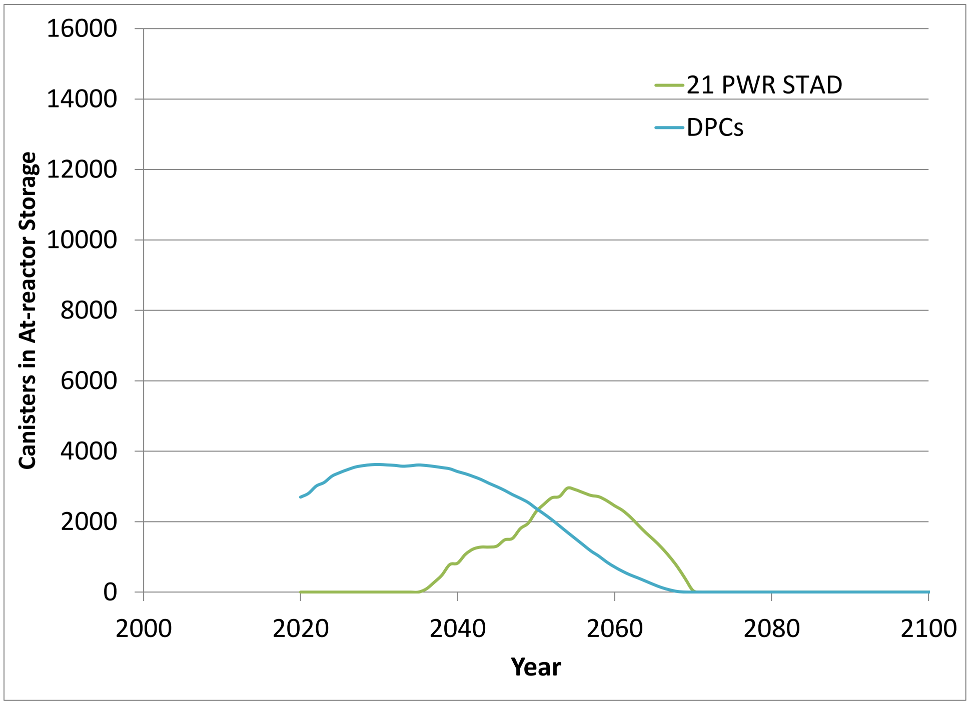

Figure A-2. Total canisters in storage at reactors for a scenario when 21-sized WPs begin being loaded at reactors in 2036 and where an ISF is incorporated into the system (scenario ID: 14).

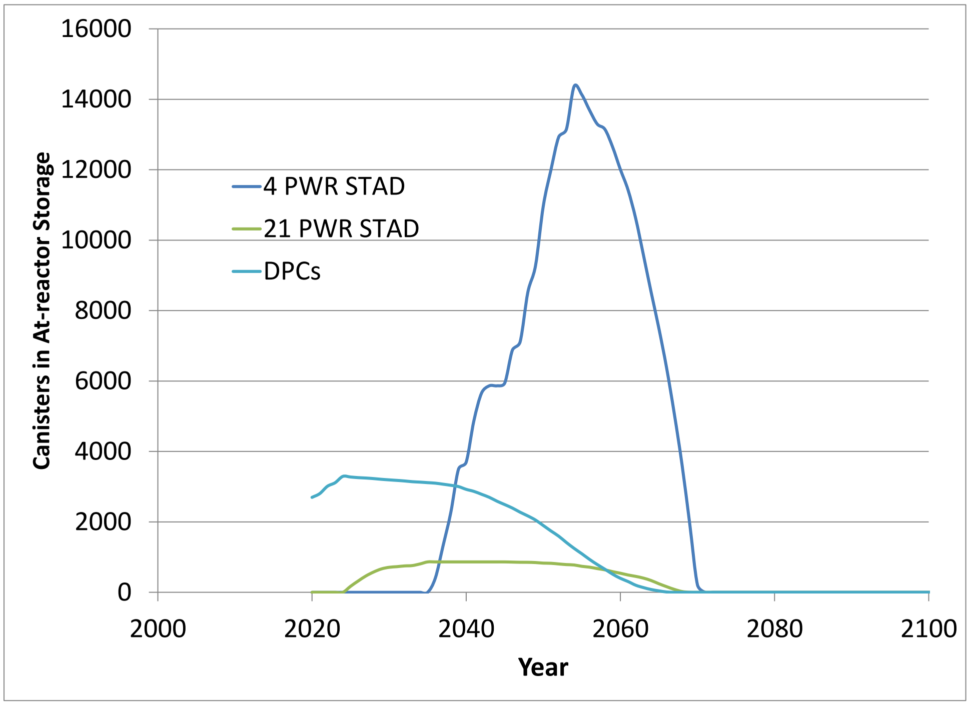

Figure A-3. Total canisters in storage at reactors for a scenario when 21 PWR standardized canisters begin being loaded at reactors in 2025 and a 4 PWR WP is selected in 2036 and where an ISF is incorporated into the system in 2025 (scenario ID: 23).

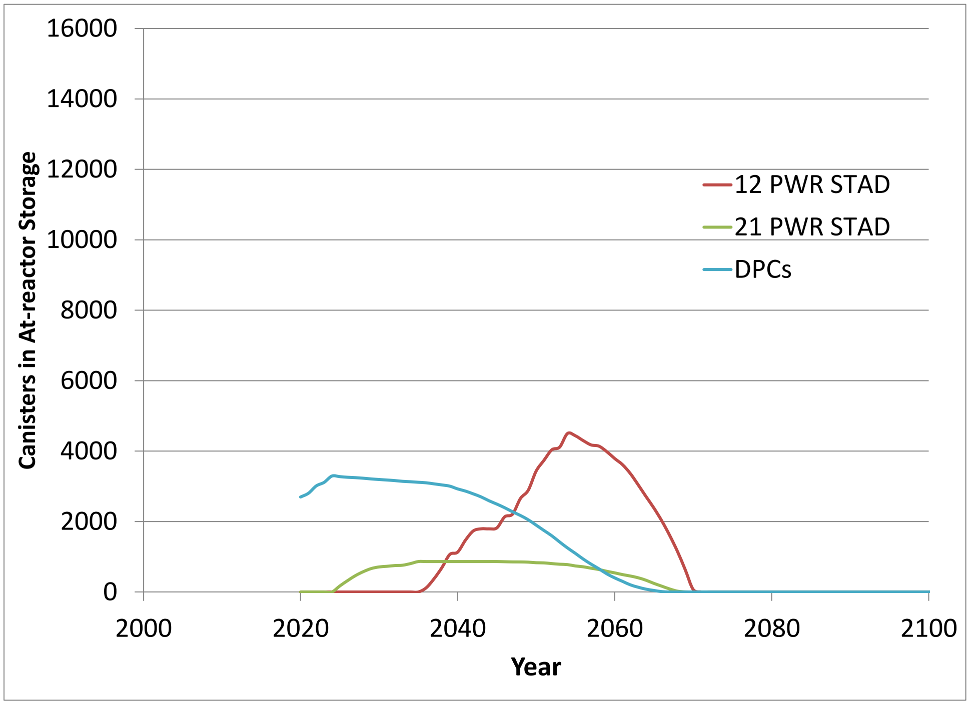

Figure A-4. Total canisters in storage at reactors for a scenario when 21 PWR standardized canisters begin being loaded at reactors in 2025 and a 12 PWR WP is selected in 2036 and where an ISF is incorporated into the system in 2025 (scenario ID: 24).

