Potential Cost Implications of an Interim Storage Facility for Commercial SNF[+] - 17132

Joshua Jarrell*, Robert A. Joseph III*, Rob Howard*, Riley Cumberland*,
Gordon Petersen*, Mark Nutt**, Joe Carter***, Tom Cotton****
* Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
jarrelljj@ornl.gov, 865-574-9643
** Argonne National Laboratory, Argonne, IL 60439, USA
*** Savannah River National Laboratory, Aiken, SC 29808, USA
**** Complex Systems Group, LLC, Washington, D.C., USA

ABSTRACT

The question of whether or not consolidated interim storage of commercial spent nuclear fuel (SNF) should be part of the federal waste management system as an intermediate step before permanent disposal has been debated for more than four decades. This paper summarizes an evaluation of the cost implications of incorporating a consolidated interim storage facility (ISF) into the waste management system (WMS). In this study, the order-of-magnitude estimates of total system[a] costs[b] were calculated and tabulated. The analyzed scenarios involve shipment of SNF from reactors in dual-purpose storage and transportation canisters (DPCs) currently being used by utilities for dry storage at reactor sites. A number of pertinent conclusions can be drawn from this evaluation, including:

- **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 multiple independent spent fuel storage installations (ISFSIs) or at an ISF, until waste can be disposed of.

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

[a] *"Total system" in this 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 2015 constant dollars. Future work will apply different escalation, inflation, and discounting rates.*

- **There is a potential total system lifecycle cost avoidance in realistic[c] scenarios with an ISF when compared to scenarios with no ISF**. 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 storing the fuel in a consolidated facility rather than at individual reactor sites.

- **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.

- **Transportation costs have little impact on a WMS 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 driver relative to other system costs.

In conclusion, designing, licensing, and constructing an ISF will require a large near-term financial investment. However, reduced annual operating and maintenance costs for an integrated waste management system with an ISF, compared to a system without an ISF, could eventually result in system-wide (integrated) cost avoidance due to reductions in at-reactor storage costs in the long term. The largest cost avoidances would not occur for several decades, so assumptions about inflation, escalation, and discount rates will have a significant effect on potential economic impacts of an ISF. It should be noted that other benefits associated with the investment of an ISF—such as earlier removal of SNF from shutdown reactor sites, earlier prospects for site reutilization, and additional overall integrated waste management system flexibility—were not addressed in this study.

INTRODUCTION

The Nuclear Fuel Storage and Transportation Planning Project (NFST), under DOE's Office of Nuclear Energy, Office of Fuel Cycle Technologies, is performing waste management system (WMS) analysis to inform future decisions that will affect how the entire integrated waste management system (IWMS) is configured, deployed, and operated. In support of this task, NFST sponsored a rough order of magnitude (ROM) analysis of the direct cost implications of including an interim storage facility (ISF) in the WMS.

The preliminary ROM cost estimates presented in this study are not project cost and schedule baseline quality data and should only be used with full recognition of the constraints of this analysis. Simplified assumptions are used to define and evaluate 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. This study compares the cost of continued distributed at-reactor

[c] **Realistic scenarios** *are those in which an ISF is fully operational at least 10 years prior to the repository.*

storage to an IWMS that includes an ISF, but it does not examine all 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.

This work initially compares the *constant 2015 dollar* future life cycle costs of IWMS scenarios consisting of (1) continuation of at-reactor SNF management (including on-site dry storage only) and (2) at-reactor SNF management supplemented by a centralized ISF located at a hypothetical site. A variety of scenarios defined by parameters such as the opening dates for an ISF and ultimately for a geologic SNF repository at a hypothetical site were analyzed. For various scenarios, constant dollar annual cash flows spanning the time period from 2020 to 2110 are presented. Only SNF arising from the continued operation of today's decommissioned, shut-down, and operating domestic nuclear power plants is considered, for a total amount projected to be on the order of 142,000 metric tons of heavy metal (MTHM). In addition to this constant dollar evaluation, various inflation, escalation, and discounting assumptions for scenarios with and without an ISF were also evaluated.

