Cost Implications of an Interim Storage Facility in the Waste Management System

Fuel Cycle Research & Development

Prepared for
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Nuclear Fuels Storage and Transportation Planning Project

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HISTORY OF CHANGE

Rev. 0 (Draft)	Initial Issuance on 01-30-2015.
Rev. 1	Revised to incorporate comments from Department of Energy.

EXECUTIVE SUMMARY

This report provides an evaluation of the cost implications of incorporating a consolidated interim storage facility (ISF) into the waste management system (WMS). Specifically, the impacts of the timing of opening an ISF relative to opening a repository were analyzed to understand the potential effects on total system costs.

In this study, the following total system[a] costs[b] were calculated and tabulated as order of magnitude estimates:

- **At-reactor costs**, including independent spent fuel storage installation (ISFSI) operational and maintenance costs, spent fuel pool (SFP) operational and maintenance costs starting five years after the reactor shutdown, and all canister and overpack loading and procurement costs;
- **Transportation costs**, including fleet capital costs, operational costs, and maintenance costs; and
- **ISF costs**, including receipt and shipping facility capital and operational costs, storage pad and overpack costs, deactivation & decommissioning costs, and canisters purchased (only incurred in bare fuel scenarios).

This report documents evaluations of different scenarios involving shipment of spent nuclear fuel (SNF) from reactors in dual-purpose storage and transportation canisters (DPCs) currently being used by utilities for dry storage at reactor sites. In some scenarios, all fuel is shipped and stored in such canisters. In other scenarios, once a federal facility is available to accept it, bare fuel is shipped directly from the SFPs in reusable transportation casks where it is stored in DPCs at the ISF. For simplicity and conservatism in estimating cost impacts of incorporating an ISF facility, the detailed analysis presented in this report focuses on the scenarios in which fuel is stored and transported in DPCs. The focus on canister storage was selected because it is the current utility practice and has been for almost three decades. As such, it is appropriate to initially focus on canistered fuel storage as the basis for an economic evaluation of an ISF. Figure ES-1 illustrates total system costs for scenarios without an ISF and scenarios with a full-scale[c] ISF opening in 2025 with a repository becoming operational in 2040, 2050, or 2060. The cost differences between the scenarios with and without an ISF are also shown. A number of pertinent conclusions can be drawn from this evaluation, such as:

- **Delay in repository availability increases total system costs**. Any delay in opening a repository increases total system costs, regardless of whether the system has an ISF or not. This is due to the increased cost associated with an extended duration for storage, whether at an ISFSI or ISF, until such time as the waste can be disposed.
- **There is a (potentially large) total system lifecycle cost avoidance in all scenarios with an ISF when compared to scenarios with no ISF for the assumptions used in this study**. However, most of the cost avoidance occurs several decades after the ISF is opened. The total WMS cost differential over the long-term is mainly attributed to the reduced operational costs of

[a] "Total system" in this particular study is focused on management of commercial spent nuclear fuel (SNF) (not defense waste) and is defined as at-reactor, ISF, and transportation activities starting at the reactor until the SNF arrives at the repository. Repository and repackaging costs are not considered in this study and are not included in the total system costs because their costs are not expected to vary significantly between the different scenarios analyzed in this report. Since the system in this study includes activities associated with spent fuel management at reactor sites, it provides results from a broader societal or national perspective, as opposed to a more limited perspective associated with only the portion of the system managed by federal government.

[b] All costs are in year 2014 constant dollars.

[c] Full-scale refers to the ISF being fully operational. The full-scale ISF date is assumed to be preceded by four years of Pilot ISF operations. This Pilot ISF will focus on accepting fuel from the shutdown sites.

storing the fuel in a consolidated facility versus at individual reactor sites. Future work will explore the sensitivity of these results to assumptions related to the economic environment such as discount, escalation, and inflation rates.

- **Earlier establishment of an ISF allows for more avoidance of post-shutdown at-reactor storage costs for any repository opening date.** An ISF allows earlier acceptance of fuel from reactors, which reduces at-reactor costs from a total system perspective.

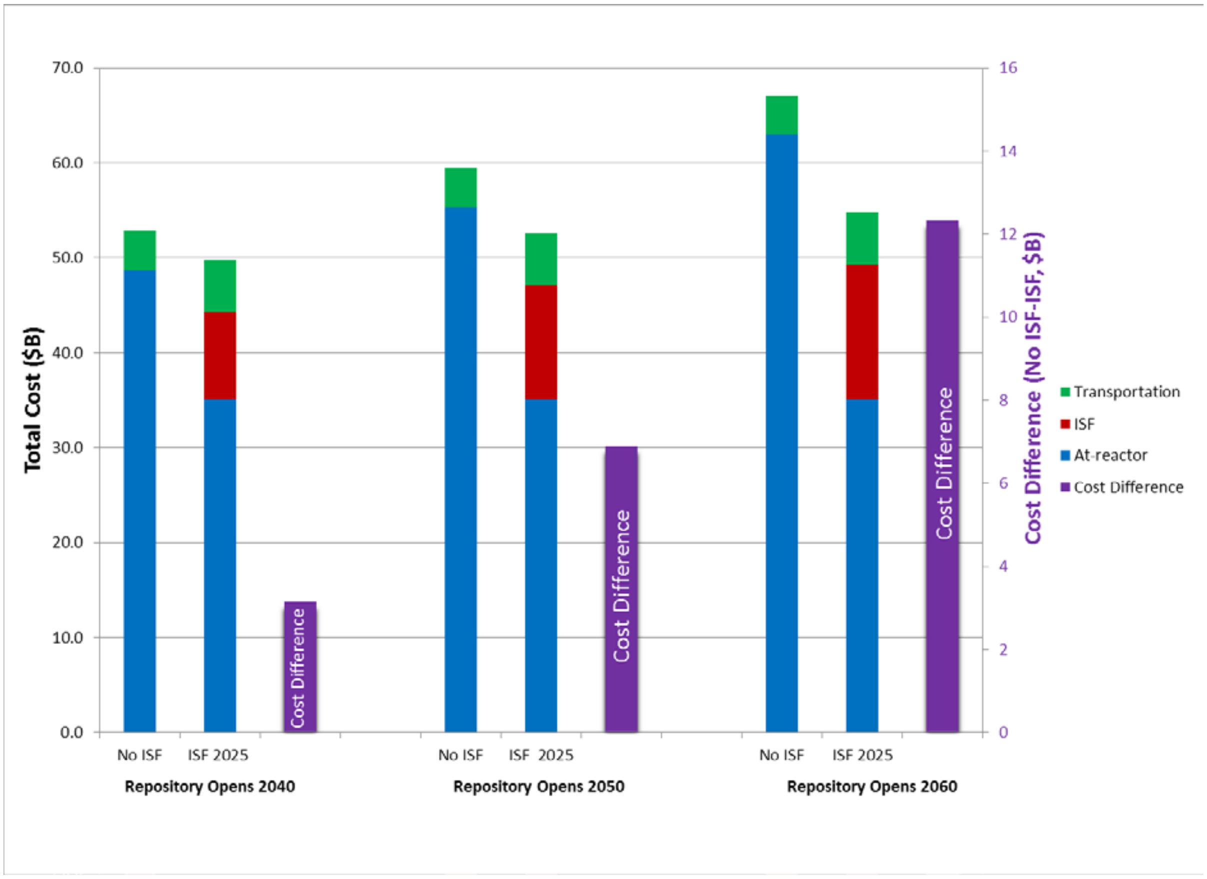

Figure ES-1. Total system costs (at-reactor, ISF, and transportation) for scenarios with no ISF and with a full-scale ISF start date of 2025 with a repository becoming operational in 2040, 2050, and 2060.

Figure ES-2 and Figure ES-3 illustrate that

- **Transportation costs have little impact on a waste management system with or without an ISF**. These impacts range from 3–11% of the total cost in all scenarios. Therefore, transporting the fuel twice does not appear to be a significant cost concern relative to other system costs.
- **At-reactor costs dominate the total system life-cycle cost**, while the ISF comprises ~20–21% of total costs.[d]

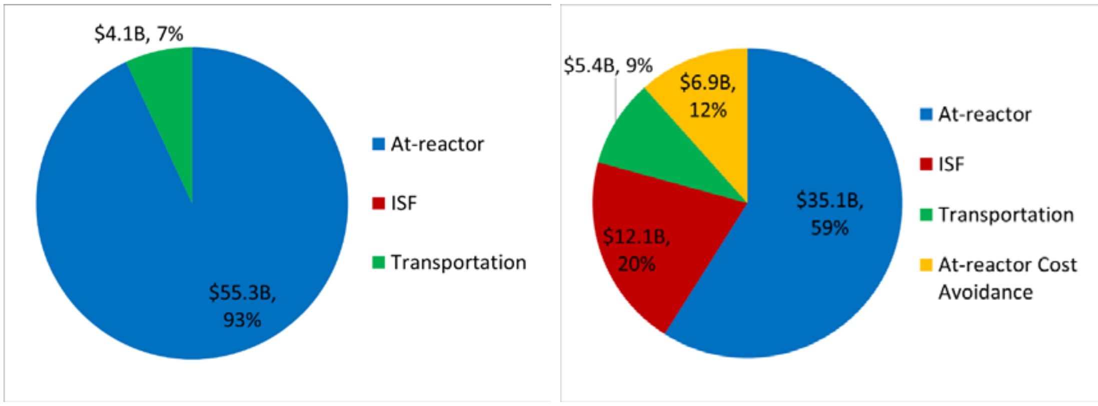

Figure ES-2. Cost breakdown for at-reactor, ISF, and transportation costs for scenarios without an ISF (left) and with a full-scale ISF opening in 2025 (right). Both scenarios assume a repository will open in 2050.

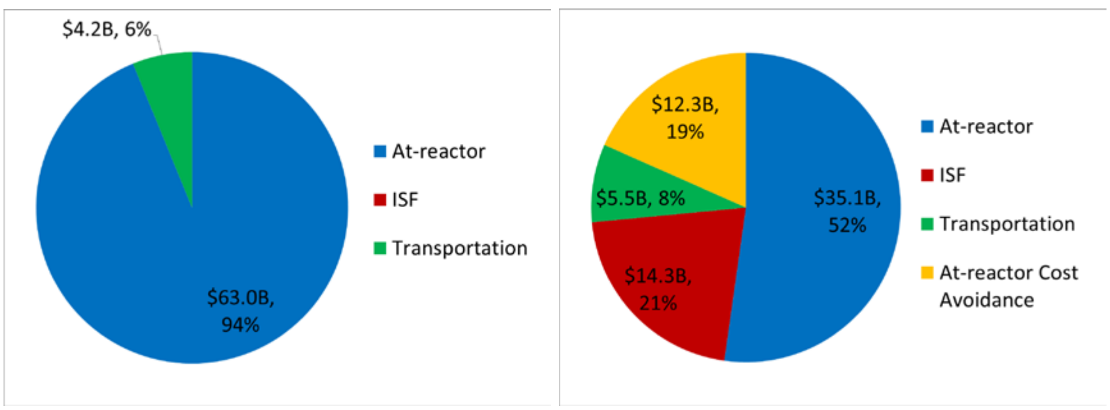

Figure ES-3. Cost breakdown for at-reactor, ISF, and transportation costs for scenarios without an ISF (left) and with a full-scale ISF opening in 2025 (right). Both scenarios assume a repository will open in 2060.

In conclusion, an *ISF integrated into the waste management system can have a total system economic benefit relative to the status quo, but that benefit will not be realized for many decades*. An ISF has the potential to avoid billions of dollars of total system cost in the long run. However, alternative economic assumptions, to be explored in a future sensitivity study, may affect the results of this evaluation. Therefore, it may be best to view an ISF as an economic investment in the nuclear waste management system, providing a range of benefits that have been identified in previous studies, most recently in the Blue Ribbon Commission on America's Nuclear Future's final report. These benefits include accelerated initiation of federal waste acceptance, enhanced stakeholder confidence, enhanced waste management system flexibility, and the development of experience related to large-scale SNF handling, storage, and transportation to benefit design and operation of a repository.

This study assumes a constant 3,000 metric tons of heavy metal/year (MTHM/yr) acceptance rate and, following shipment of SNF from an initial set of nine shutdown reactor sites, applies an allocation strategy according to the oldest-fuel-first acceptance priority ranking as defined in 10 CFR Part 961 (i.e., the Standard Contract). Other studies [1] have shown that both a site-specific allocation strategy and an accelerated acceptance rate could reduce at-reactor costs, which would make an ISF even more attractive because it would allow earlier implementation of these strategies.

CONTENTS

FIGURES

TABLES

ACRONYMS

ANL	Argonne National Laboratory
CALVIN	CRWMS analysis and logistics visually interactive
CRWMS	Civilian Radioactive Waste Management System
D&D	deactivation and decommissioning
DOE	US Department of Energy
DPC	dual purpose (storage and transportation) canisters
HSM	horizontal storage module
ISF	interim storage facility
ISFSI	independent spent fuel storage installation
MRS	monitored retrievable storage
MTHM	metric tons of heavy metal
NFST	Nuclear Fuels Storage and Transportation Planning Project
OCRWM	Office of Civilian Radioactive Waste Management
ORNL	Oak Ridge National Laboratory
ROM	rough order of magnitude
SFP	spent fuel pool
SNF	spent nuclear fuel
SNL	Sandia National Laboratory
TOM	transportation operations model
TSL	transportation storage logistics
VCC	vertical concrete cask
WMS	waste management system

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COST IMPLICATIONS OF AN ISF IN THE WMS

1. INTRODUCTION

This report fulfills the Level 2 Milestone M2FT-15OR0902071 entitled "Interim Storage Facility Cost-Benefit Analysis" in the Waste Management System (WMS) Architecture Analysis – ORNL work package, FT-15OR090207.[e]

The Nuclear Fuel Storage and Transportation Planning Project (NFST), under the US Department of Energy, Office of Nuclear Energy, Office of Fuel Cycle Technologies, is performing waste management system analysis to inform future decisions that will affect how the entire spent nuclear fuel (SNF) management system is configured, deployed, and operated. In support of this task, the NFST sponsored a rough order of magnitude (ROM) analysis of the direct cost implications of including an interim storage facility (ISF) in the waste management system as called for in the *Administration's Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste*[f] [2]. This report presents the results of that analysis.

Full program implementation as specified in the Administration's *Strategy* will require legislation to enable the timely deployment of an ISF. Many steps will be required for deployment. First, the US Department of Energy (DOE) or a new entity must select an ISF site using a consent-based process. After a site is selected, routes must be selected for transport of SNF to the site. Further, an ISF must be designed, licensed, and constructed before SNF can be removed from shutdown sites and transported for interim storage. This analysis assumes that all of those steps have been completed in time to allow initial operation of a pilot ISF in 2021 and of a full-scale ISF in 2025 in some scenarios. Other full-scale ISF start dates considered in this report are 2030 and 2035.

The preliminary ROM cost estimates presented in this study are not ISF project cost and schedule baseline quality data and should only be used with full recognition of the constraints of this analysis. These constraints include:

1. Simplified assumptions are used in defining and evaluating the alternative SNF management strategies. Changes in those assumptions, such as those concerning the rate and priority of acceptance of SNF from reactors, could change the results.
2. This study compares the cost of continued distributed at-reactor storage to a waste management system that includes an ISF but does not examine all the costs associated with the entire back end of the fuel cycle. Key factors that do not affect the comparison of ISF strategies, such as the costs of developing repository or repackaging facilities (if required), are not included.
3. The scenarios evaluated in this analysis are constant over the time frames analyzed and do not reflect the ability to adapt ISF deployment strategies to future developments in ways that would minimize costs and maximize benefits.