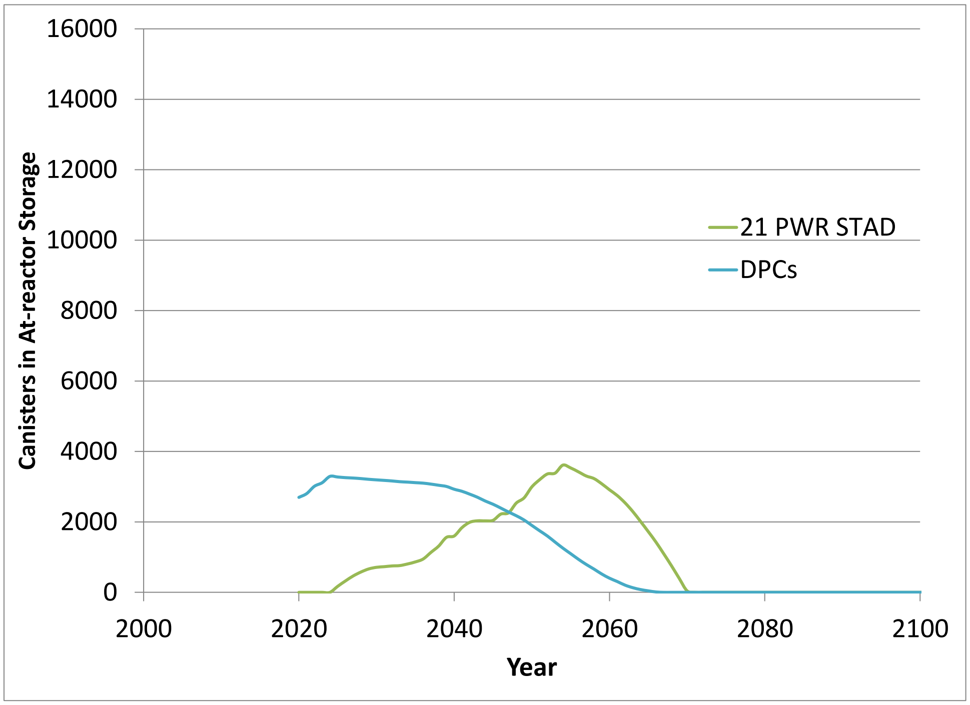

Figure A-5. Total canisters in storage at reactors for a scenario when 21 PWR standardized canisters begin being loaded at reactors in 2025 and a 21 PWR WP is confirmed in 2036 and where an ISF is incorporated into the system in 2025 (scenario ID: 25).

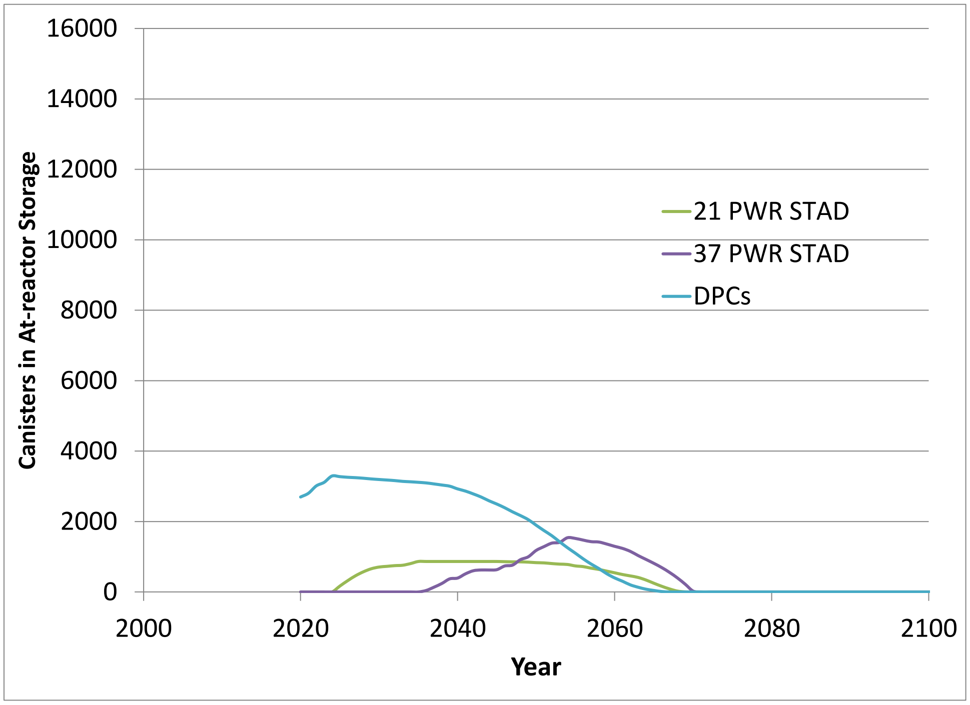

Figure A-6. Total canisters in storage at reactors for a scenario when 21 PWR standardized canisters begin being loaded at reactors in 2025 and a 37 PWR WP is selected in 2036 and where an ISF is incorporated into the system in 2025 (scenario ID: 26).