While this paper focuses on cost implications, cost is only one of several important factors when planning deployment of an ISF as part of an IWMS. Such objectives, which are discussed most recently in the report of the Blue Ribbon Commission and the Administration's *Strategy* [1], include but are not limited to (1) demonstration of the federal commitment to addressing SNF and high-level radioactive waste disposal, (2) expeditious initiation of the fulfillment of government contractual responsibilities, (3) reduction of long-term financial liabilities, (4) enhanced WMS flexibility, including the ability to respond to emergencies and other situations until and while a repository is active, (4) 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, (5) development of trust among stakeholders regarding consent-based process to benefit future siting of a repository and other facilities, and (6) 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 global development of nuclear energy.

SCENARIOS AND ASSUMPTIONS

In FY2015, NFST analyzed 42 system alternatives with and without an ISF [2]. These scenarios were based on a combination of four questions:

1. How is an ISF used in the system? No ISF, all fuel goes through the ISF, some fuel goes through the ISF?
2. When does a full-scale ISF begin operations? 2025, 2030, or 2035?
3. When does a repository begin operations? 2040, 2050, of 2060?
4. Is all fuel loaded into welded canisters, or are reusable transportation casks used?

In these system scenarios, the assumptions below were made to provide a conservative estimate of ISF costs based on current industry practice:

1. 3,000 MTHM/yr acceptance rate is anticipated from the reactor sites.
2. 3,000 MTHM/yr acceptance rate is anticipated at a repository.
3. The nine reactor sites[d] 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.
4. Oldest-fuel-first allocation[e] and youngest-fuel-first[f] acceptance strategies are implemented for all other reactors.
5. All repackaging (if required) is performed at a repository.
6. No bare fuel is stored at the ISF.
7. No blending, SNF mixing, or thermal constraints are imposed at a repository.

Based on the results of these scenario evaluations, this paper focuses on two system alternatives that were downselected for more detailed investigation. These two scenarios are described below:

1. No-ISF Scenario: No ISF is used in the IWMS, the repository opens in 2050, and all fuel is loaded into welded canisters.
2. ISF Scenario: A full-scale ISF opens in 2025 and all fuel passes through the ISF, the repository opens in 2050, and all fuel is loaded into welded canisters.

These two scenarios were selected because (1) the current industry practice is to use canisters instead of bare fuel casks for fuel storage, and (2) it is deemed unlikely that a reactor would maintain bare fuel access in spent fuel pools for multiple decades once it is shut down. While the analysis in this report is based on the previous cost implications report [2], updated unit cost estimates for an ISF based on industry-led design activities have been used to update the initial 2015 calculations.

CONSTANT DOLLAR RESULTS

Assuming constant dollars (i.e., no inflation, discount rate), the system cost as a function of year for the two scenarios can be seen in Fig. 1. Major ISF-related expenditures are shown in years 2021, when the ISF begins pilot operation, 2025, when the ISF begins full operation, and 2100, when the ISF is decommissioned. The highest expenditure occurs in year 2021, which includes the pilot ISF infrastructure and transportation capital costs, as well as an assumed $1B of

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[d] *The nine original shutdown sites in this study are Big Rock Point, Connecticut Yankee, Maine Yankee, Yankee Rowe, Rancho Seco, Trojan, Humboldt Bay, LaCrosse, and Zion.*

[e] *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.*

[f] *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).*

accumulated programmatic cost from the prior decade. Assuming that these costs occur in a single year is conservative for this study.