1.1 Purpose

The high-level goal of this analysis is to provide ROM estimates of how an ISF could impact the cost of a waste management system and how dependent those impacts are on the relative timing of an ISF and a repository and on the strategy for use of the ISF. A number of previous studies have estimated the potential costs associated with ISF construction, operation, and licensing. However, due to the continual

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[e] This report was originally prepared in early fiscal year 2015; therefore, certain of its assumptions should be read in the context of that timeframe.

[f] Consistent with the *Strategy*, this analysis is site independent. Legislation is needed before DOE or a new entity can select sites for an ISF and a repository using a consent-based process.

changes of unit costs, system facility and component designs, and regulatory/policy environments, it is appropriate to re-examine the cost aspects of interim storage at this time.

Managing the back end of the nuclear fuel is impacted by a number of issues, one of which is cost. All decisions about storage, transportation, and disposal of SNF would not be solely based on costs. Also, because the ISF would only be built as needed, the potential for under-utilization would be *relatively* small, whereas the cost avoidance has the potential to be substantial (based on the Administrations' *Strategy)*.

The direct cost of developing and operating an ISF has historically been defined as the price for achieving a range of important policy and strategy objectives [3]. While this study focuses on cost implications, cost is only one of several important factors when planning the deployment of an ISF as part of an integrated SNF management system. Such objectives, which are discussed most recently in the report of the Blue Ribbon Commission and the Administration's *Strategy*, include but are not limited to:

- demonstration of the federal commitment to addressing SNF and high-level radioactive waste disposal,
- expeditious initiation of the fulfillment of government contractual responsibilities,
- reduction of long-term financial liabilities,
- enhanced waste management system flexibility, including the ability to respond to emergencies and other situations until and while a repository is active,
- development of experience related to large-scale SNF handling, storage, and transportation that will improve the efficiency of the future repository and/or other back-end facilities,
- development of trust among stakeholders regarding consent-based process to benefit future siting of a repository and other facilities, and
- support for availability of nuclear power as part of a national clean-energy portfolio and for US ability to influence the development of a safety and security framework for development of nuclear energy globally.

These considerations will be explored further in future analyses.

1.2 Background

The Transportation Storage Logistics (TSL) model [4] was used for all parts of this analysis. TSL is the merger of the Civilian Radioactive Waste Management System (CRWMS) Analysis and Logistics Visually Interactive (CALVIN) [5] and Transportation Operations Model (TOM) [6] codes into a simulation framework for evaluating a range of potential back-end SNF management scenarios. Developed for the Office of Civilian Radioactive Waste Management (OCRWM) over a decade ago, CALVIN creates shipping schedules for transporting SNF from onsite storage to interim and/or ultimate disposal facilities. TOM provides logistics analysis and multi-modal routing to estimate transportation capital acquisition and maintenance costs. Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), and Sandia National Laboratories (SNL) merged CALVIN and TOM into TSL to provide system-level modeling of cost and logistics of transportation, storage, repackaging (if needed), and disposal.

In order to consistently compare different system scenarios, unit-level costs were established. Recently, the NFST updated these unit costs based on current data [7]. These updated values include the yearly operational costs associated with independent spent fuel storage installations (ISFSIs) and at-reactor spent fuel pools (SFPs), as well as costs related to dry storage systems (both horizontal storage modules [HSMs] and vertical concrete casks [VCCs]). The costs listed in Appendix A are used by the system modeling tools in an "average" manner. While each reactor's actual cost will vary due to geographic, political, and economic factors, the tools assign the same cost to each reactor based on its current status (e.g., operating, decommissioned). Therefore, these costs represent an average representative reactor and do not model individual reactors and their potentially wide cost ranges.

This study assumes a constant 3,000 MTHM/yr acceptance rate and, following shipment of SNF from an initial set of nine shutdown reactor sites, applies an allocation strategy in accordance with the oldest-fuel-first (OFF) acceptance priority ranking defined in the Standard Contract. However, previous NFST research [1] determined that higher acceptance rates and/or site-specific allocation/acceptance strategies could lead to significant benefits for at-reactor management logistics and costs. Therefore, this study's assumptions of acceptance rates and strategies are deemed to be conservative[g] from an at-reactor cost perspective since implementation of an ISF combined with site-specific allocations and/or higher acceptance rates should result in an even greater reduction of at-reactor costs beyond those described in this study.

2. SCENARIOS

In this report, a specific scenario includes the following decision points:

1. In what year does a full-scale ISF open?
   (a) 2025 (b) 2030 (c) 2035
2. In what year does a repository open?
   (a) 2040 (b) 2050 (c) 2060
3. Is an ISF a part of the system?
   (a) no - go to question 4.
   (b) yes, as a flow-through facility that receives, stores, and ships all SNF before and during repository operation.
   (c) yes, as a bypassed facility that receives and stores SNF only when a repository is not able to do so.[h]
4. Do reactors begin loading bare[i] fuel for shipment to an ISF or repository once one is available?
   (1) yes (2) no

Based on these decision points, 42 scenarios are available to analyze. Detailed descriptions of the scenarios are given in Appendix B. As explained in Section 3.2, the analysis in this report focuses on the 21 canistered scenarios though a brief discussion of scenarios that also include acceptance of bare fuel is also available. This canistered fuel focus represents the current at-reactor storage practices used today.

2.1 Assumptions

Due to the large number of possible scenarios involving SNF storage, transportation, and disposal, a number of simplifying assumptions were made for all scenarios in this study. In general, and whenever

[g] For the purposes of this study, a "conservative assumption" is defined as an assumption that is believed to result in calculated cost values greater than or equal to the calculated cost value from an alternate assumption.

[h] A "flow-through ISF" is defined as an ISF that is an integral component of the nuclear waste management system throughout its entire life cycle. In flow-through ISF scenarios, all SNF from reactors will be transported first to an ISF (even if a repository is available) before being transported to a repository. A bypassed ISF is defined as an ISF where all SNF does not flow through the ISF throughout its entire life cycle. In bypassed ISF scenarios, the bypassed ISF functions as a centralized storage facility until a repository begins accepting SNF. At that point, a repository prioritizes accepting fuel directly from reactors over SNF from the ISF.

[i] Bare fuel is non-canistered assemblies. Generally bare fuel would be transported by reusable transportation casks from the reactors to an ISF or a repository.

possible, the assumptions below were made to provide a conservative estimate of ISF costs based on current industry practice.

- 3,000 MTHM/yr acceptance rate is anticipated from the reactor sites.
- 3,000 MTHM/yr acceptance rate is anticipated at a repository.
- The nine reactor sites[j] that were fully shut down as of 2011 will be de-inventoried first as part of a pilot ISF; this will be accomplished in the four years before the full-scale ISF begins operation.
- Oldest-fuel-first allocation[k] and youngest fuel first[l] acceptance strategies are used for all other reactors.
- All costs are in year 2014 constant dollars.
- All repackaging (if required) is performed at a repository.
- There is no bare fuel storage at the ISF.
- No blending or thermal constraints are imposed at a repository.

2.2 Description

In this report, the 42 scenarios (Appendix B) are divided into six base scenario categories (see Table 1), with each category (except the no-ISF scenarios) containing 9 scenarios (3 ISF start dates x 3 repository start dates). The no-ISF categories have only 3 scenarios (3 repository start dates). Additional detail is available in Table B-1 in Appendix B.

The three canister-only scenario categories only include movement of SNF in welded canisters meant for storage and transportation (using appropriate overpacks), not in bare fuel transportation casks.

- Scenario category 1a does not include an ISF. In this category, all SNF is shipped directly from reactor sites to a repository. This is the defacto reference scenario for this study.
- Scenario category 1b includes a flow-through ISF as an integral component of the nuclear waste management system throughout its entire life-cycle. In this category, all SNF from reactors will be transported first to an ISF (even if a repository is available) before being transported to a repository. This is defined as a "flow-through ISF" in this report.
- Scenario category 1c includes a bypassed ISF that accepts SNF from reactors until a repository begins accepting SNF. At that point, the ISF stops accepting SNF and a repository prioritizes accepting fuel directly from reactors over SNF from the ISF. This is defined as a "bypassed ISF" in this report.

At reactor shutdown, it is assumed that utilities will load the bare fuel still in the SFPs into dry storage canisters within five years to facilitate reactor decommissioning.

The three bare-fuel-from-reactors scenario categories move fuel using both bare fuel transportation casks and welded canisters meant for storage and transportation (with appropriate overpacks) from the reactors to the ISF or from the reactors to a repository. In all three scenario categories, once an ISF or repository is available, bare fuel will be preferentially shipped from the reactors to that facility before the fuel stored in

[j] For this study, the nine original shutdown sites are Big Rock Point, Connecticut Yankee, Maine Yankee, Yankee Rowe, Rancho Seco, Trojan, Humboldt Bay, LaCrosse, and Zion.

[k] In this system analysis study, "allocation strategy" refers to the logic used to determine how much SNF the modeled waste management system attempts to ship from each reactor site in a given year. "Acceptance strategy" refers to the logic used to calculate which SNF assemblies and how many of them are accepted for transport from reactor sites by the modeled system.

[l] For the purposes of this report, it is assumed that utilities will use their allocations to deliver their youngest fuel first (which must have been out of the reactor at least 5 years)

in DPCs. After reactor shutdown, the SFPs are kept in operation until the fuel is removed in transportation casks for direct shipment offsite rather than being offloaded into DPCs within five years, as assumed in the canister-only scenarios. All bare fuel received at the ISF is packaged into dual purpose canisters for storage and subsequent transportation to the repository. This means that there is no bare fuel transportation from the ISF to a repository.

- Scenario category 2a does not include an ISF. In this category, all SNF is shipped directly from reactor sites to a repository that is accepting SNF. As noted, once a repository is available, bare fuel will be preferentially shipped to the repository before the fuel in DPCs.
- Scenario category 2b includes a flow-through ISF as an integral component of the nuclear waste management system. In this scenario category, all SNF from reactors will be transported first to an ISF (even if a repository is available) before being transported to a repository. Conservatively, all SNF will be placed in DPCs for ISF storage and shipment to a repository.
- Scenario category 2c includes a bypassed ISF that receives fuel until a repository begins accepting SNF. At that point, a repository prioritizes accepting fuel directly from reactors over SNF from the ISF. Specifically, the bare SNF at reactors will be accepted before the canistered SNF from the ISF.

Table 1. Reference scenarios category description.

		Storage facility		
		No ISF (a)	Flow-through ISF (b)	Bypassed ISF (c)
From reactor shipment mode	Canisters only (1)	1, 5, 9	13, 14, 15, 16, 17, 18, 19, 20, 21	2, 3, 4, 6, 7, 8, 10, 11, 12
	Bare fuel and canisters (2)	22, 26, 30	34, 35, 36, 37, 38, 39, 40, 41, 42	23, 24, 25, 27, 28, 29, 31, 32, 33

In categories 1b and 2b, all fuel is processed through the ISF, even after a repository opens (3,000 MTHM/yr acceptance rate at ISF, and 3000 MTHM/yr acceptance rate at a repository). Therefore, the ISF is treated as an intermediate location for all SNF and as an integral part of the disposal system. For example, for scenarios in category 2b the ISF inventory provides a large number of fuel assemblies to help with blending requirements to meet a repository waste package decay heat criteria. This is consistent with previous DOE monitored retrievable storage (MRS) operational planning studies [3]. In categories 1c and 2c, the ISF receives fuel until a repository opens. After that point, fuel is preferentially shipped directly from reactors to a repository. Once all remaining fuel from reactor sites is moved to a repository, fuel is also moved from the ISF to a repository at a rate of 3,000 MTHM/yr. In other words, fuel at reactor sites is higher priority than fuel at the ISF for shipment to an operating repository. Categories 1a and 2a are modeled without an ISF and provide the basis for comparison to determine the potential cost impacts of incorporating an ISF into the waste management system.

For each scenario that includes an ISF, full-scale[m] ISF opening dates of 2025, 2030, and 2035 were modeled. For each ISF opening date, repository opening dates of 2040, 2050, and 2060 were modeled. The system analysis period continues until all SNF arrives at a repository.

[m] All ISF dates in this report are full-scale ISF dates. As documented in the Section 2.1, the nine shutdown sites as of 2011 are de-inventoried in the four years prior to full-scale deployment. For example, a full-scale ISF implementation date of 2025 implies that pilot ISF operations began in 2021.

3. RESULTS AND ANALYSIS

In this study, the total ROM system costs were calculated, compared, and analyzed to quantify the impact of adding an ISF to the waste management system for several different scenarios (Section 3.1). Based on these results, two specific scenarios were selected for a detailed cost comparison (Sections 3.2 and 3.3) and a logistics comparison (Section 3.4).

3.1 Total Rough Order of Magnitude System Costs

In this study, the following ROM total system[n] costs were calculated and tabulated including:

- **at-reactor costs**, including ISFSI operational and maintenance costs, SFP operational and maintenance costs starting five years after the reactor shutdown, and all canister and overpack loading and procurement costs;
- **transportation costs**, including fleet capital costs, operational costs, and maintenance costs; and
- **ISF costs**, including receipt and shipping facility capital and operational costs, storage overpack costs, deactivation & decommissioning (D&D) costs, and canisters purchased (only incurred in bare fuel scenarios).

This assessment did not consider any repackaging costs or repository costs because it was assumed that these costs would be identical for all scenarios since the same quantity of fuel is disposed in each scenario, as a result they cannot be used as discriminating factors. As mentioned earlier, these are ROM costs used to show how the various fuel management scenarios affect relative costs. Application of the ROM cost results beyond this purpose should be avoided due to the fact that simplified assumptions were used in this evaluation and in describing different scenarios; all values are tabulated from 2020 forward[o].

3.1.1 Canister only scenarios

This section will focus on ROM system cost estimates for canister-only scenarios that only move SNF in welded canisters meant for storage and transportation (with appropriate overpacks) like those currently being used by utilities, not in bare fuel transportation casks.

Total system life cycle costs for scenarios without an ISF and with a bypassed ISF and flow-through ISF implemented in 2025, 2030, and 2035 are shown below in Figure 1 (repository open in 2040), Figure 2 (repository open in 2050), and Figure 3 (repository open in 2060).

[n] "Total system" in this particular study is focused on management of commercial spent nuclear fuel (not defense waste) and is defined as at-reactor, ISF, and transportation activities starting at the reactor until the SNF arrives at the repository. Repository and repackaging costs are not considered in this study and not included in the total system costs because their costs are not expected to vary significantly between the different scenarios. Since the system in this study includes activities associated with spent fuel management at reactor sites, it provides results from a broader societal or national perspective, as opposed to a more limited perspective associated with only the portion of the system managed by federal government.

[o] ROM system costs were only calculated starting in year 2020 because costs before this point were assumed to be the same for all scenarios studied.