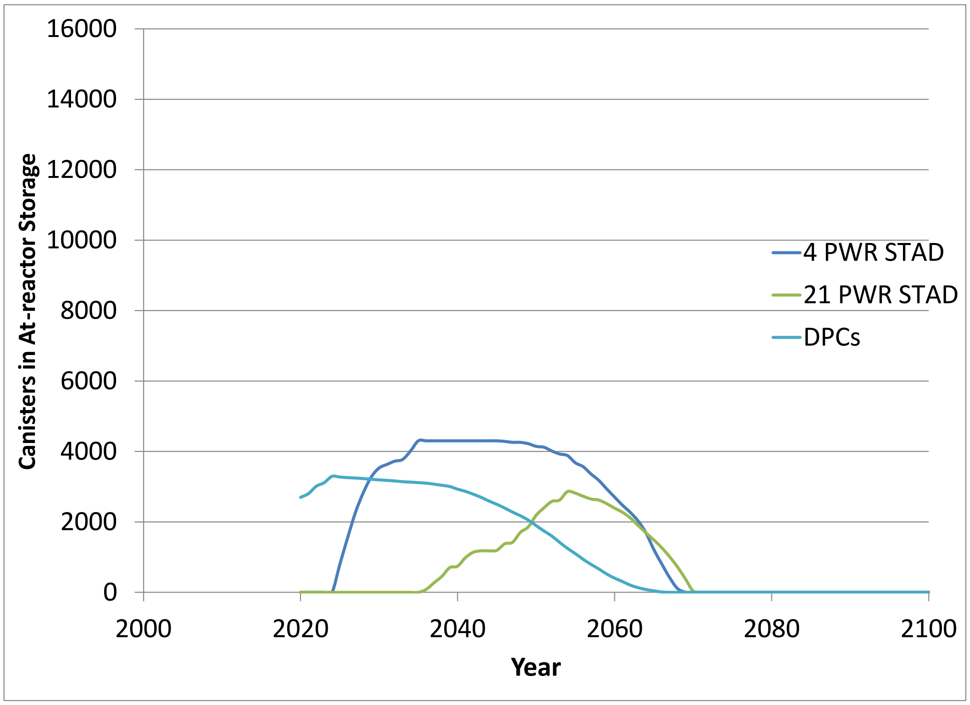

Figure A-7. Total canisters in storage at reactors for a scenario when 4 PWR standardized canisters begin being loaded at reactors in 2025 and a 21 PWR WP is selected in 2036 and where an ISF is incorporated into the system in 2025 (scenario ID: 17).

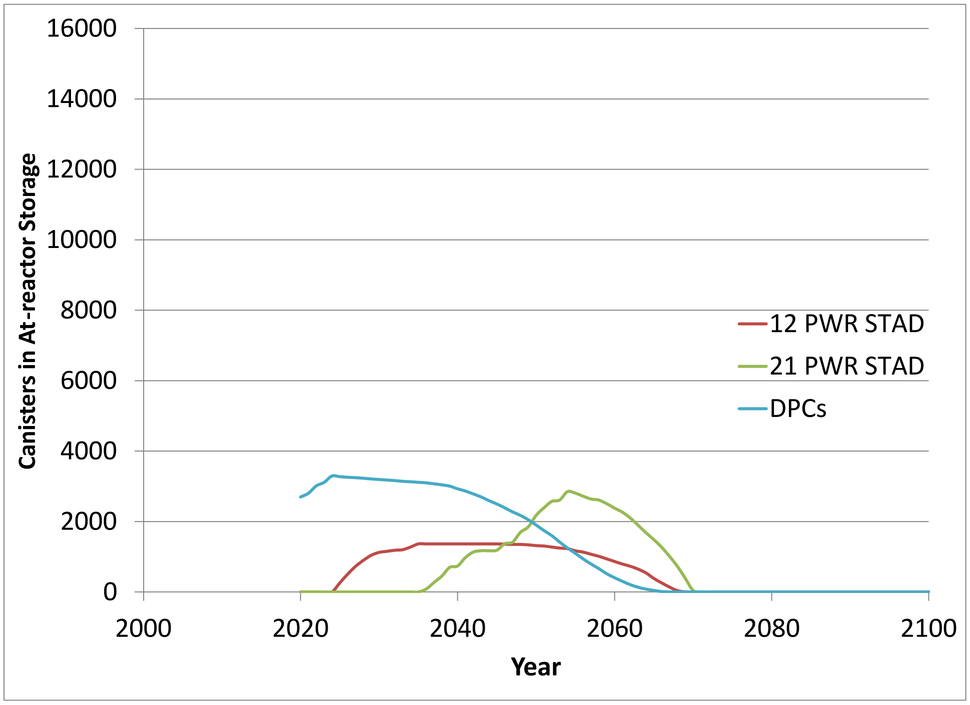

Figure A-8. Total canisters in storage at reactors for a scenario when 12 PWR standardized canisters begin being loaded at reactors in 2025 and a 21 PWR WP is selected in 2036 and where an ISF is incorporated into the system in 2025 (scenario ID: 21).

Table A-1. Maximum number of canisters in storage at reactors for each scenario.[22]

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	Maximum Number of 4 PWR Canisters in Storage	Maximum Number of 12 PWR Canisters in Storage	Maximum Number of 21 PWR Canisters in Storage	Maximum Number of 37 PWR Canisters in Storage	Maximum Number of DPCs in Storage	Maximum Number of Canisters (Any Type) in Storage
1	Status Quo	Class 1	DPCs loaded at-Rx; 4 PWR WPs repackaged at Repo(2048); no ISF	SQ 1.a	0	0	0	0	9,378	9,378
2	Status Quo	Class 1	DPCs loaded at-Rx; 12 PWR WP repackaged at Repo (2048); no ISF	SQ 1.b	0	0	0	0	9,378	9,378
3	Status Quo	Class 1	DPCs loaded at-Rx; 21 PWR WP repackaged at Repo (2048); no ISF	SQ 1.c	0	0	0	0	9,378	9,378
4	Status Quo	Class 1	DPCs loaded at-Rx; all DPCs disposable (2048); no ISF	SQ 1.d	0	0	0	0	9,378	9,378
5	Status Quo	Class 2	DPCs loaded at-Rx; 4 PWR WP Size repackaged at Repo (2048); ISF (2021)	SQ 2.a	0	0	0	0	4,107	4,107
6	Status Quo	Class 2	DPCs loaded at-Rx; 12 PWR WP Size repackaged at Repo (2048); ISF (2021)	SQ 2.b	0	0	0	0	4,107	4,107
7	Status Quo	Class 2	DPCs loaded at-Rx; 21 PWR WP Size repackaged at Repo (2048); ISF (2021)	SQ 2.c	0	0	0	0	4,107	4,107
8	Status Quo	Class 2	DPCs loaded at-Rx; all DPCs disposable (2048); ISF (2021)	SQ 2.d	0	0	0	0	4,107	4,107
9	Status Quo	Class 3	4 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.a	40,729	0	0	0	5,382	46,111
10	Status Quo	Class 3	12 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.b	0	12,829	0	0	5,382	18,211
11	Status Quo	Class 3	21 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.c	0	0	8,000	0	5,382	13,382
12	Status Quo	Class 4	4 PWR WPs loaded at Rx (2036); Repo open (2048); ISF (2021)	SQ 4.a	14,959	0	0	0	3,624	18,583
13	Status Quo	Class 4	12 PWR WPs loaded at Rx (2036); Repo open (2048); ISF (2021)	SQ 4.b	0	4,704	0	0	3,624	8,328
14	Status Quo	Class 4	21 PWR WPs loaded at Rx (2036); Repo open (2048); ISF (2021)	SQ 4.c	0	0	2,953	0	3,624	6,577
15	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); ISF (2021)	SCS 1.4.2025.4.2036	18,316	0	0	0	3,293	21,609
16	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.4.2025.12.2036	4,303	4,526	0	0	3,293	12,122
17	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.4.2025.21.2036	4,303	0	2,862	0	3,293	10,458
18	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.4.2025.37.2036	4,303	0	0	1,547	3,293	9,143
19	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.12.2025.4.2036	14,391	1,365	0	0	3,293	19,049
20	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); ISF (2021)	SCS 1.12.2025.12.2036	0	5,745	0	0	3,293	9,038