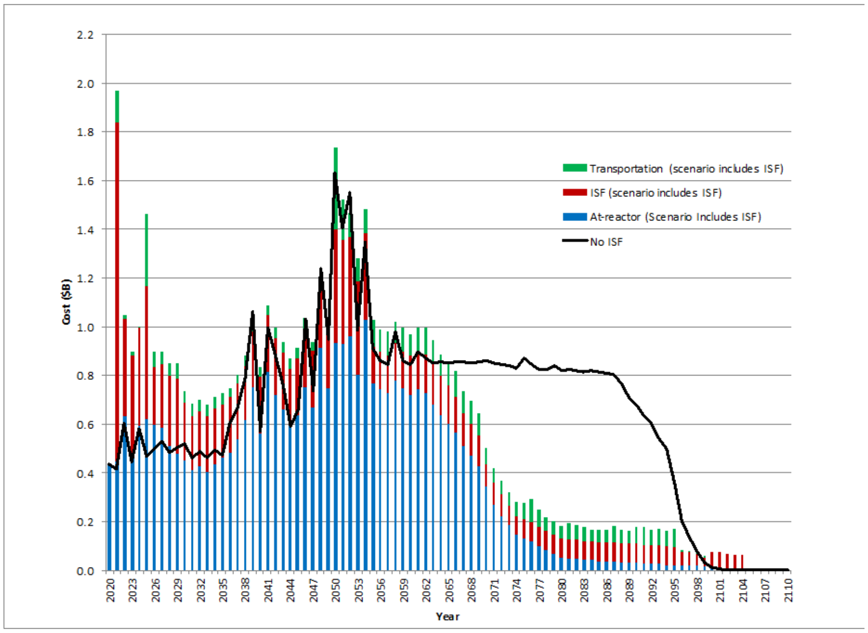

Fig. 1. Total Annual System Cost of Implementing an ISF in 2025 with a Repository Beginning in 2050 Compared to a Scenario without an ISF but with a Repository Beginning in 2050 for a Canister-Only System.

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, while the ISF scenario has higher yearly costs before then. This cost avoidance is driven by the reduction in the high cost of post-shutdown at-reactor storage. While the ISF scenario has higher yearly costs through 2065.

The yearly at-reactor costs are illustrated in Fig. 2. 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 2065.

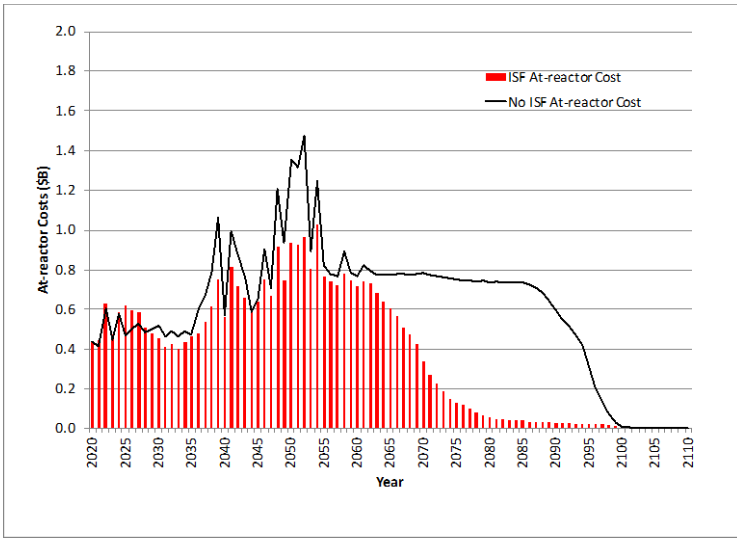

Fig. 2. Comparison of At-Reactor Costs for Scenarios With and Without an ISF, With an ISF Beginning Operation in 2025 and a Repository Opening in 2050.

The at-reactor ISFSI maintenance costs broken down by whether the reactors have shut down by year are shown in Fig. 3. 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.