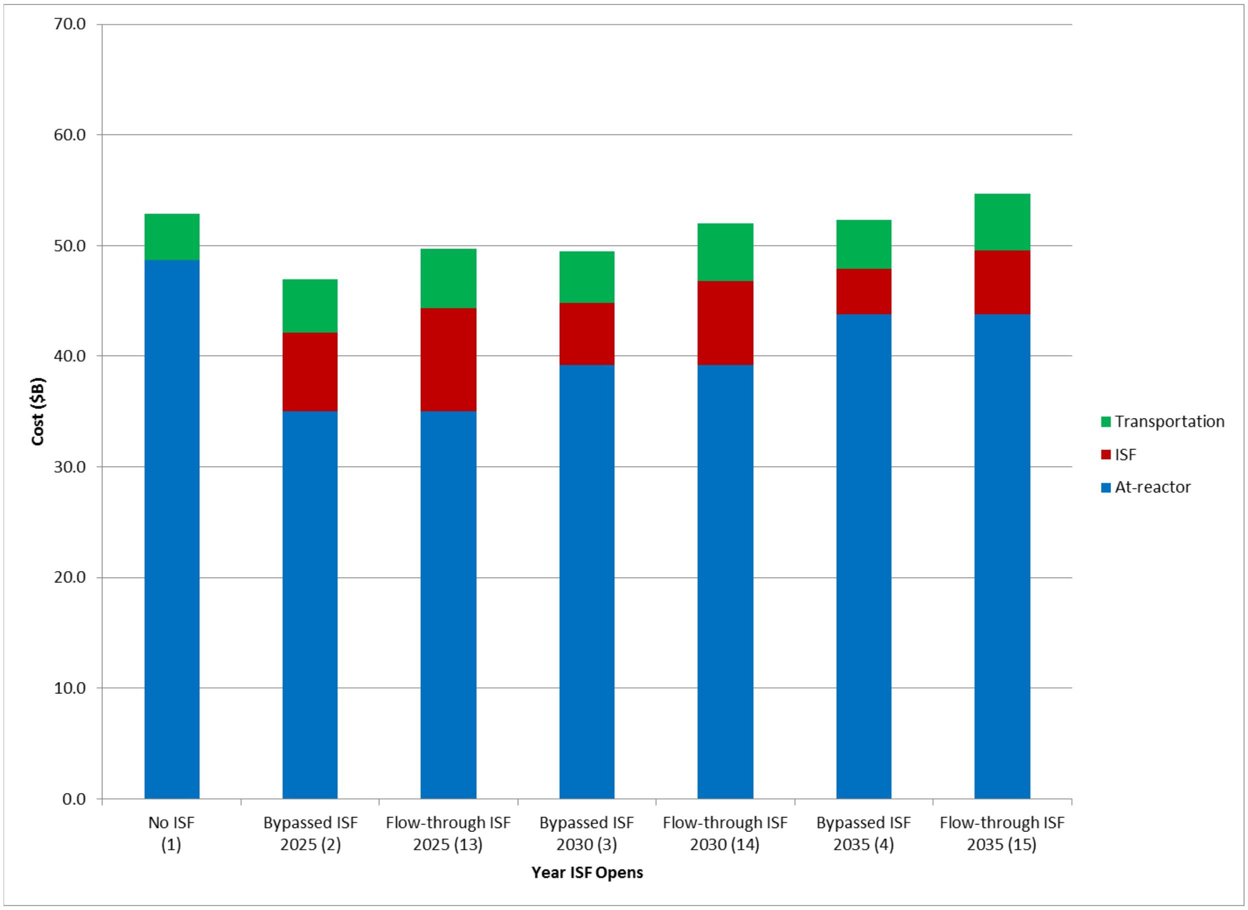

Figure 1. Total system costs (at-reactor, ISF, and transportation) for canister-only scenarios with no ISF, bypassed ISF, and flow-through ISF start dates of 2025, 2030, and 2035 with a repository becoming operational in 2040 (Scenarios 1, 2, 13, 3, 14, 4, 15).

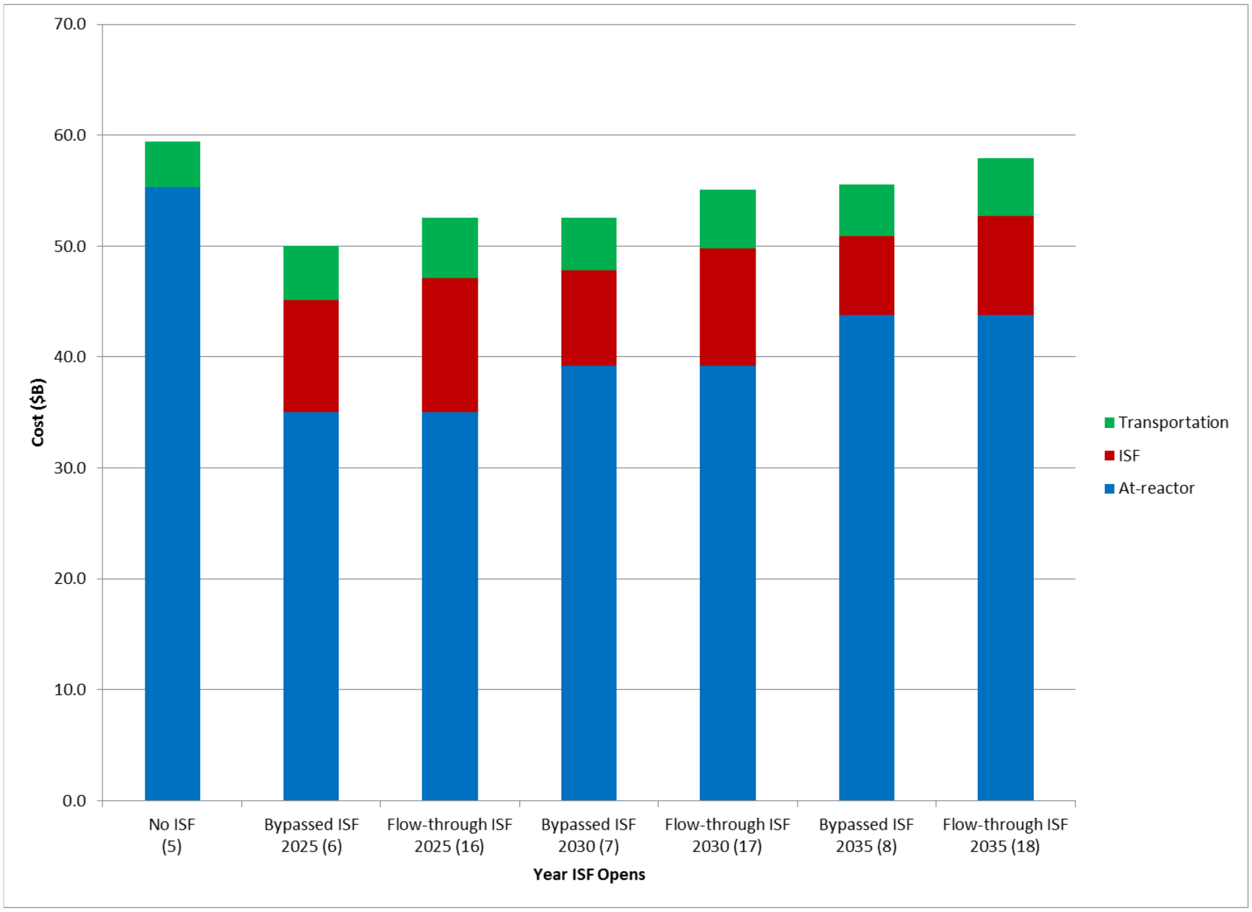

Figure 2. Total system costs (at-reactor, ISF, and transportation) for canister-only scenarios with no ISF, bypassed ISF, and flow-through ISF start dates of 2025, 2030, and 2035 with a repository becoming operational in 2050 (Scenarios 5, 6, 16, 7, 17, 8, 18).

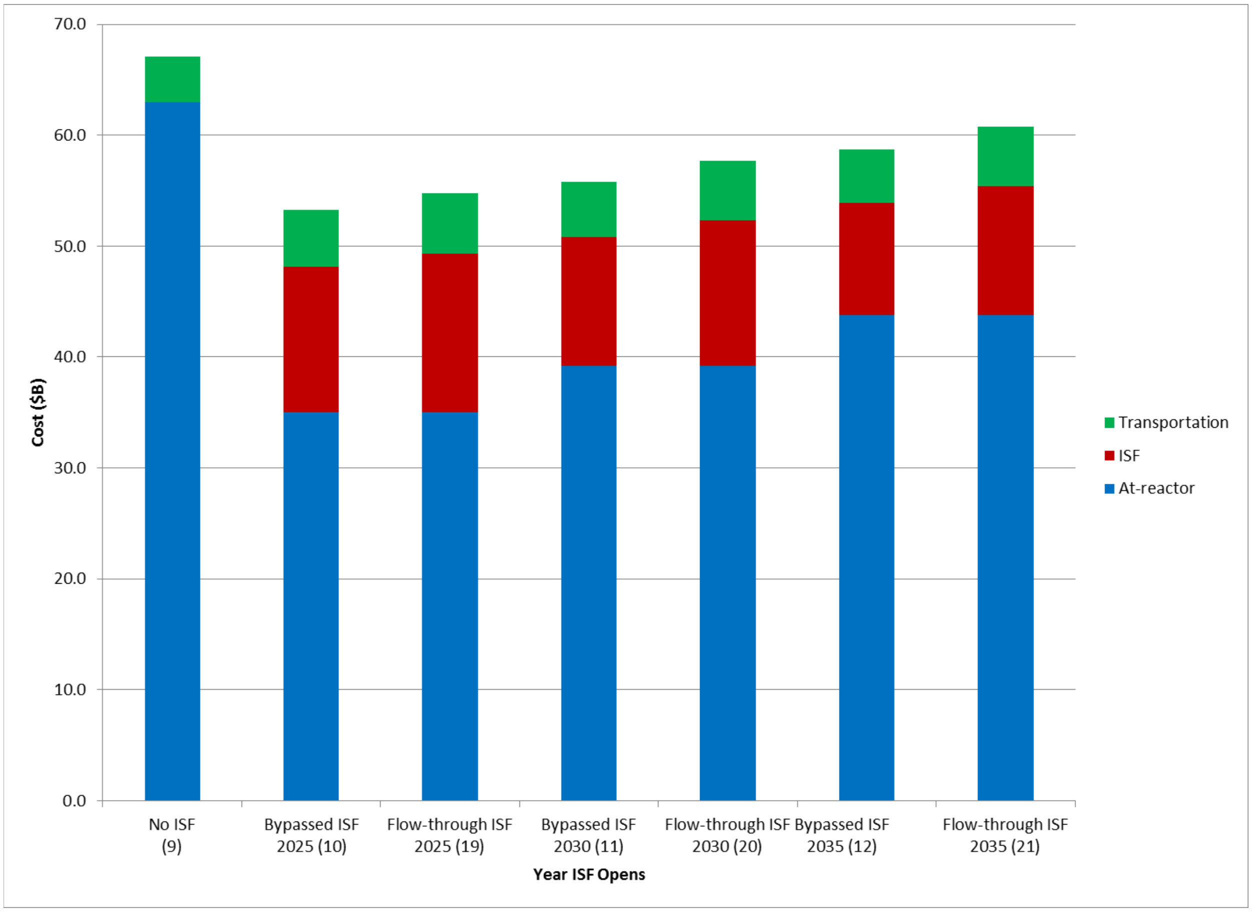

Figure 3. Total system costs (at-reactor, ISF, and transportation) for canister-only scenarios with no ISF, bypassed ISF, and flow-through ISF start dates of 2025, 2030, and 2035 with a repository becoming operational in 2060 (Scenarios 9, 10, 19, 11, 20, 12, 21).

As illustrated in Figure 1 through Figure 3, an ISF reduces total system costs in all scenarios with the exception of comparing scenario 15 to scenario 1. Scenario 15 incorporates a flow-through ISF in 2035 and a repository opens in 2040. There is a $0.9B (~2%) increase in total cost by incorporating an ISF. As described in more detail in Section 3.1.1.1, there are operational ISF improvements and efficiencies that would reduce the ISF costs below the conservative estimate in this study. Figures 4 and 5 are similar to Figure 1 through Figure 3, except that in each figure, the ISF start date is held constant and the repository opening dates are varied. Figures 4 and 5 also contain a second y-axis to show the difference between the scenarios with an ISF and those without an ISF.

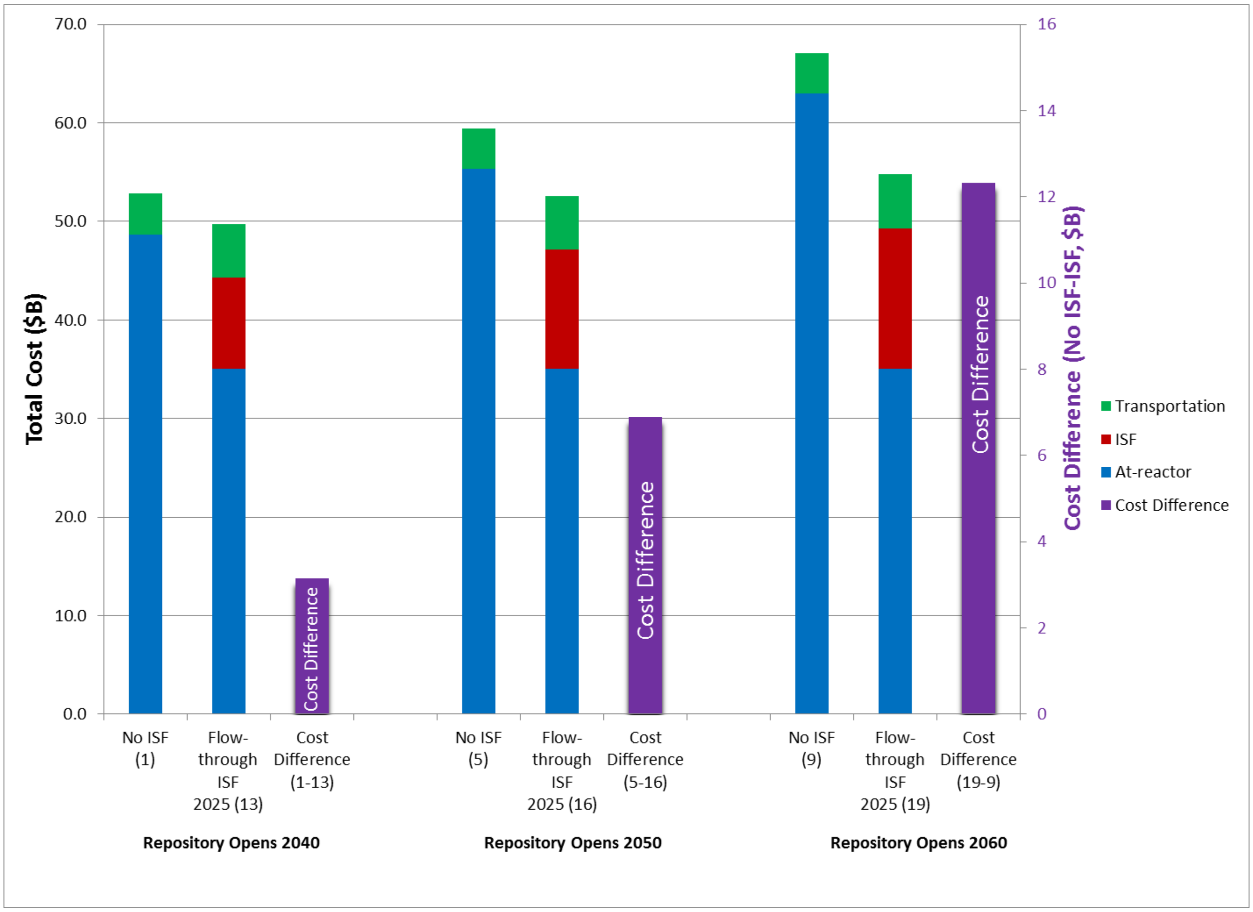

Figure 4. Total system costs (at-reactor, ISF, and transportation) for canister-only scenarios with no ISF and a flow-through ISF start date of 2025 with a repository becoming operational in 2040, 2050, 2060 (Scenarios 1, 13, 5, 16, 9, 19).