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[22] As mentioned in Section 4.1.6, if the 37 PWR WP is feasible, all DPCs are assumed to be disposable.

Table A-1 Maximum number of canisters in storage at reactors for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	Maximum Number of 4 PWR Canisters in Storage	Maximum Number of 12 PWR Canisters in Storage	Maximum Number of 21 PWR Canisters in Storage	Maximum Number of 37 PWR Canisters in Storage	Maximum Number of DPCs in Storage	Maximum Number of Canisters (Any Type) in Storage
21	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.12.2025.21.2036	0	1,365	2,850	0	3,293	7,508
22	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.12.2025.37.2036	0	1,365	0	1,542	3,293	6,200
23	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.21.2025.4.2036	14,366	0	864	0	3,293	18,523
24	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.21.2025.12.2036	0	4,501	864	0	3,293	8,658
25	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); ISF (2021)	SCS 1.21.2025.21.2036	0	0	3,613	0	3,293	6,906
26	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.21.2025.37.2036	0	0	866	1,541	3,293	5,700
27	Standardized Canister	Class 2	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 2.4.2025.4.2036	26,642	0	0	0	3,549	30,191
28	Standardized Canister	Class 2	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 2.12.2025.12.2036	0	8,351	0	0	3,549	11,900
29	Standardized Canister	Class 2	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 2.21.2025.21.2036	0	0	5,249	0	3,549	8,798
30	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.4.2025.4.2036	53,557	0	0	0	3,549	57,106
31	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.12.2036	13,672	12,809	0	0	3,549	30,030
32	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.21.2036	13,672	0	7,994	0	3,549	25,215
33	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.37.2036	13,672	0	0	4,328	3,549	21,549
34	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.4.2036	40,597	4,320	0	0	3,549	48,466
35	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.12.2025.12.2036	0	16,822	0	0	3,549	20,371
36	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.21.2036	0	4,320	7,972	0	3,549	15,841
37	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.37.2036	0	4,320	0	4,318	3,549	12,187
38	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.4.2036	40,530	0	2,710	0	3,549	46,789
39	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.12.2036	0	12,759	2,710	0	3,549	19,018

Table A-1 Maximum number of canisters in storage at reactors for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	Maximum Number of 4 PWR Canisters in Storage	Maximum Number of 12 PWR Canisters in Storage	Maximum Number of 21 PWR Canisters in Storage	Maximum Number of 37 PWR Canisters in Storage	Maximum Number of DPCs in Storage	Maximum Number of Canisters (Any Type) in Storage
40	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.21.2025.21.2036	0	0	10,518	0	3,549	14,067
41	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.37.2036	0	0	2,710	4,309	3,549	10,568
42	Standardized Canister	Class 4	4 PWR STADs loaded at Rx (2030); 4 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 4.4.2030.4.2036	21,018	0	0	0	4,129	25,147
43	Standardized Canister	Class 4	12 PWR STADs loaded at Rx (2030); 12 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 4.12.2030.12.2036	0	6,595	0	0	4,129	10,724
44	Standardized Canister	Class 4	21 PWR STADs loaded at Rx (2030); 21 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 4.21.2030.21.2036	0	0	4,150	0	4,129	8,279
45	Standardized Canister	Class 5	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2030); Repo open (2042); ISF (2021)	SCS 5.4.2025.21.2030	3,273	0	3,033	0	3,293	9,599
46	Standardized Canister	Class 5	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2030); Repo open (2042); ISF (2021)	SCS 5.12.2025.21.2030	0	1,042	3,026	0	3,293	7,361
47	Standardized Canister	Class 5	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2030); Repo open (2042); ISF (2021)	SCS 5.12.2025.4.2030	15,281	1,042	0	0	3,293	19,616
48	Standardized Canister	Class 5	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2030); Repo open (2042); ISF (2021)	SCS 5.21.2025.4.2030	15,226	0	665	0	3,293	19,184
49	Standardized Canister	Class 6	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2040); Repo open (2050); ISF (2021)	SCS 6.4.2025.21.2040	7,799	0	2,263	0	3,293	13,355
50	Standardized Canister	Class 6	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2040); Repo open (2050); ISF (2021)	SCS 6.12.2025.21.2040	0	2,428	2,255	0	3,293	7,976
51	Standardized Canister	Class 6	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2040); Repo open (2050); ISF (2021)	SCS 6.12.2025.4.2040	11,448	2,428	0	0	3,293	17,169
52	Standardized Canister	Class 6	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2040); Repo open (2050); ISF (2021)	SCS 6.21.2025.4.2040	11,416	0	1,561	0	3,293	16,270