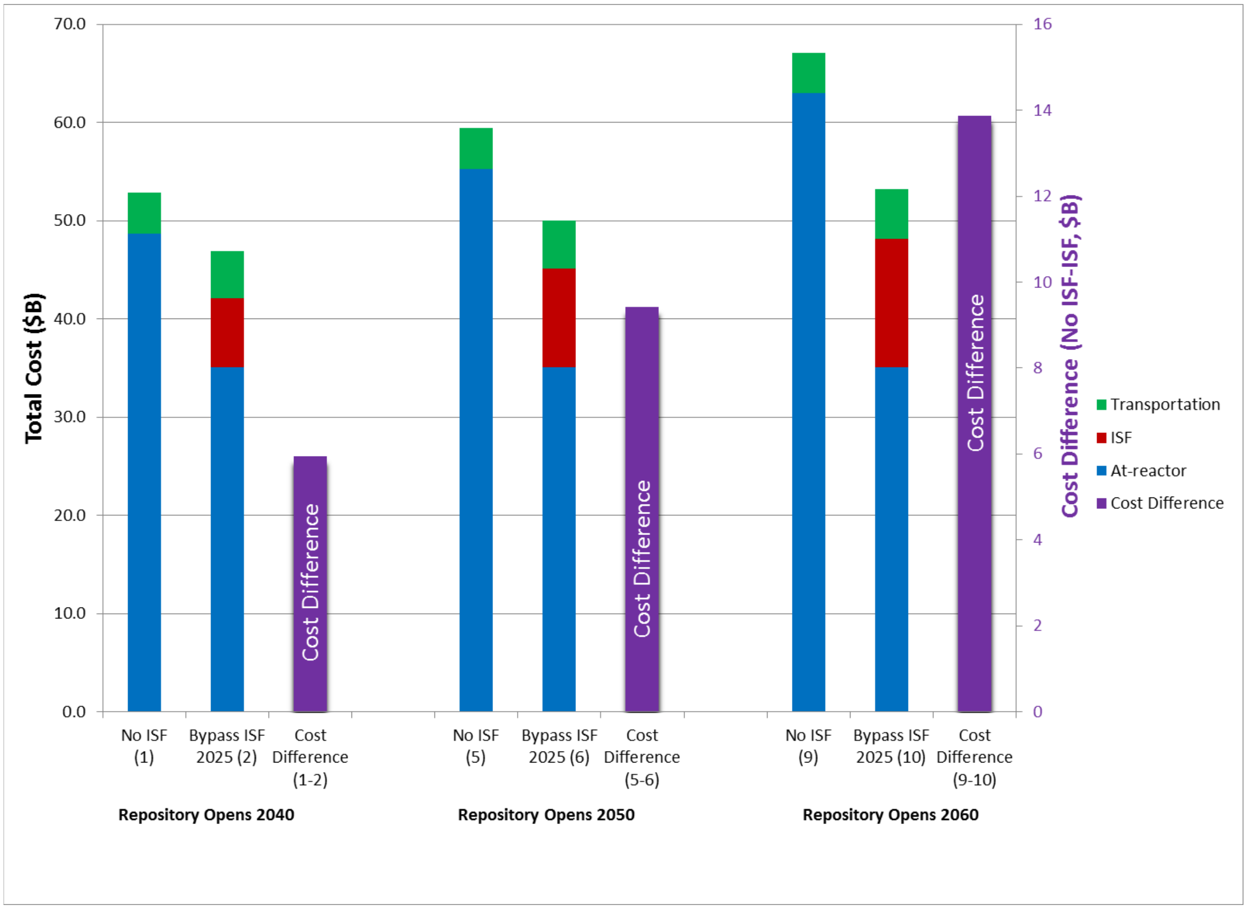

Figure 5. Total system costs (at-reactor, ISF, and transportation) for canister-only scenarios with no ISF and a bypassed ISF start date of 2025 with a repository becoming operational in 2040, 2050, 2060 (Scenarios 1, 2, 5, 6, 9, and 10).

In Figure 4 and Figure 5, the left axis is total system cost and the right axis (which applies to the purple bars only) is the difference between scenarios with and without an ISF.

3.1.1.1 ISF operational options

Comparison of plots showing total system lifecycle costs for the bypassed and flow-through ISF strategies (Figure 1 through Figure 3) show that the flow-through ISF scenarios result in higher total system costs (~5%). This is due to increased cost for operations of the ISF, including additional capital for greater storage capacity and additional transportation costs. All scenarios assume that the fuel shipment schedule at the ISF is based on a first-in, first-out schedule. As a result, in flow-through ISF scenarios, some canister-based systems arrive later and must be stored, resulting in an increased cost of building storage modules for those canisters. Therefore, to ensure conservatism, the flow-through ISF was selected for detailed analysis. In reality, the operations of an ISF would be performed for a number of economic and operational reasons, with the potential to substantially reduce the storage costs associated with building more storage overpacks than required, as well as reusing some or all of the receipt bays for shipment to the repository.

3.1.1.2 Canister storage scenario overall trends

Figures 4 and 5 indicate (1) the longer the delay in availability of a repository, the higher the cost for the management of SNF prior to the preparation for and ultimate waste disposal, regardless of integration of an ISF, and (2) incorporation of an ISF into the SNF management system avoids some of the cost compared to the current distributed-at-reactor management approach. The avoided cost (~$3B to $15B) in this study will continue to increase with even further delays in the repository. Neither conclusion is surprising, as at-reactor costs will continue to mount until the SNF is removed. This removal is accelerated by incorporating an ISF into the system. The cost avoidance from the reduction in at-reactor post-shutdown storage costs (which will continue to accumulate well after a repository and ISF are opened due to the finite acceptance rate of the ISF and repository) is greater than the total ISF costs.

While the total system costs are reduced by incorporating an ISF in all scenarios shown above, other considerations related to annual and decade-dependent cash flows are also important. These are considered in Section 3.2.

3.1.2 Bare fuel scenarios

This section focuses on ROM system cost estimates for bare-fuel-from-reactors scenarios that move fuel using both bare fuel transportation casks and welded canisters meant for storage and transportation (with appropriate overpacks) from the reactors to the ISF or from the reactors to a repository. As previously noted, all bare fuel received at the ISF is packaged into dual purpose canisters for storage, which simplifies the comparison with at-reactor storage and ensures that there is no bare fuel transportation from the ISF to a repository.

Total system life cycle costs for bare fuel scenarios with a repository opening in 2050 and with no ISF and with a full-scale ISF opening in 2025, 2030, and 2035 are shown in Figure 6.

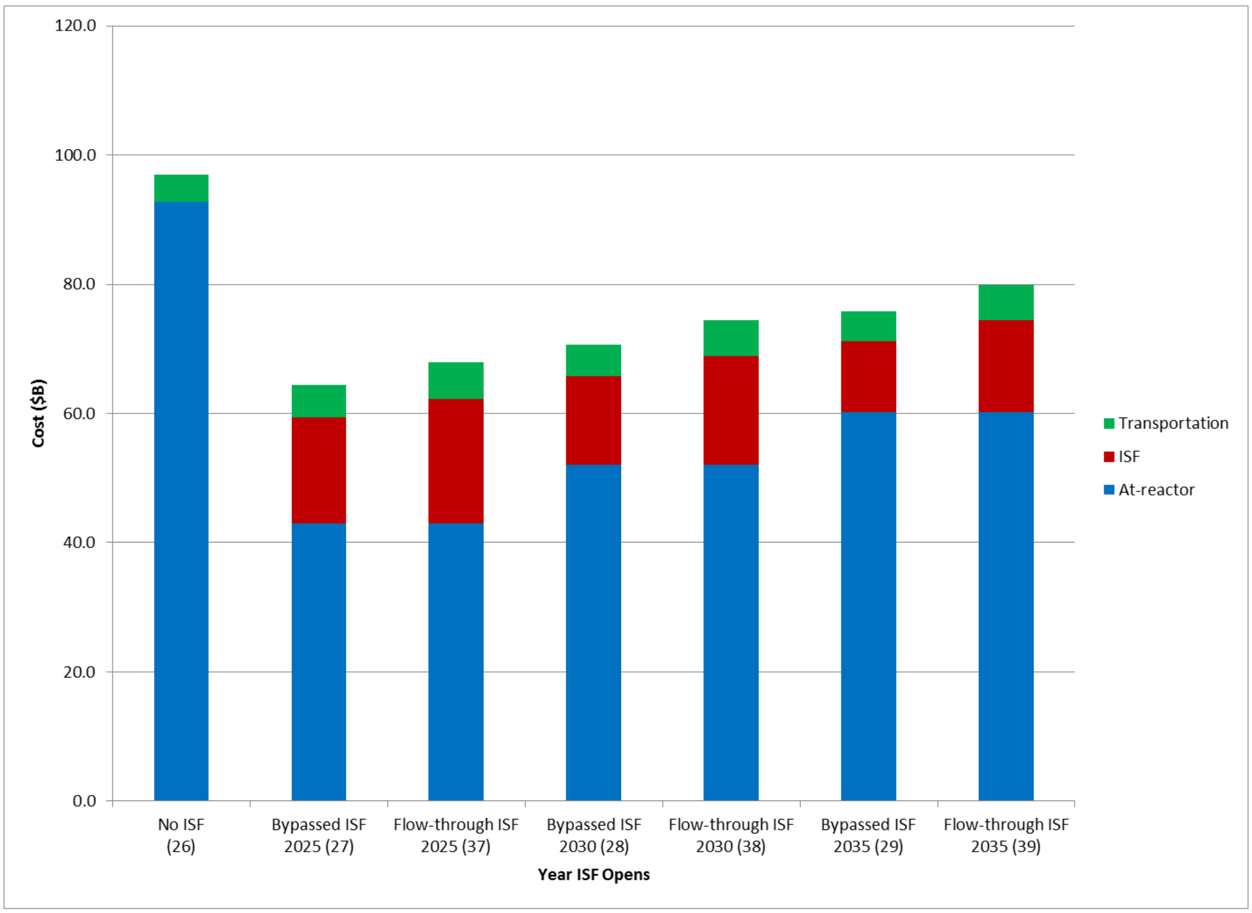

Figure 6. Total system cost (at-reactor, ISF, and transportation) for scenarios with different starting dates of an ISF (including no ISF) with a repository becoming operational in 2050 for bare fuel and canisters (Scenarios 26, 27, 37, 28, 38, 29, 39).

It should be noted that the scale of the cost axis for Figure 6 is different from Figures 1–5 with the maximum value $120B instead of $70B. The use of bare fuel and canisters costs significantly more than using only canisters in every scenario that was modeled because SFPs must stay open until all of the bare fuel is shipped to an ISF or repository. This results in much higher at-reactor costs due to keeping SFPs open after the reactor has shut down (~$24M per year for the first SFP on a site, and $2M additional for a second SFP). Typically, once a reactor is decommissioned, utilities move all bare fuel to an ISFSI pad and decommission the SFP, as assumed in the canister-only scenarios. Maintenance of an ISFSI is estimated at ~$10M/year. Thus, scenarios assuming long-term operation of SFPs at decommissioned reactor sites are not considered reasonable representations. Future analyses will consider scenarios in which fuel cannot be shipped bare from a shutdown reactor SFP within five years due to acceptance limits, for example. In these scenarios, SNF will be loaded into dry canisters for onsite storage in time to ensure that the SFP is emptied within five years. For purposes of this study, however, the more detailed cost analyses presented below focus on simpler canister-only scenarios.

3.2 Detailed Cost Analysis of Two Scenarios

As discussed in Section 3.1.2, this results section focuses on the canister-only scenarios instead of bare fuel scenarios. Movement of bare fuel has been shown to empty reactor sites earlier than canistered fuel scenarios, thus reducing at-reactor storage costs. Therefore, this section only focuses on the most conservative estimate of the potential reduction in long-term cost avoidance that could result from incorporation of ISF scenarios. This is for two reasons: (1) the current industry practice is to use canisters instead of bare fuel casks for fuel storage, and (2) it was deemed to be unlikely that reactors would maintain bare fuel access in SFPs for multiple decades once a reactor was shut down. This ongoing storage of bare fuel in SFPs would be the scenario if there were no ISF and if a repository did not open until 2040 or later.

As discussed earlier, considerations related to annual cash flows are explored in this section. To allow for more in-depth studies and because the trends from Figure 1through Figure 6 are quite similar regardless of ISF opening date and repository start date, the following two canister-only scenarios were selected for comparison:

- Scenario 5: no bare fuel is shipped from reactors, an ISF is *not* incorporated into the system, and a repository opens in 2050.
- Scenario 16: no bare fuel is shipped from reactors, a full-scale, flow-through ISF is incorporated into the system and begins operation in 2025, and a repository opens in 2050.

3.2.1 Detailed comparison between an ISF scenario and the no-ISF scenario

This section continues the investigation into the factors driving the cost impacts of incorporating an ISF into the waste management system. **Figure** 7 shows the annual total system ROM costs including at-reactor, ISF, and transportation costs. The solid black line tracks the total cost of the scenario *without* an ISF, and the bars show the costs for at-reactor, ISF, and transportation categories *with* an ISF.

Major ISF-related expenditures are shown in years 2021, 2025 and 2100. These years represent when the ISF begins pilot operation, when the ISF begins full operation, and the decommissioning of the ISF, respectively. The highest expenditure occurs in year 2021, which includes the pilot ISF infrastructure and transportation capital costs, as well as an assumed $1B of accumulated programmatic cost from the prior decade. Assuming these costs occur in a single year is conservative for this study.

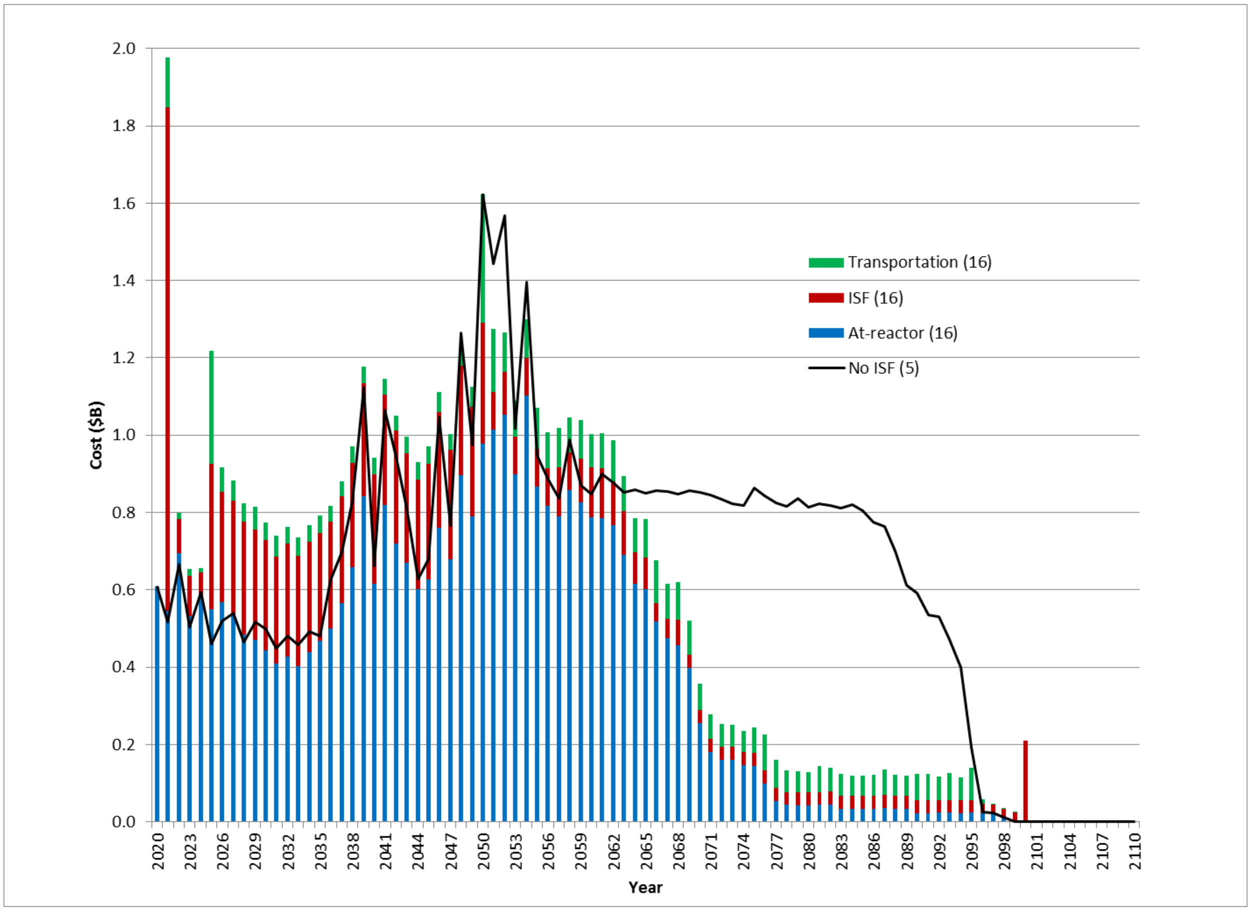

Figure 7. Total annual system cost of implementing an ISF in 2025 with a repository beginning in 2050 compared to a scenario without an ISF also with a repository beginning in 2050 (Scenarios 5 and 16), for a canister-only system.

Once the repository becomes operational, the annual cost of the no-ISF scenario exceeds that for the ISF scenario until ISF decommissioning begins. The area under the solid black line represents the total cost of the no-ISF scenario. Major cost advantages of implementing an ISF in 2025 begin in 2065. This cost avoidance is driven by the reduction in the high cost of post-shutdown at-reactor storage.

The figure shows that while higher ISF costs are incurred earlier in the system life, even greater at-reactor cost reductions in the longer term are gained by implementing the ISF. The majority of the ISF cost is accrued before 2050, the year a repository begins operation.

Figure 7 also illustrates that transportation costs are not a major cost driver for the system.

3.2.2 Cumulative costs and break-even point

This section presents the total system ROM cost for both scenarios to help determine when the break-even[p] point would occur.

Figure 8 displays the cumulative yearly cost of implementing an ISF in 2025 and 2035 compared to the scenario with no ISF.

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[p] "Break-even" refers to the point when the projected cumulative cost of the ISF scenario first equals and starts to fall below that of the no-ISF scenario.

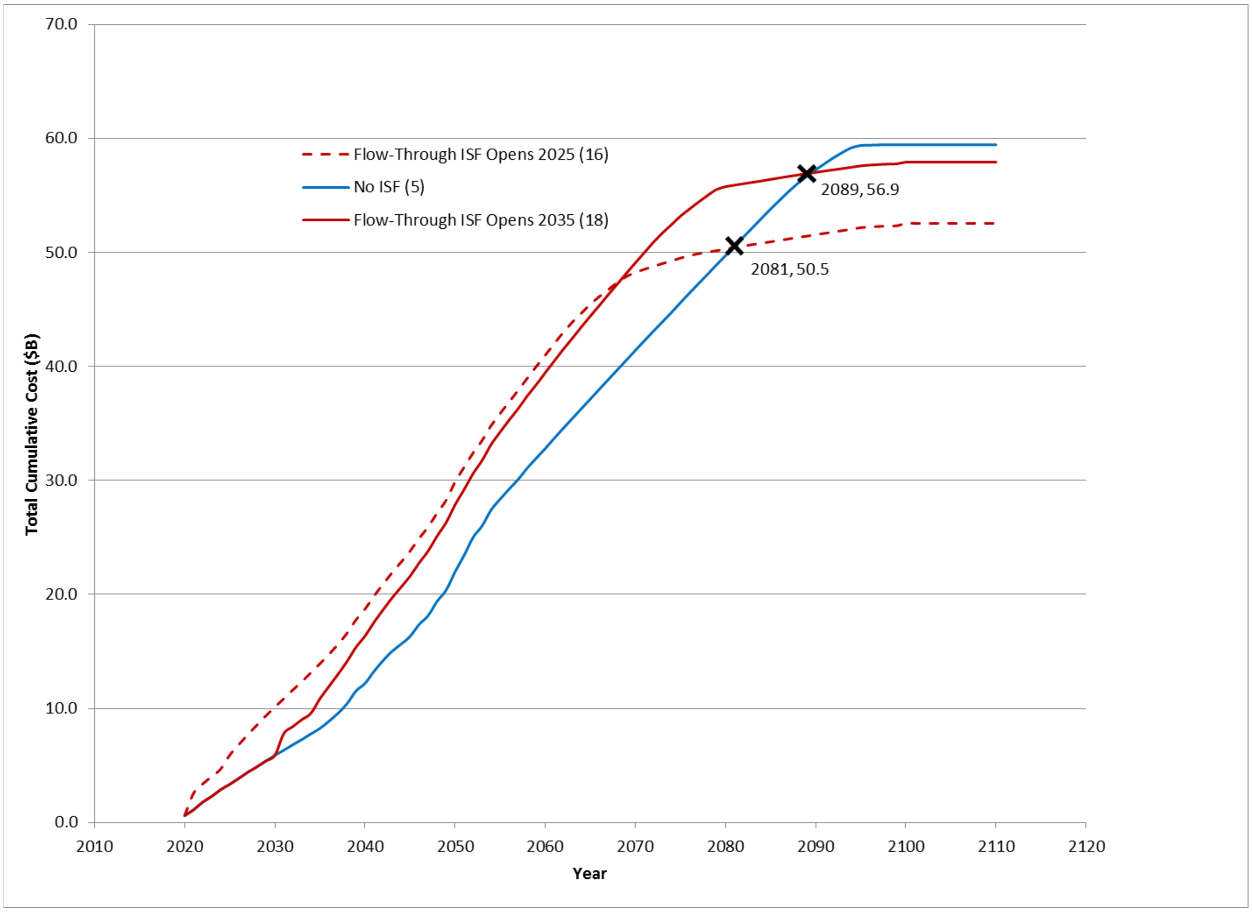

Figure 8. Total cumulative undiscounted system cost for scenarios with no ISF and with an ISF implemented in 2025 and 2035 with a repository opening date of 2050 (Scenarios 5, 16, 18).

Figure 8 shows that a system without an ISF is initially less expensive than a system with an ISF (starting in 2025 or 2035). The system without an ISF becomes more expensive by 2081 due to more at-reactor costs than the system with an ISF.

The X symbols on the figure marks the break-even points when the cumulative costs of the ISF scenarios drop below the cumulative costs of the no-ISF scenario. In 2081, the total cumulative cost of a scenario in which an ISF begins operation in 2025 is equal to the total cumulative cost of a scenario with no ISF and with a repository beginning operation in 2050 in both scenarios. Although the scenario with an ISF has lower yearly costs starting in 2050 (due to the reduction in at-reactor costs), the reduction in total cost in the ISF scenario does not ensure a lower total system cost until 2081 due to the increased costs during the first three decades. For the scenario in which an ISF begins operation in 2035, the total cost break-even point is not reached until 2089.

Figure 9 shows the years in which scenarios with and without an ISF have accumulated the same total costs with ISF start dates of 2025, 2030, and 2035, and repository open dates of 2040, 2050, and 2060.

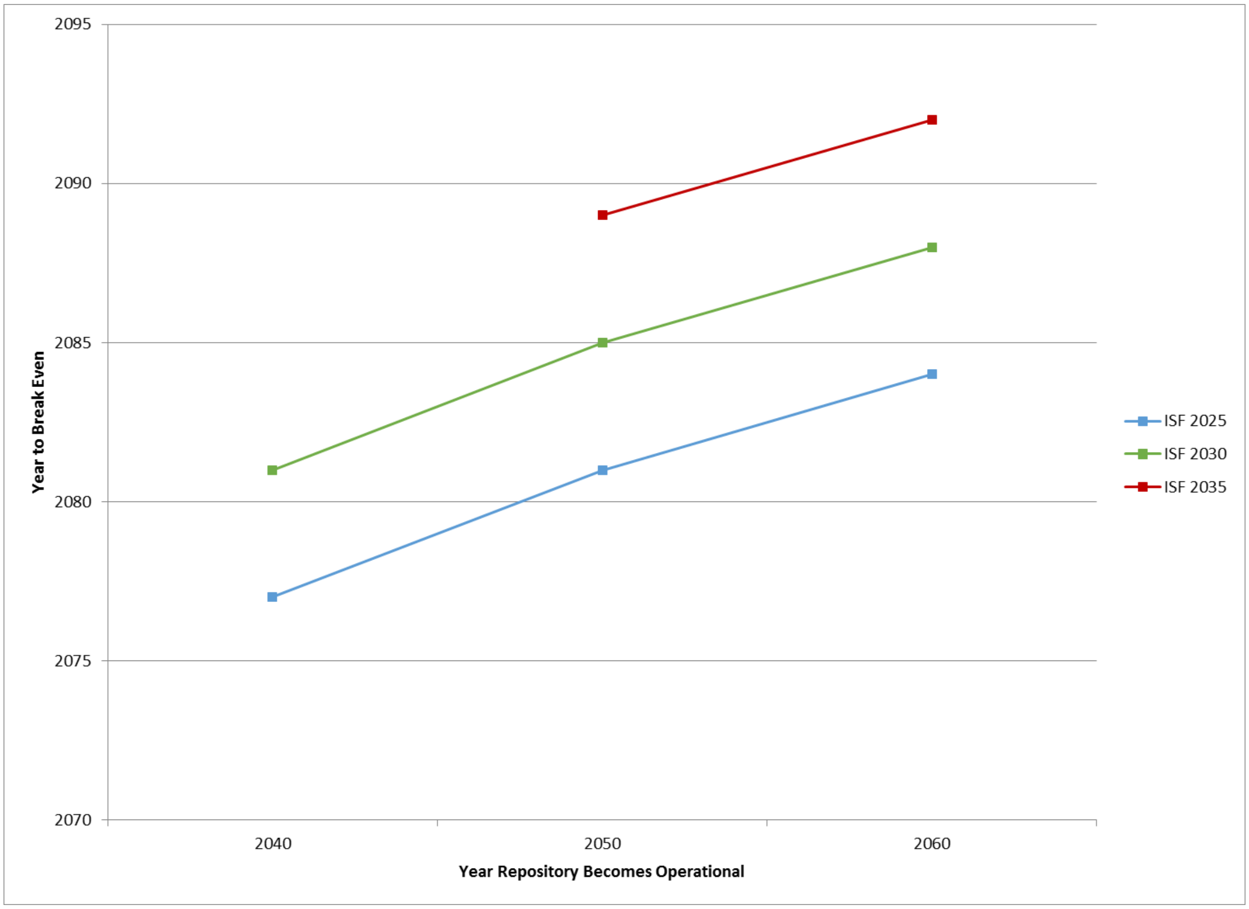

Figure 9. Break-even years when the no ISF and ISF scenarios accumulate the same total system cost with ISF start dates of 2025, 2030, and 2035, and repository open dates of 2040, 2050, and 2060.

As can be seen in Figure 9, eight of the nine scenario comparisons reach a point at which the no-ISF costs exceed the ISF costs. The actual date is determined by the relative startup dates for the ISF and the repository. The scenario without a breakeven point assumes that a flow-through ISF opens in 2035 and repository opens in 2040. As mentioned above, there are straightforward ISF optimizations that could (and most likely would) be used to reduce the ISF costs (e.g., reusing receipt bays, minimizing overpack construction by managing inventory). The plot also shows that delaying either an ISF or a repository results in a delay in the break-even point when comparing ISF and no-ISF scenarios.

3.3 Detailed System Activity Cost Analysis

This section explores the three different system activities (at-reactor, ISF, and transportation) that contribute to the total ROM system cost.

3.3.1 At-reactor costs

This section focuses on costs resulting from activities at reactors. These costs include ISFSI operational and maintenance costs before and after reactor shutdown, SFP operational and maintenance costs five years after the reactor shutdown, and all canister and overpack loading and procurement costs.

Figure 10 is similar to Figure 8 in Section 3.2.2, but only includes the at-reactor portion of the cost. ISF and transportation costs are ignored.

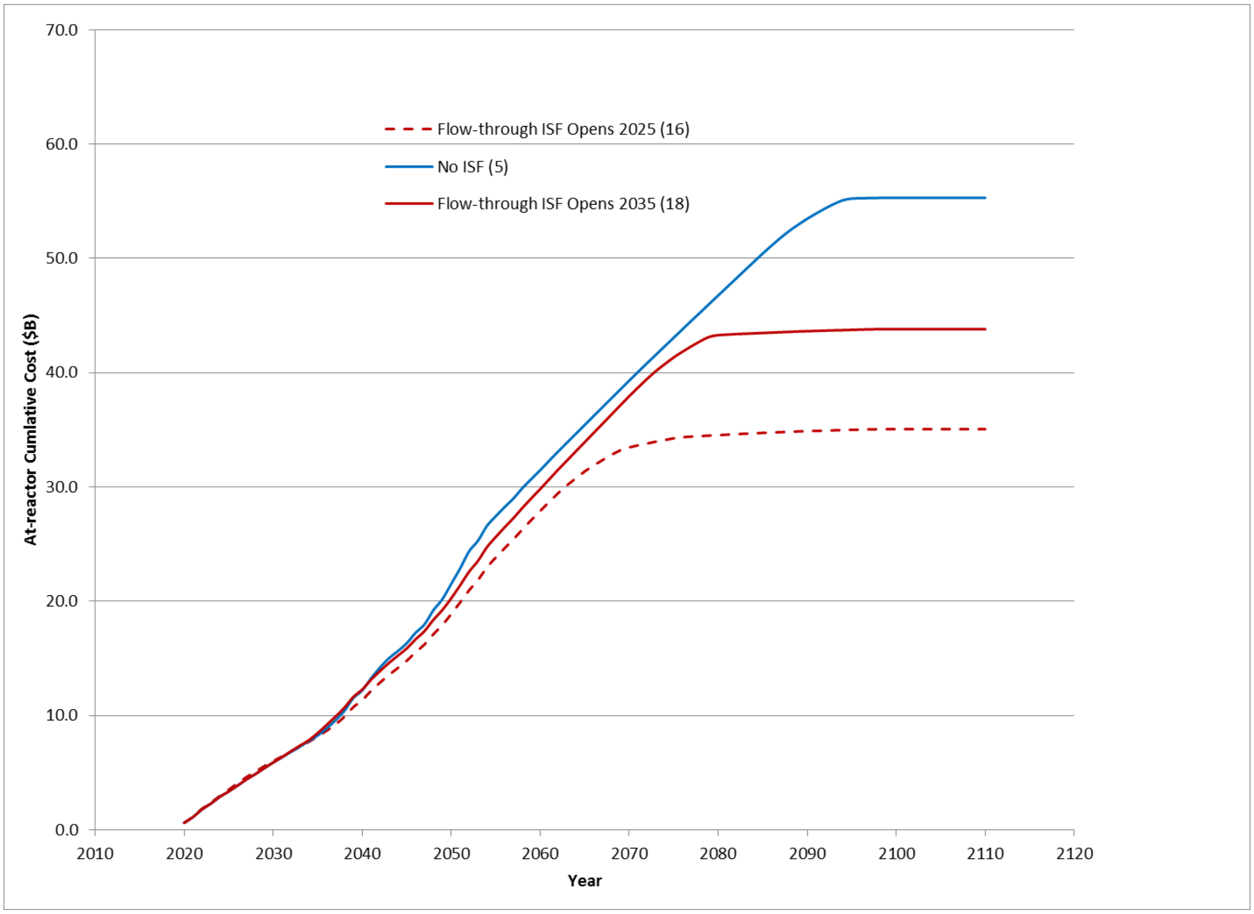

Figure 10. Total cumulative at-reactor costs for scenarios in which an ISF is implemented in 2025, in 2035, and a scenario in which an ISF is not implemented. All scenarios assume a repository will open in 2050 (Scenarios 5, 6, 8).