Appendix B: At-Reactor ROM Cost Breakdown

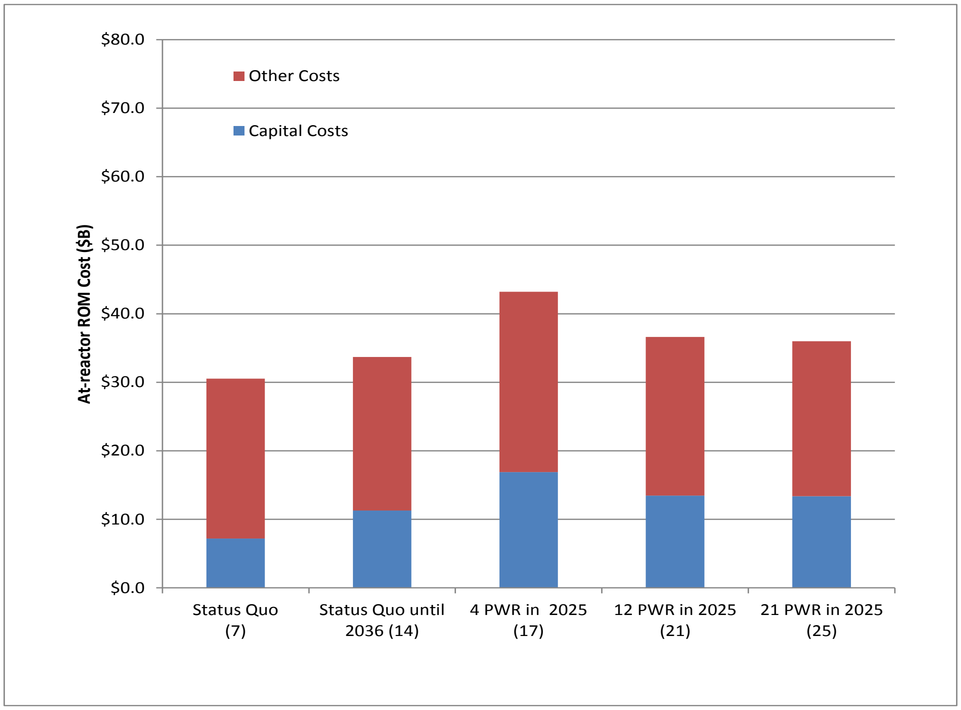

Figure B-1. At-reactor ROM cost for different starting canisters disposing in 21 WP with an ISF (scenario IDs: 7, 14, 17, 21, and25).

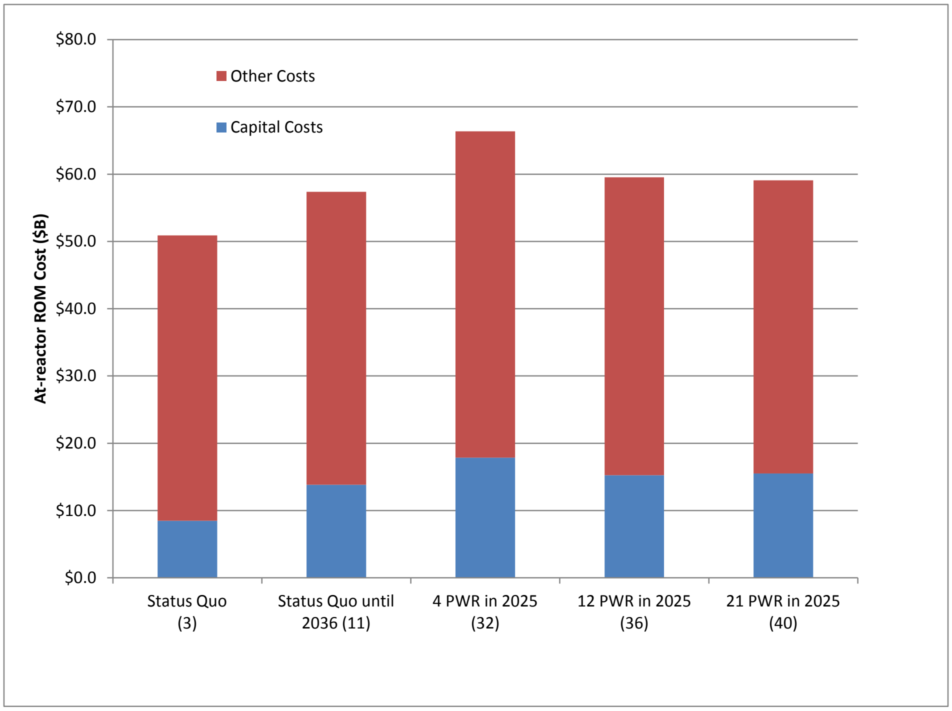

Figure B-2. At-reactor ROM cost for different starting canisters disposing in 21 WP without an ISF (scenario IDs: 3, 11, 32, 36, and 40).

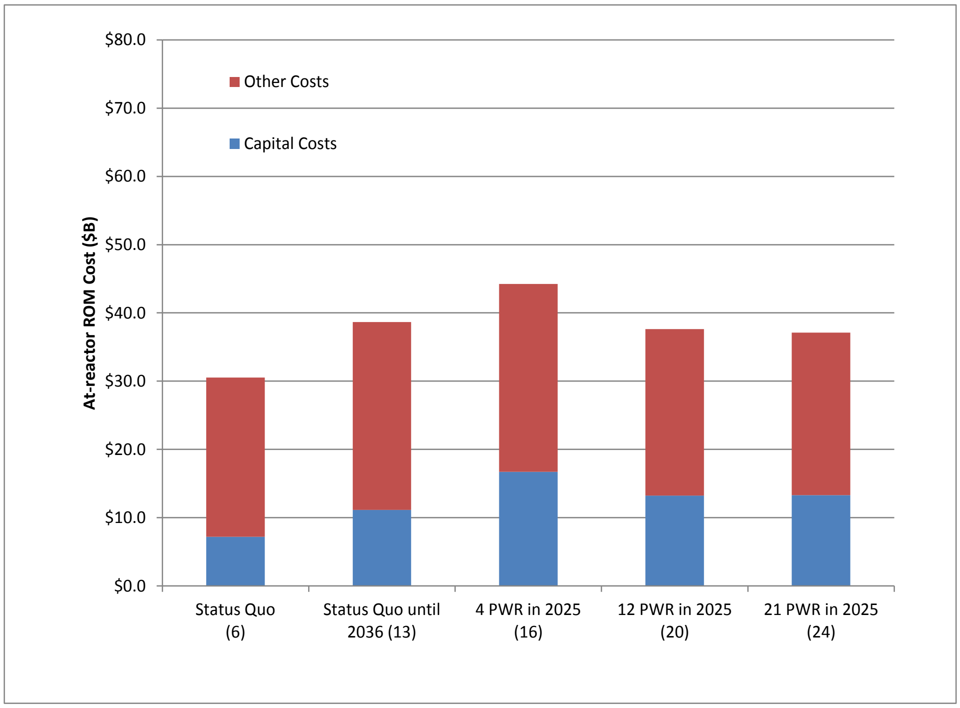

Figure B-3. At-reactor ROM cost for different starting canisters disposing in 12 WP with an ISF (scenario IDs: 6, 13, 16, 20, and 24).