When comparing costs for an ISF commissioned in 2025 with a no-ISF scenario, lower at-reactor costs are not seen until approximately 2040. This is because, though some sites have all their SNF cleared, there is an increased loading of SNF canisters that then accrues more costs at reactors. These competing effects (sites being completely cleared of SNF vs. increased loading operations and canisters) keep the yearly at-reactor costs fairly similar through 2040.

After 2040, total at-reactor costs of scenarios using an ISF begin to decline as more reactors shut down, as the ISF allows those sites to be cleared, and the higher costs of post-shutdown storage are avoided. These factors are discussed further below. The scenario in which an ISF is opened in 2035, 10 years later, shifts the at-reactor cost reduction by 10 years, as well.

In general, the at-reactor cost savings (including SFP costs and dry storage pad costs) result from lower maintenance and surveillance costs, which are realized almost entirely after the reactor has shut down. These savings are directly associated with earlier acceptance of SNF at an ISF.

Figure 11 presents the yearly at-reactor costs for scenarios with and without an ISF.

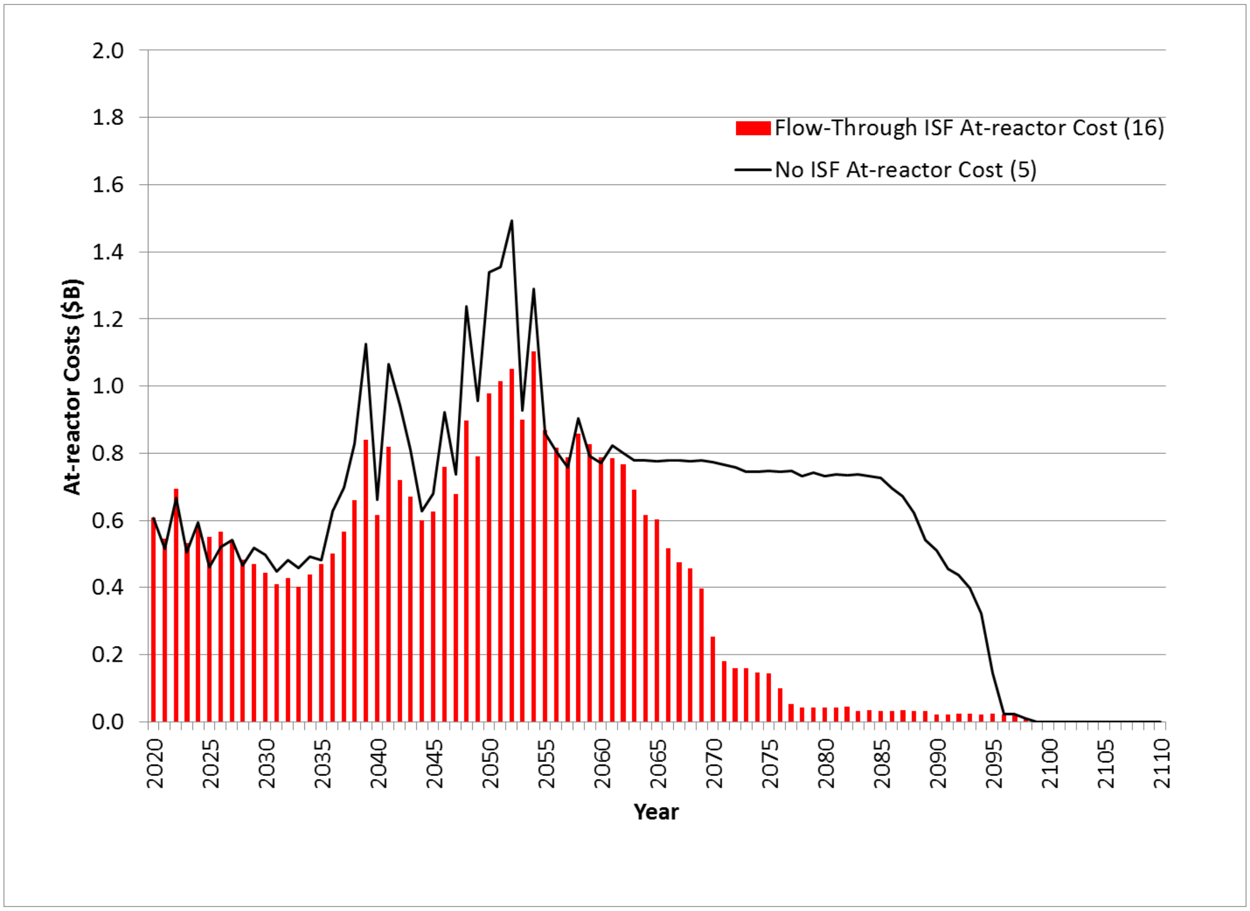

Figure 11. Comparison of at-reactor costs for scenarios with and without an ISF, with an ISF beginning operation in 2025 and a repository opening in 2050 (Scenarios 5 and 16).

When all at-reactor costs are incorporated (including loading operations and canister-based system purchases), the most significant cost differences between the ISF and no-ISF scenarios are not seen until after 2060.

Figure 12 breaks down the ISFSI maintenance and surveillance costs (loading and canister costs excluded) further into pre-shutdown and post-shutdown costs.

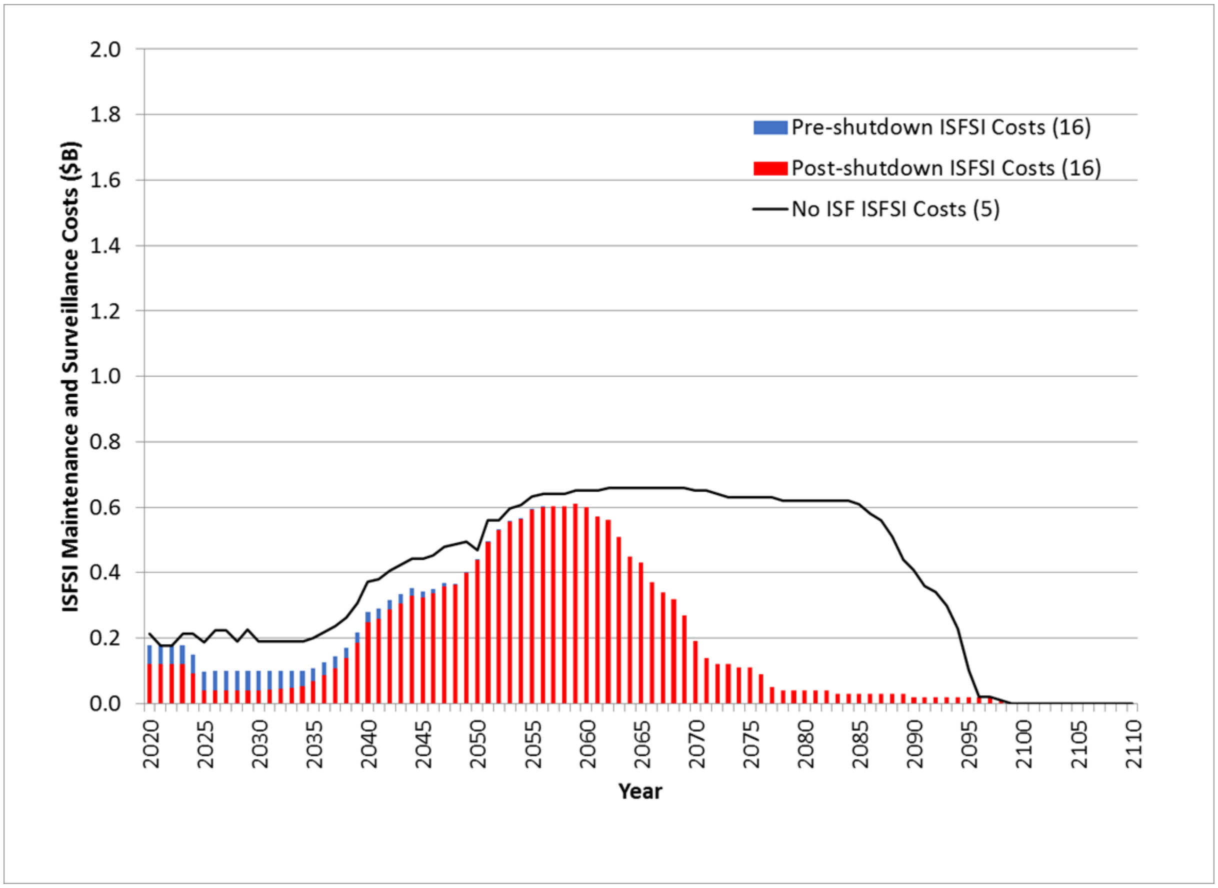

Figure 12. Comparison of the post-shutdown with the pre-shutdown ISFSI maintenance and surveillance costs for scenarios with and without an ISF providing an ISF beginning operation in 2025 and a repository opening in 2050 (Scenarios 5 and 16).

The post shutdown costs dominate the ISFSI costs because the full costs of maintenance and security for the fuel stored at the site can no longer be shared with the operating reactor and are attributed only to the continued presence of SNF on the site. Reduced ISFSI maintenance and surveillance costs are seen throughout the life of the system, but significant reductions due to incorporation of an ISF into the system start in ~2060, as ISFSIs begin to be cleared by shipment of SNF to the ISF.

3.3.2 ISF costs

This section focuses on costs resulting from activities at an ISF. As discussed earlier, these costs include receipt and shipping capital and operational costs, storage costs, and canisters (which would only be incurred in bare fuel scenarios), and overpacks purchased.

In addition, the studies investigated in this report use two different cost approximations for ISF dry storage systems. For the purpose of this study, ranges of costs for ISF dry storage systems were used to assess the impacts of an ISF on the system. The upper variant cost estimates were used to obtain a conservative estimate of the costs of ISF dry storage systems for all of the analyses shown in this report (outside of Section 3.3.2).

For ISF costs, the cost of dry storage modules (HSMs and VCCs) drives the added costs that result from building additional storage at the ISF. To see the impacts from varying the cost of ISF storage, a range of values is used. The HSMs are constructed in sets of 12 per pad; the cost per HSM is reduced from $1.319 million to $1.012 million (decrease of ~23%). The VCCs are constructed in sets of 8 per pad; however, the cost per VCC is reduced from $1.025 million to $0.8 million (decrease of ~22%). The upper variant costs ($1.319 and $1.025 million) are described in the FY12 system architecture report, and the lower variant costs ($1.012 and $0.8 million) were generated by a TechSource report [8]. The results using the TechSource information [8] show an increase in the cost avoidance associated with an ISF. See Appendix A for more information about costs used in this study.

Figure 13 compares the difference of the high and low ISF storage system cost estimates for an ISF becoming operational in 2025 and a repository in 2050.

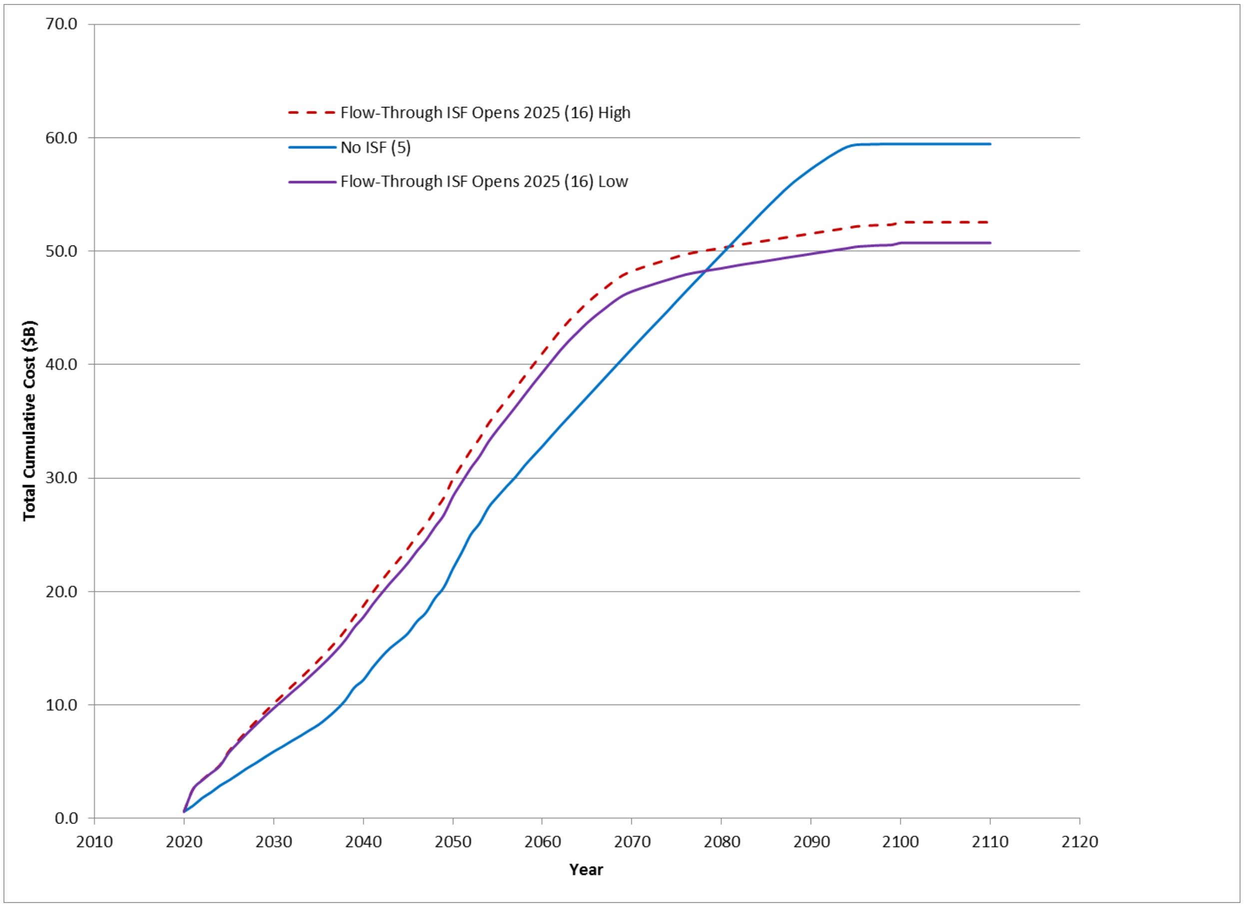

Figure 13. Comparison of the impact of high and low ISF storage cost assumptions on total cumulative system cost for an ISF beginning operation in 2025 and a no ISF scenario. All scenarios assume a repository will open in 2050 (Scenarios 5 and 16).

The results indicate that the scenario using high variant costs for ISF storage systems results in only slightly higher total system costs than a scenario using the low variant costs for ISF storage systems. Further study is needed to determine how much the ISF storage costs would need to vary to change the conclusions of this study.

3.3.3 Transportation costs

This section focuses on costs due to transportation activities. Using the same assumptions for transportation as those in Reference [9] and Table A-1 of this report, these costs include fleet capital costs, operational costs, and maintenance costs.

Using current assumptions, total life-cycle transportation costs only vary between ~$4.1 billion and ~$5.7 billion for all analyzed scenarios. Scenarios with all fuel flowing through the ISF average ~$1.1 billion in additional transportation costs when compared to the scenarios without an ISF, and scenarios with fuel that bypasses the ISF once a repository opens have an average of ~$0.6 billion in additional transportation costs when compared to scenarios without an ISF. These values show that transportation costs are not a large contributor for the cost differences between ISF and no-ISF scenarios. For this simulation, transporting the fuel twice does not appear to be a significant cost factor. Also, there are optimizations not included in this study (for conservatism) that could (and most likely would) be used to minimize transportation costs (e.g., larger consist sizes from ISF to repository).

Figure 14 breaks down the cost distribution between at-reactor, ISF, and transportation for scenarios without an ISF and with an ISF becoming operational in 2025 and with a repository opening in 2050.

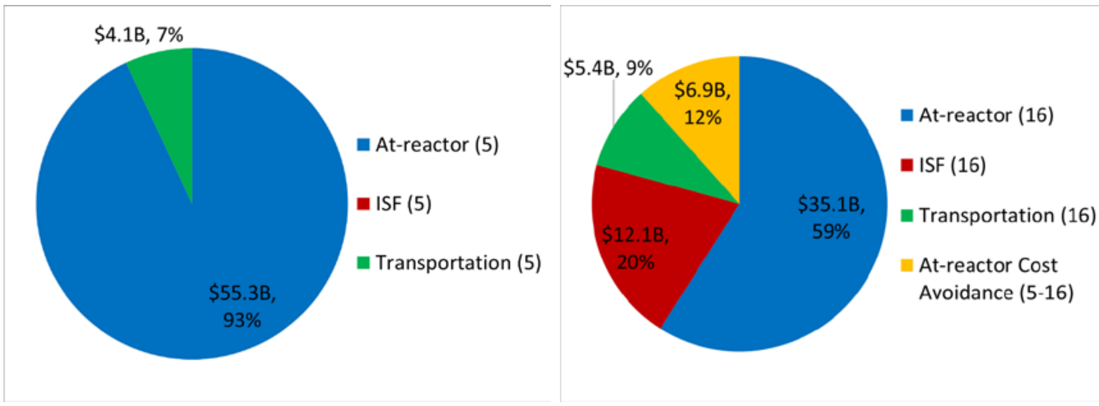

Figure 14. Cost breakdown for at-reactor, ISF, and transportation costs for scenarios without an ISF (left) and with an ISF opening in 2025 (right). Both scenarios assume a repository will open in 2050 (Scenarios 5 and 16).

Figure 14 shows that the transportation portion of total system costs is not significantly different ($4.1B vs $5.4 B) compared to total system costs for scenarios with and without an ISF. It also shows how an ISF affects the contributions from different sources (at-reactor, ISF, transportation), and the portion of the at-reactor cost that is avoided because the ISF clears the reactor sites faster.

Figure 15 breaks down the cost distribution between at-reactor, ISF and transportation for an ISF becoming operational in 2025 and with a repository opening in 2060.

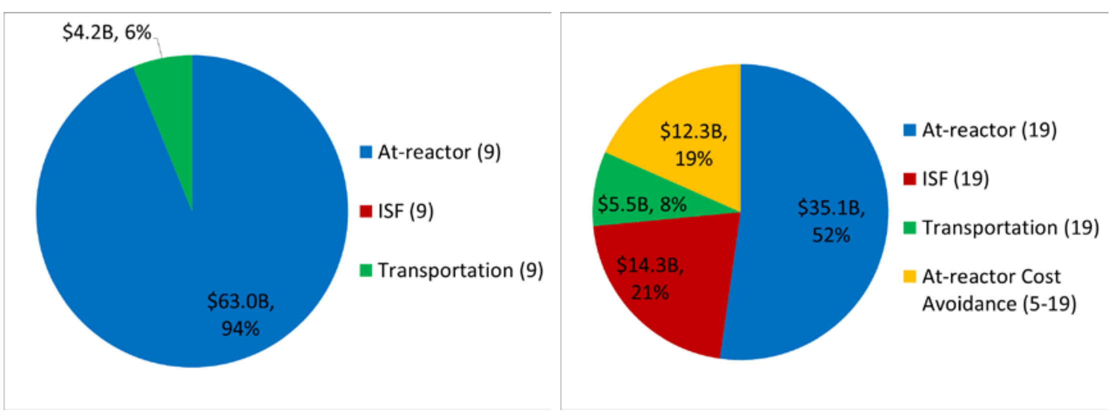

Figure 15. Cost breakdown for at-reactor, ISF, and transportation costs for scenarios without an ISF (left) and with an ISF opening in 2025 (right). Both scenarios assume a repository will open in 2060 (Scenarios 9 and 19).

Figure 15 further illustrates the point that the transportation portion of total system costs is not significantly different ($4.2B vs. $5.5B) in relation to total system costs when comparing scenarios with and without an ISF. Comparison of Figure 14 and Figure 15 shows that varying the opening date of a repository also has an insignificant effect on the portion of total system costs attributable to transportation.

These charts show that at-reactor costs dominate the total system life-cycle cost, and the ISF comprises ~20-21% of total costs. The contributions toward the total cost from transportation are not significant when compared to the contributions from at-reactor and ISF costs.

3.4 Logistics

This section focuses on the logistics of implementing an ISF in the system to provide additional insight into which operations are driving the costs.

3.4.1 Summary table

The logistics information discussed throughout this section is summarized in Table 2. Table 2 compares the cumulative number of shutdown site-years that SNF is onsite, the peak number of canisters at the ISF, and the number of years an ISF remains open with fuel onsite. Scenarios compared are those with a repository opening date of 2040, 2050, or 2060 with either no ISF or an ISF opening in 2025 or 2035.

Table 2. Logistics summary table.

	Repository (Year)	**2040**	**2050**	**2060**
Flow-through ISF 2025	Years ISFSI operates without SFP	1903	1903	1903
	Peak canisters at ISF	3996	6430	8799
	Number of years fuel at ISF	78	78	85
Flow-through ISF 2035	Years ISFSI operates without SFP	2550	2550	2550
	Peak canisters at ISF	1514	3954	6311
	Number of years fuel at ISF	68	68	75
No ISF	Years ISFSI operates without SFP	2906	3632	4244
	Peak canisters at ISF	0	0	0
	Number of years fuel at ISF	0	0	0

3.4.2 Cumulative number of shutdown site-years SNF is on-site

This section analyzes the total number of years that shutdown sites have SNF on-site.

Figure 16 compares the number of years the ISFSI operates without the SFP.

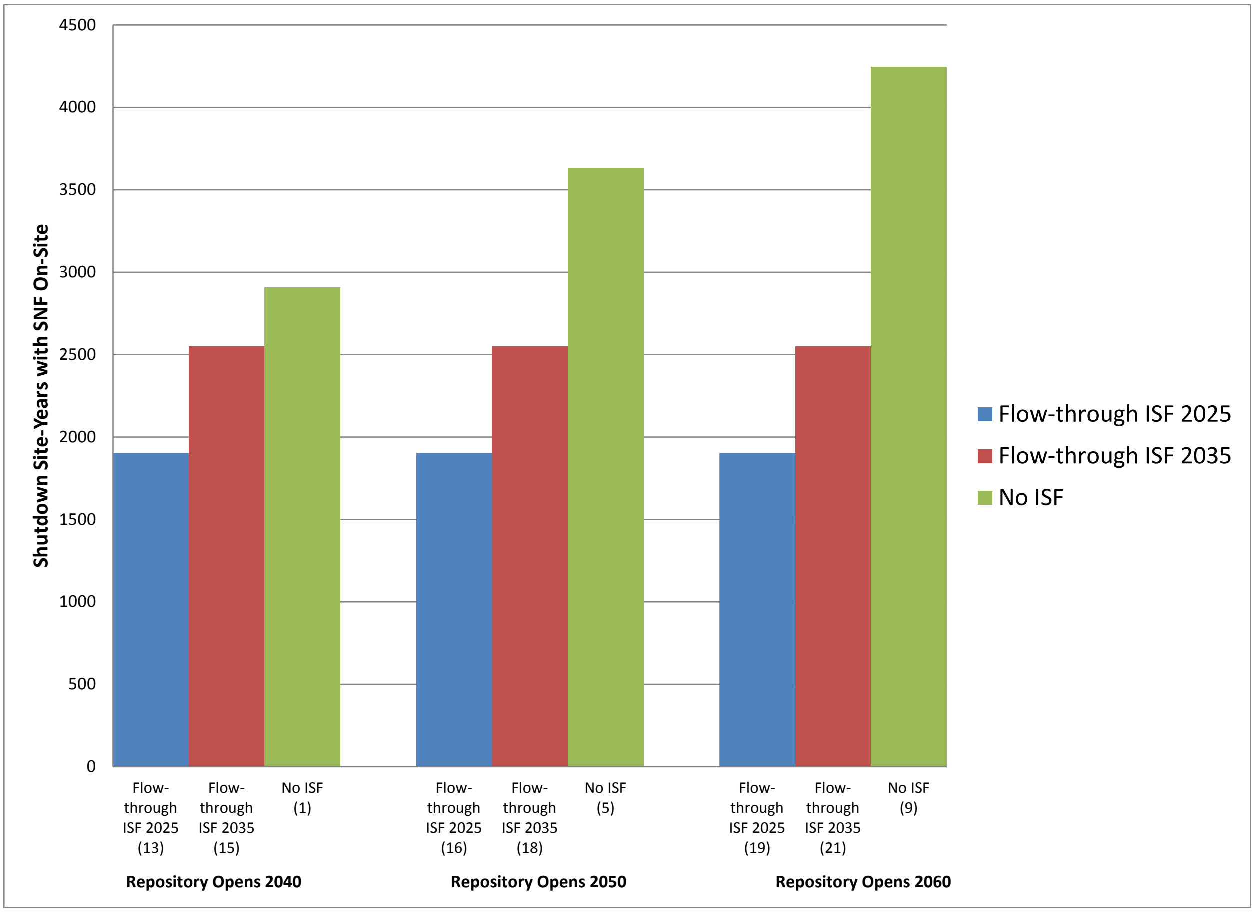

Figure 16. Comparison of the cumulative number of shutdown site-years that SNF remains on-site with varying start dates for both an ISF and repository (Scenarios 13, 15, 1, 16, 18, 5, 19, 21, 9).

The year of first fuel acceptance is directly related to the number of years shutdown reactors have fuel onsite. Figure 16 shows that if an ISF opens in 2025, the date that a repository opens has no effect on the total cumulative number of shutdown site-years with SNF onsite. However, if an ISF never opens, then the date when a repository opens has a significant impact on the total site-years with SNF onsite (the total number site-years with SNF onsite increases as a repository is delayed). Increases in the number of site-years with SNF onsite directly correlate to an increase in total at-reactor costs because the post-shutdown costs dominate the total costs.

3.4.3 Peak number of canisters at ISF

This section analyzes the peak number of canisters stored at the ISF as a function of ISF and repository start date, which is shown in Figure 17.

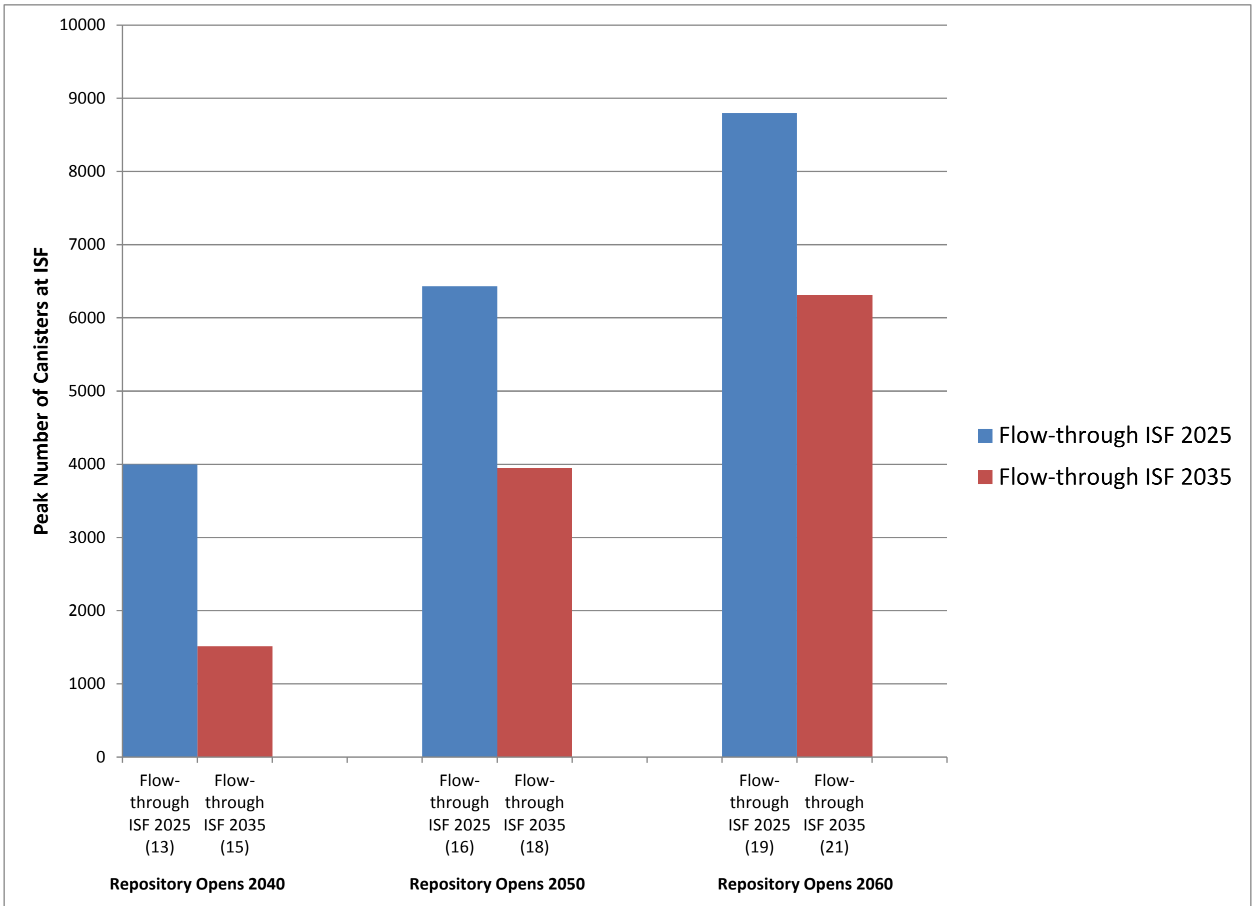

Figure 17. Comparison of the peak number of canisters stored at an ISF with various start dates for an ISF and repository (Scenarios 13, 15, 16, 18, 19, 21).

As expected, the results indicate that the longer the ISF is open without a repository, the more canisters accumulate at the ISF. The major factors affecting the peak number of canisters at an ISF are the ISF start date and the repository start date. In general, as the peak number of canisters stored at the ISF increases, the ISF storage costs increase because more modules must be purchased to store all of the canisters at the ISF.

3.4.4 Number of years an ISF operates

This section analyzes the number of years an ISF operates as a function of ISF and repository start dates, which is shown in Figure 18.