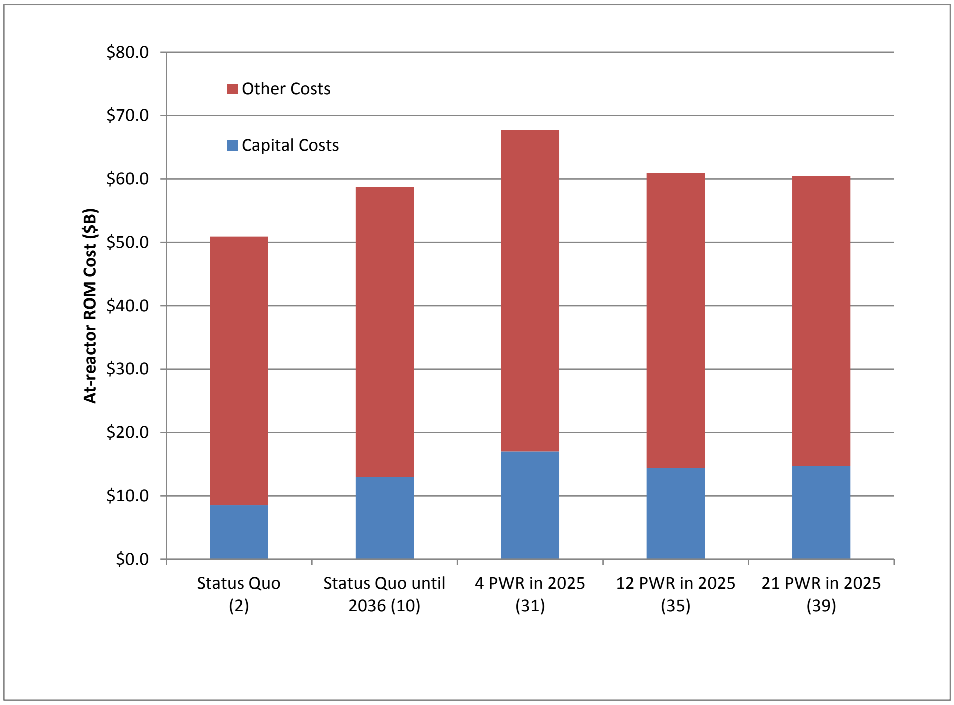

Figure B-4. At-reactor ROM cost for different starting canisters disposing in 12 WP without an ISF (scenario IDs: 2, 10, 31, 35, and 39).

Table B-1. Detailed at-reactor costs ($B) for each scenario[23].

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	ISFSI Site Construction Costs	At-reactor ISFSI Operations Costs (if Pool/Reactor Operational)	At-reactor ISFSI Operations Costs (After Reactor Shutdown)	At-reactor Loading into Dry Storage Costs	At-reactor Loading Dry Storage Canisters for Shipment Costs	At-reactor New Dry Storage Canisters/Over packs Costs	At-reactor New Canisters for Pool Transport Costs	Total at-reactor Costs
1	Status Quo	Class 1	DPCs loaded at-Rx; 4 PWR WPs repackaged at Repo(2048); no ISF	SQ 1.a	$0.2	$1.6	$33.6	$3.4	$3.6	$8.5	$0.0	$50.9
2	Status Quo	Class 1	DPCs loaded at-Rx; 12 PWR WP repackaged at Repo (2048); no ISF	SQ 1.b	$0.2	$1.6	$33.6	$3.4	$3.6	$8.5	$0.0	$50.9
3	Status Quo	Class 1	DPCs loaded at-Rx; 21 PWR WP repackaged at Repo (2048); no ISF	SQ 1.c	$0.2	$1.6	$33.6	$3.4	$3.6	$8.5	$0.0	$50.9
4	Status Quo	Class 1	DPCs loaded at-Rx; all DPCs disposable (2048); no ISF	SQ 1.d	$0.2	$1.6	$33.6	$3.4	$3.6	$8.5	$0.0	$50.9
5	Status Quo	Class 2	DPCs loaded at-Rx; 4 PWR WP Size repackaged at Repo (2048); ISF (2021)	SQ 2.a	$0.2	$1.5	$16.3	$1.6	$3.7	$4.0	$3.2	$30.5
6	Status Quo	Class 2	DPCs loaded at-Rx; 12 PWR WP Size repackaged at Repo (2048); ISF (2021)	SQ 2.b	$0.2	$1.5	$16.3	$1.6	$3.7	$4.0	$3.2	$30.5
7	Status Quo	Class 2	DPCs loaded at-Rx; 21 PWR WP Size repackaged at Repo (2048); ISF (2021)	SQ 2.c	$0.2	$1.5	$16.3	$1.6	$3.7	$4.0	$3.2	$30.5
8	Status Quo	Class 2	DPCs loaded at-Rx; all DPCs disposable (2048); ISF (2021)	SQ 2.d	$0.2	$1.5	$16.3	$1.6	$3.7	$4.0	$3.2	$30.5
9	Status Quo	Class 3	4 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.a	$0.2	$1.6	$33.5	$14.3	$9.2	$20.8	$0.3	$79.9
10	Status Quo	Class 3	12 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.b	$0.2	$1.6	$33.5	$5.7	$4.8	$12.9	$0.1	$58.8
11	Status Quo	Class 3	21 PWR WPs loaded at Rx (2036); Repo open (2048); no ISF	SQ 3.c	$0.2	$1.6	$33.5	$4.2	$4.0	$13.7	$0.2	$57.4
12	Status Quo	Class 4	4 PWR WPs loaded at Rx (2036); Repo open (2048); ISF (2021)	SQ 4.a	$0.2	$1.5	$14.9	$5.9	$8.2	$8.8	$8.1	$47.6

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[23] As mentioned in Section 3.1.6, if the 37 PWR standardized canister is assumed to be disposable, all DPCs are also assumed to be disposable.

Table B-1. Detailed at-reactor costs ($B) for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	ISFSI Site Construction Costs	At-reactor ISFSI Operations Costs (if Pool/Reactor Operational)	At-reactor ISFSI Operations Costs (After Reactor Shutdown)	At-reactor Loading into Dry Storage Costs	At-reactor Loading Dry Storage Canisters for Shipment Costs	At-reactor New Dry Storage Canisters/Over packs Costs	At-reactor New Canisters for Pool Transport Costs	Total at-reactor Costs
13	Status Quo	Class 4	12 PWR WPs loaded at Rx (2036); Repo open (2048); ISF (2021)	SQ 4.b	$0.2	$1.5	$14.9	$2.5	$4.6	$5.7	$5.5	$34.8
14	Status Quo	Class 4	21 PWR WPs loaded at Rx (2036); Repo open (2048); ISF (2021)	SQ 4.c	$0.2	$1.5	$14.9	$1.9	$3.9	$6.0	$5.3	$33.7
15	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); ISF (2021)	SCS 1.4.2025.4.2036	$0.2	$1.6	$14.9	$6.8	$11.0	$9.8	$12.6	$56.8
16	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.4.2025.12.2036	$0.2	$1.6	$14.9	$3.5	$7.4	$6.7	$10.0	$44.3
17	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.4.2025.21.2036	$0.2	$1.6	$14.9	$3.0	$6.8	$7.1	$9.8	$43.2
18	Standardized Canister	Class 1	4 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.4.2025.37.2036	$0.2	$1.6	$14.9	$2.5	$6.3	$5.3	$8.3	$38.9
19	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.12.2025.4.2036	$0.2	$1.6	$14.9	$5.9	$8.7	$8.9	$10.1	$50.3
20	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); ISF (2021)	SCS 1.12.2025.12.2036	$0.2	$1.6	$14.9	$2.6	$5.1	$5.9	$7.4	$37.6
21	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.12.2025.21.2036	$0.2	$1.6	$14.9	$2.1	$4.5	$6.2	$7.2	$36.6
22	Standardized Canister	Class 1	12 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.12.2025.37.2036	$0.2	$1.6	$14.9	$1.6	$4.0	$4.4	$5.7	$32.4

Table B-1. Detailed at-reactor costs ($B) for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	ISFSI Site Construction Costs	At-reactor ISFSI Operations Costs (if Pool/Reactor Operational)	At-reactor ISFSI Operations Costs (After Reactor Shutdown)	At-reactor Loading into Dry Storage Costs	At-reactor Loading Dry Storage Canisters for Shipment Costs	At-reactor New Dry Storage Canisters/Over packs Costs	At-reactor New Canisters for Pool Transport Costs	Total at-reactor Costs
23	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.21.2025.4.2036	$0.2	$1.5	$14.9	$5.8	$8.3	$9.0	$10.0	$49.7
24	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.21.2025.12.2036	$0.2	$1.5	$14.9	$2.5	$4.7	$6.0	$7.3	$37.1
25	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); ISF (2021)	SCS 1.21.2025.21.2036	$0.2	$1.5	$14.9	$1.9	$4.1	$6.3	$7.1	$36.0
26	Standardized Canister	Class 1	21 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); ISF (2021)	SCS 1.21.2025.37.2036	$0.2	$1.5	$14.9	$1.5	$3.4	$4.5	$4.0	$30.0
27	Standardized Canister	Class 2	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 2.4.2025.4.2036	$0.2	$1.6	$18.6	$9.6	$11.0	$13.4	$9.6	$63.9
28	Standardized Canister	Class 2	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 2.12.2025.12.2036	$0.2	$1.6	$18.6	$3.6	$5.1	$7.9	$5.6	$42.6
29	Standardized Canister	Class 2	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 2.21.2025.21.2036	$0.2	$1.6	$18.6	$2.6	$4.1	$8.5	$5.4	$41.0
30	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 4 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.4.2025.4.2036	$0.2	$1.6	$33.2	$17.9	$11.0	$24.8	$0.3	$88.9
31	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.12.2036	$0.2	$1.6	$33.2	$9.2	$6.6	$16.9	$0.2	$67.8
32	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.21.2036	$0.2	$1.6	$33.2	$7.8	$5.8	$17.7	$0.2	$66.4

Table B-1. Detailed at-reactor costs ($B) for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	ISFSI Site Construction Costs	At-reactor ISFSI Operations Costs (if Pool/Reactor Operational)	At-reactor ISFSI Operations Costs (After Reactor Shutdown)	At-reactor Loading into Dry Storage Costs	At-reactor Loading Dry Storage Canisters for Shipment Costs	At-reactor New Dry Storage Canisters/Overpacks Costs	At-reactor New Canisters for Pool Transport Costs	Total at-reactor Costs
33	Standardized Canister	Class 3	4 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.4.2025.37.2036	$0.2	$1.6	$33.2	$6.6	$5.2	$13.0	$0.1	$59.9
34	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.4.2036	$0.2	$1.6	$33.2	$15.0	$9.6	$22.2	$0.3	$82.1
35	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 12 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.12.2025.12.2036	$0.2	$1.6	$33.2	$6.4	$5.2	$14.3	$0.2	$61.0
36	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.21.2036	$0.2	$1.6	$33.2	$4.9	$4.4	$15.1	$0.2	$59.5
37	Standardized Canister	Class 3	12 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.12.2025.37.2036	$0.2	$1.6	$33.2	$3.8	$3.8	$10.4	$0.1	$53.1
38	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.4.2036	$0.2	$1.6	$33.2	$14.5	$9.4	$22.4	$0.3	$81.6
39	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 12 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.12.2036	$0.2	$1.6	$33.2	$5.9	$4.9	$14.5	$0.2	$60.5
40	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 21 PWR WP confirmed (2036); Repo open (2048); no ISF	SCS 3.21.2025.21.2036	$0.2	$1.6	$33.2	$4.5	$4.2	$15.3	$0.2	$59.1
41	Standardized Canister	Class 3	21 PWR STADs loaded at Rx (2025); 37 PWR WP selected (2036); Repo open (2048); no ISF	SCS 3.21.2025.37.2036	$0.2	$1.6	$33.2	$3.3	$3.6	$10.7	$0.1	$52.6
42	Standardized Canister	Class 4	4 PWR STADs loaded at Rx (2030); 4 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 4.4.2030.4.2036	$0.2	$1.6	$18.6	$7.9	$10.2	$11.5	$9.7	$59.7
43	Standardized Canister	Class 4	12 PWR STADs loaded at Rx (2030); 12 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 4.12.2030.12.2036	$0.2	$1.6	$18.6	$3.3	$4.9	$7.2	$5.7	$41.5

Table B-1. Detailed at-reactor costs ($B) for each scenario (Continued)