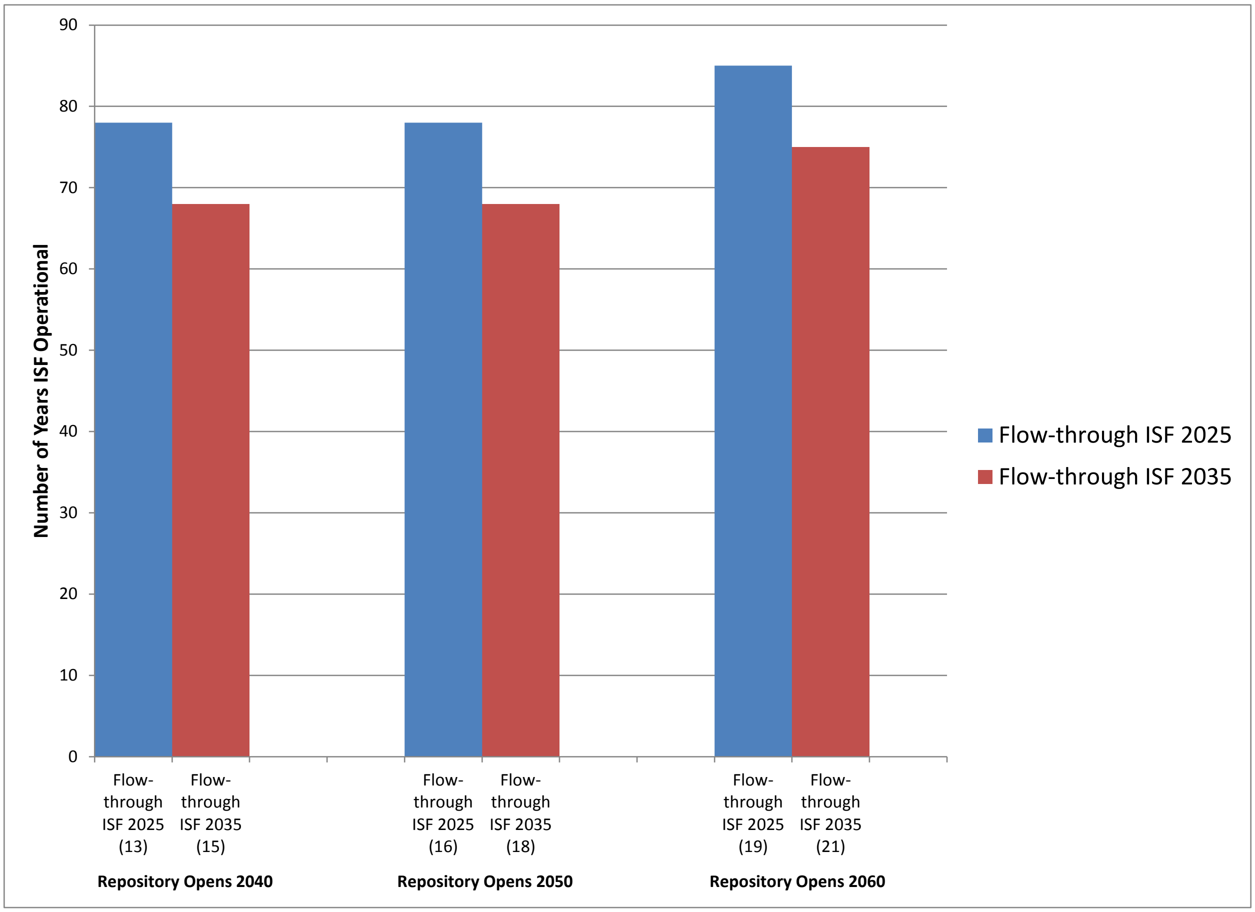

Figure 18. Comparison of the number of years an ISF is operational using different start dates for an ISF and repository (Scenarios 13, 15, 16, 18, 19, 21).

The number of years an ISF is operational depends on the start dates of the ISF and the repository. If the repository is delayed past 2050, the ISF remains in operation longer, regardless of when the ISF begins operation.

4. CONCLUSIONS

This report provides an evaluation of the cost implications of incorporating an ISF into the waste management system. Specifically, the impacts of the timing of opening an ISF relative to opening a repository were analyzed to understand the potential effects on total system costs.

In this study, the following ROM total system costs were calculated and tabulated including:

- **At-reactor costs**, including ISFSI operational and maintenance costs, SFP operational and maintenance costs five years after the reactor shutdown, and all canister and overpack loading and procurement costs;
- **Transportation costs**, including fleet capital costs, operational costs, and maintenance costs; and
- **ISF costs**, including receipt and shipping facility capital and operational costs, storage overpack costs, deactivation & decommissioning costs, and canisters purchased (only incurred in bare fuel scenarios).

This assessment did not consider any repackaging costs or repository costs, because it was assumed that these costs would be identical for all scenarios since the same quantity of SNF is disposed in each scenario.

This report documents evaluations of different scenarios involving shipment of SNF from reactors in DPCs currently being used by utilities for dry storage at reactor sites. In some scenarios, all fuel is shipped and stored in such canisters. In other scenarios, once a federal facility is available to accept it, bare fuel is shipped directly from the SFPs in reusable transportation casks where it is stored in DPCs at the ISF. For simplicity and conservatism in estimating cost impacts of incorporating an ISF facility, the detailed analysis presented in this report focuses on the scenarios in which fuel is stored and transported in DPC systems. The focus on dry canister storage was selected because it is the current utility practice and has been for almost three decades. As such, it is appropriate to initially focus on canistered fuel storage as the basis for an economic evaluation of an ISF. A number of pertinent conclusions can be drawn from this evaluation.

- **Delay in repository availability increases total system costs**. Any delay in opening a repository increases total system costs, regardless of whether the system has an ISF or not. This is due to the increased at-reactor costs, including monitoring and maintenance of ISFSIs at shutdown reactor sites for more years.
- **There is a (potentially large) total system lifecycle cost avoidance in all scenarios with an ISF when compared to scenarios with no ISF for the assumptions used in this study**. However, most of the cost avoidance occurs several decades after the ISF is opened.
- **Earlier establishment of an ISF allows for more avoidance of post-shutdown at-reactor storage costs for any repository opening date than not incorporating an ISF.** An ISF allows earlier acceptance of fuel from reactors, which reduces at-reactor costs from a total system perspective.

Along with these summary points**, this analysis showed**

- **Transportation costs have little impact on a waste management system with or without an ISF**. These impacts range from 3–11% in all scenarios. Therefore, transporting the fuel twice does not appear to be a significant cost concern relative to other system costs.
- **At-reactor costs dominate the total system life-cycle cost,** while the ISF comprises ~20–21% of total costs.

In conclusion, an *ISF integrated into the waste management system has a total system economic benefit relative to the status quo, but that benefit will not be realized for many decades*. An ISF has the potential to avoid billions of dollars of total system cost in the long run. However, alternative economic assumptions, to be explored in a future sensitivity study, may affect the results of this evaluation. Therefore, it may be best to view an ISF as an economic investment in the nuclear waste management system, providing a range of benefits that have been identified in previous studies. These benefits include accelerated initiation of federal waste acceptance, enhanced stakeholder confidence, enhanced waste management system flexibility, and the development of experience related to large-scale SNF handling, storage, and transportation to benefit design and operation of a repository.

This study assumes a constant 3,000 MTHM/yr acceptance rate and, following shipment of SNF from an initial set of nine shutdown reactor sites, applies an allocation strategy according to the oldest-fuel-first acceptance priority ranking as defined in 10 CFR Part 961 (i.e., the Standard Contract). Other studies [1] have shown that both a site-specific allocation strategy and an accelerated acceptance rate could reduce at-reactor costs, which would make an ISF even more attractive because it would allow earlier implementation of these strategies.

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APPENDIX A: Input Data Assumptions

This section details the data assumptions used in this report.

The annual cost to maintain an SFP after the reactor is shut down is increased from $10 million to $23.8 million (though the at-reactor costs do not start accruing until five years after shutdown) with each additional SFP onsite assumed to add $2 million per year. The annual cost to maintain an ISFSI while there is fuel in the SFPs is increased from $0.6 million to $1 million. The annual cost to maintain an ISFSI after all the SFPs on a site have been emptied is increased from $6 million to $10 million.

The HSMs continue to be constructed in sets of 12 HSMs per pad; however, the cost per HSM is reduced from $1.319 million to $1.012 million (decrease of ~23%). The VCCs are constructed in sets of 8 per pad; however, the cost per VCC is reduced from $1.025 million to $0.8 million (decrease of ~22%).

A-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 [9] as shown in Table A-1.

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

Description of item	Value from data report
ISF location	Eastern US
Cask maintenance facility, trailer maintenance facility, railcar maintenance facility	Eastern US
Repository location	Western US
SNF canister module capacity - VCCs	8
SNF canister module capacity - HSMs	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
At-reactor ISFSI operations cost per year (if SFP/reactor operational)	$1M
At-reactor ISFSI operations cost per year (if SFP/reactor shutdown)	$10M

Description of item	Value from data report
At-reactor pool operations costs per year for 1st SFP (if reactor shutdown)	$23.8M
At-reactor pool operations costs per year for each additional SFP after the first (if reactor shutdown)	$2M
At-reactor SFP to ISFSI loading cost per campaign	$0.75M
At-reactor SFP 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[q]	$0.3M
At-reactor SFP to ISFSI loading cost per canister	$0.5M
At-reactor SFP to transportation cask (rail) loading cost per canister	$0.5M
At-reactor SFP to transportation cask (legal weight truck) loading cost per canister	$0.3M
Cask railcar capital cost	$2M
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[r]	$116.3M
ISF D&D cost: fraction of all capital costs	0.1
ISF canister processing bay capital cost	$73.8M
ISF bare fuel processing bay capital cost	$154.1M
Dry storage module capital cost: VCCs (cost per module) (upper variant)	$8.2M
Dry storage module capital cost: HSMs (cost per module) (upper variant)	$15.8M
Heavy haul truck speed	4 mph
Mainline rail track classes G, H, and X speed and shortline rail	20 mph
ISFSI construction costs	$35M

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

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

A-2. Evaluation-Specific Input data

This section lists data that were assumed for this evaluation and are shown in Table A-2.

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

Description of Item	Assumption for Value
Dry storage module capital cost: VCCs (cost per module) (lower variant)	$6.4M
Dry storage module capital cost: HSMs (cost per module) (lower variant)	$12.144M
Barge speed	5 mph
Mainline rail track classes A, B, and C speed	50 mph
Legal weight truck speed	50 mph
Time required to handle a cask (e.g., receipt, shipment) at the ISF	720 minutes
Default consist size for original 9 shutdown reactors	2
Default consist size for all other reactors	4
Default consist size for ISF-to-MGR shipments	4
ISF capital cost	$1B

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APPENDIX B: Scenario Descriptions

This section describes the different scenarios given in this report. As described in Section 2, specific scenarios include the following decision points:

Based on these decision points, 42 scenarios were analyzed. The different scenarios analyzed in this study are shown in Table B.1.

1. In what year does a full-scale ISF open?
   (a) 2025 (b) 2030 (c) 2035
2. In what year does a repository open?
   (a) 2040 (b) 2050 (c) 2060
3. Is an ISF a part of the system?
   (a) no, go to question 4.
   (b) yes, as a flow-through part that receives, stores, and ships all SNF before and during repository operation.
   (c) yes, as a bypassed facility that receives and stores SNF only when a repository is not able to do so.[s]
4. Do reactors begin loading bare[t] fuel for shipment to an ISF or repository once one is available?
   (1) yes (2) no

[s] A "flow-through ISF" is defined as an ISF that is an integral component of the nuclear waste management system throughout its entire life cycle. In flow-through ISF scenarios, all SNF from reactors will be transported first to an ISF (even if a repository is available) before being transported to a repository. A bypassed ISF is defined as an ISF where all SNF does not flow through the ISF throughout its entire life cycle. In bypassed ISF scenarios, the bypassed ISF functions as a centralized storage facility until a repository begins accepting SNF. At that point, a repository prioritizes accepting fuel directly from reactors over SNF from the ISF.

[t] Bare fuel is non-canistered assemblies. Generally bare fuel would be transported by reusable transportation casks from the reactors to an ISF or a repository.

Table B-1. Descriptions of scenarios modeled in this study.

Scenario #	Type of Fuel	Type of ISF	Fully Operational Interim Storage Facility	Fully Operational Repository	Costs ($B)			
	Cans Only/ Cans & B.F.	Bypassed/ Flow-Through	None/2025/ 2030/2035	2040/2050/ 2060	At Reactor	Transport-ation	ISF	Total
1	Cans Only	None	None	2040	48.7	4.2	0.0	52.8
2	Cans Only	Bypassed	2025	2040	35.1	4.8	7.1	45.9
3	Cans Only	Bypassed	2030	2040	39.2	4.6	5.6	48.5
4	Cans Only	Bypassed	2035	2040	43.8	4.5	4.1	51.3
5	Cans Only	None	None	2050	55.3	4.1	0.0	59.4
6	Cans Only	Bypassed	2025	2050	35.1	4.9	10.1	49.0
7	Cans Only	Bypassed	2030	2050	39.2	4.8	8.6	51.6
8	Cans Only	Bypassed	2035	2050	43.8	4.6	7.1	54.5
9	Cans Only	None	None	2060	63.0	4.2	0.0	67.1
10	Cans Only	Bypassed	2025	2060	35.1	5.1	13.1	52.2
11	Cans Only	Bypassed	2030	2060	39.2	4.9	11.6	54.8
12	Cans Only	Bypassed	2035	2060	43.8	4.8	10.1	57.7
13	Cans Only	Flow-Through	2025	2040	35.1	5.4	9.3	48.7
14	Cans Only	Flow-Through	2030	2040	39.2	5.3	7.6	51.0
15	Cans Only	Flow-Through	2035	2040	43.8	5.2	5.8	53.7
16	Cans Only	Flow-Through	2025	2050	35.1	5.4	12.1	51.5
17	Cans Only	Flow-Through	2030	2050	39.2	5.3	10.6	54.1
18	Cans Only	Flow-Through	2035	2050	43.8	5.2	8.9	56.9
19	Cans Only	Flow-Through	2025	2060	35.1	5.5	14.3	53.8
20	Cans Only	Flow-Through	2030	2060	39.2	5.4	13.1	56.7
21	Cans Only	Flow-Through	2035	2060	43.8	5.4	11.6	59.8
22	Cans & B.F.	None	None	2040	70.7	4.2	0.0	74.9
23	Cans & B.F.	Bypassed	2025	2040	43.0	4.8	11.4	58.2
24	Cans & B.F.	Bypassed	2030	2040	52.1	4.6	8.6	64.3
25	Cans & B.F.	Bypassed	2035	2040	60.2	4.5	5.7	69.5
26	Cans & B.F.	None	None	2050	92.8	4.2	0.0	97.0
27	Cans & B.F.	Bypassed	2025	2050	43.0	5.0	16.5	63.5
28	Cans & B.F.	Bypassed	2030	2050	52.1	4.9	13.7	69.6
29	Cans & B.F.	Bypassed	2035	2050	60.2	4.7	10.9	74.9
30	Cans & B.F.	None	None	2060	115.8	4.2	0.0	119.9
31	Cans & B.F.	Bypassed	2025	2060	43.0	5.2	20.5	67.7
32	Cans & B.F.	Bypassed	2030	2060	52.1	5.1	17.8	74.0
33	Cans & B.F.	Bypassed	2035	2060	60.2	4.9	15.0	79.2
34	Cans & B.F.	Flow-Through	2025	2040	43.0	5.6	16.1	63.7
35	Cans & B.F.	Flow-Through	2030	2040	52.1	5.5	13.4	70.0
36	Cans & B.F.	Flow-Through	2035	2040	60.2	5.4	10.7	75.4
37	Cans & B.F.	Flow-Through	2025	2050	43.0	5.7	19.3	66.9
38	Cans & B.F.	Flow-Through	2030	2050	52.1	5.5	16.9	73.4
39	Cans & B.F.	Flow-Through	2035	2050	60.2	5.4	14.3	78.9
40	Cans & B.F.	Flow-Through	2025	2060	43.0	5.7	21.6	69.3
41	Cans & B.F.	Flow-Through	2030	2060	52.1	5.5	19.5	76.1
42	Cans & B.F.	Flow-Through	2035	2060	60.2	5.4	17.3	82.0