Scenario #	Major Class	Scenario Class	Scenario Description	Scenario Description Numbering	ISFSI Site Construction Costs	At-reactor ISFSI Operations Costs (if Pool/Reactor Operational)	At-reactor ISFSI Operations Costs (After Reactor Shutdown)	At-reactor Loading into Dry Storage Costs	At-reactor Loading Dry Storage Canisters for Shipment Costs	At-reactor New Dry Storage Canisters/Over packs Costs	At-reactor New Canisters for Pool Transport Costs	Total at-reactor Costs
44	Standardized Canister	Class 4	21 PWR STADs loaded at Rx (2030); 21 PWR WP confirmed (2036); Repo open (2048); ISF (2026)	SCS 4.21.2030.21.2036	$0.2	$1.6	$18.6	$2.5	$4.1	$7.7	$5.4	$40.1
45	Standardized Canister	Class 5	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2030); Repo open (2042); ISF (2021)	SCS 5.4.2025.21.2030	$0.2	$1.6	$14.9	$2.7	$5.4	$6.9	$8.3	$39.9
46	Standardized Canister	Class 5	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2030); Repo open (2042); ISF (2021)	SCS 5.12.2025.21.2030	$0.2	$1.6	$14.9	$2.0	$4.3	$6.2	$7.1	$36.3
47	Standardized Canister	Class 5	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2030); Repo open (2042); ISF (2021)	SCS 5.12.2025.4.2030	$0.2	$1.6	$14.9	$6.2	$9.9	$9.1	$11.5	$53.3
48	Standardized Canister	Class 5	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2030); Repo open (2042); ISF (2021)	SCS 5.21.2025.4.2030	$0.2	$1.5	$14.9	$6.0	$9.7	$9.2	$11.5	$52.9
49	Standardized Canister	Class 6	4 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2040); Repo open (2050); ISF (2021)	SCS 6.4.2025.21.2040	$0.2	$1.6	$14.9	$3.8	$7.9	$7.6	$10.9	$46.8
50	Standardized Canister	Class 6	12 PWR STADs loaded at Rx (2025); 21 PWR WP selected (2040); Repo open (2050); ISF (2021)	SCS 6.12.2025.21.2040	$0.2	$1.6	$14.9	$2.2	$4.7	$6.1	$7.3	$36.9
51	Standardized Canister	Class 6	12 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2040); Repo open (2050); ISF (2021)	SCS 6.12.2025.4.2040	$0.2	$1.6	$14.9	$5.2	$7.7	$8.2	$9.2	$47.0
52	Standardized Canister	Class 6	21 PWR STADs loaded at Rx (2025); 4 PWR WP selected (2040); Repo open (2050); ISF (2021)	SCS 6.21.2025.4.2040	$0.2	$1.5	$14.9	$4.9	$7.2	$8.3	$9.1	$46.0

Appendix C: Input Data Assumptions

C-1. Direct Input Data

The data in this section are used directly (without modification) from the “Data Identification and Verification for Waste Management System Analyses” report (Ref. 22) and is shown in Table C-1.

Table C-1. General reference data used in this evaluation.

Description of Item	Value from Data Report
ISF location	Eastern US
SNF canister module capacity - vertical canisters	8
SNF canister module capacity - horizontal canisters	12
ISF infrastructure: number of managers for facility operation	7
ISF infrastructure: number of exempt staff for facility operation	30
ISF infrastructure: number of salaried staff for facility operation	39
Canister processing: crews per canister processing bay	0.5
Canister processing: number of managers for facility operation per crew	5
Canister processing: number of exempt staff for facility operation per crew	20
Canister processing: number of salaried staff for facility operation per crew	30
Repackaging facility infrastructure: number of managers for facility operation	7
Repackaging facility infrastructure: number of exempt staff for facility operation	30
Repackaging facility infrastructure: number of salaried staff for facility operation	39
Repackaging SNF disposal canister closure station: crews per station	0.125
Repackaging SNF disposal canister closure station: number of managers for facility operation per crew	9
Repackaging SNF disposal canister closure station: number of exempt staff for facility operation per crew	50
Repackaging SNF disposal canister closure station: number of salaried staff for facility operation per crew	86
Repository Location	Western US
At-reactor ISFSI operations cost per year (if pool/reactor operational)	$1M

At-reactor ISFSI operations cost per year (if pool/reactor shutdown)	$10M
At-reactor pool operations costs per year (if reactor shutdown)	$30M
At-reactor pool to ISFSI loading cost per campaign	$0.75M
At-reactor pool to transportation cask loading cost per campaign	$0.75M
At-reactor ISFSI to transportation cask loading cost per campaign	$0.75M
At-reactor ISFSI to transportation cask loading cost per cask[24]	$0.3M
Buffer railcar capital cost	$1.5M
Escort railcar capital cost	$6M
Cask trailer capital cost	$0.05M
Escort truck capital cost	$0.05M
ISF infrastructure cost[25]	$116.3M
ISF D&D cost: fraction of all capital costs	0.1
ISF canister processing bay capital cost	$73.8M
Dry storage module capital cost: vertical canisters (cost per module)	$8.2M
Dry storage module capital cost: horizontal canisters (cost per module)	$15.8M
Repackaging facility D&D cost: fraction of all Capital Costs	0.1
Barge speed	2 mph
Mainline rail track classes A, B, and C speed	55 mph
Mainline rail track classes G, H, and X speed and shortline rail	20 mph

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[24] The same loading costs are used for all canister/cask types

[25] This cost includes conceptual design, site improvement and infrastructure, and balance of plant.

C- 2. Evaluation-Specific Input data

This section lists data that were assumed for this evaluation or that are different than the data given in the reference listed in Section C-1 and are shown in Table C-2.

Table C-2. Evaluation-specific data used in this evaluation.

Description of Item	Assumption for Value
SNF canister module capacity - standard canisters	8
ISFSI construction costs	$25M
Cask railcar capital cost	$5M
Heavy haul truck speed	20 mph
Legal weight truck speed	20 mph
4PWR/9BWR standardized canister cost	$0.352M
12PWR/24BWR standardized canister cost	$0.655M
21PWR/44BWR standardized canister cost	$1.010M
37PWR/89BWR standardized canister cost	$1.050M
STAD overpack capital cost for all canister sizes	$0.3M
Repackaging facility infrastructure: infrastructure cost[26]	$116.3M
Repackaging canister opening station: capital cost	$47M
Repackaging canister closure station: capital cost	$38M
Repackaging canister receipt/release bay: capital cost	$159M
At-reactor pool to ISFSI loading cost per canister[27]	$0.3M
At-reactor pool to transportation cask loading cost per canister[28]	$0.3M
4PWR/9BWR: LLW generated per canister	2.5 m^3
12PWR/24BWR: LLW generated per canister	5.0 m^3
21PWR/44BWR, 37PWR/89BWR, and DPCs: LLW generated per canister	12.0 m^3
Cask opening time at repackaging facility[28]	600 minutes
Canister opening time at repackaging facility[29]	1,200 minutes

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[26] This cost includes conceptual design, site improvement and infrastructure, and balance of plant.

[27] The same loading costs are used for all canister types.

[28] The assumed opening time for all casks is the same regardless of cask size, capacity, etc.

[29] The assumed opening time for all canisters is the same regardless of canister size or capacity.

Description of Item	Assumption for Value
Canister closing time at repackaging facility[30]	1,500 minutes
Time required to handle a cask (e.g., receipt, shipment) at the ISF or the repackaging facility[31]	720 minutes

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[30] The assumed closing time for all canisters is the same regardless of canister size or capacity.

[31] The assumed move time for all casks is the same regardless of cask size, capacity, etc.