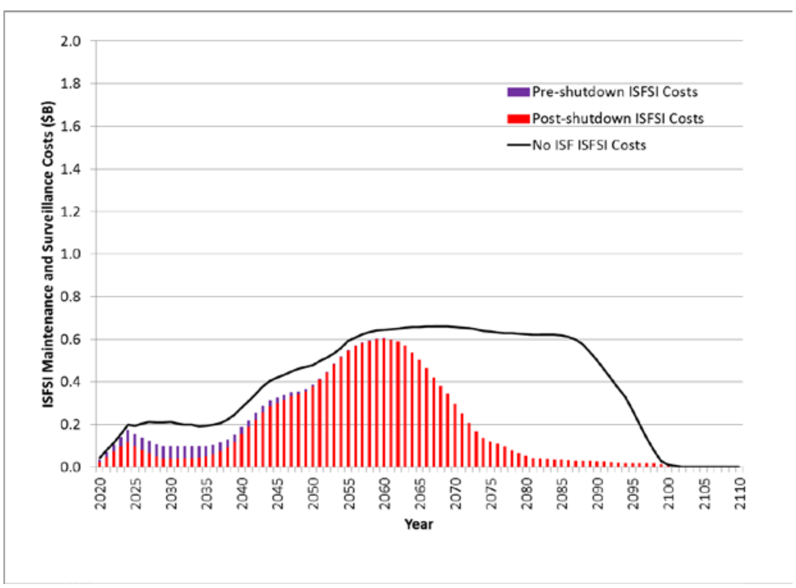

Fig. 3. Comparison of the Post-Shutdown with the Pre-Shutdown ISFSI Maintenance and Surveillance Costs for Scenarios With and Without an ISF, Providing an ISF Beginning Operation in 2025 and a Repository Opening in 2050.

Several pertinent conclusions can be drawn for the analyses performed with constant dollars:

- Delay in repository availability increases total system costs. Any delay in opening a repository increases total system costs, regardless of whether a system has an ISF or not.
- There is a (potentially large) total system lifecycle cost avoidance in all scenarios with an ISF compared to scenarios without an ISF. 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.
- Transportation costs have little impact on an IWMS with or without an ISF. Therefore, transporting the fuel twice does not appear to be a significant cost concern relative to other system costs.

Based on these results, more detailed economic evaluations were performed to include inflation, discount rates, and escalation rates.

ECONOMIC ENVIRONMENT TERMINOLOGY

Budgeting and funding planning for such a long-term enterprise requires financial *figures-of-merit* other than only lump sum *constant dollar* totals. The existence of general inflation in the US economy and incremental escalation due to generic factors endemic to nuclear projects means that the ultimate *as spent* lifecycle cost could be significantly higher than the total of the projected constant dollar cash flows. In fact, the US Congress requires that project budget estimates be appropriately presented in projected *to-be-spent* inflated dollars. Inflated dollars are sometimes called *escalated dollars*. However, total escalation can have two parts: (1) an inflation component attributable to cost/price increases in the general national economy and (2) incremental (or additional) escalation due to project-specific factors such as procurement difficulties and project execution problems.

Discounting

Discounted dollars for a given year and cash flow are calculated by dividing each constant dollar cash flow at year n by a compound interest term,

$$(1 + i_d)^n, \qquad \text{(Eq. 1)}$$

where i is discount rate and n is the number of years after the base year for constant dollar costing. *Real discount rates* are applied to constant dollar cash flow streams, and *nominal discount rates* are applied to cash flow streams affected by inflation and/or incremental cost escalation.

The sum of all of the discounted cash flows over the project life cycle is called the net present value (NPV). It can be seen that projects of long duration with significant outyear cash flows will have a lower NPV than projects costing the same amount in constant dollars but with nearer term future expenditures.

Escalation

Escalation reflects that inflation and other factors tend to drive future costs above today's costs. For this study, escalation is divided into two parts: a *general inflation* component and an *incremental escalation* factor dependent upon project-specific attributes such as use of high demand commodities, need for additional construction and regulatory person-hours, and unanticipated wage increases due to shortages of nuclear-qualified craft workers. Inflated dollars for a given year and cash flow are calculated by multiplying each constant dollar cash flow for year n by the following compound interest term:

$$(1 + i_{inf})^{n}. \quad \text{(Eq. 2)}$$

Incremental escalation above inflation can be applied by applying the same formula to the inflated dollar cash stream using the *incremental inflation rate*.

APPROPRIATE ECONOMIC PARAMETERS

The following is a discussion of the rationale for selecting the economic parameters to define a base case and ranges for study. Each of the three following parameters is discussed in a separate subsection below: (1) discount rate, (2) general inflation rates, and (3) incremental escalation rate (above general inflation). A summary of the base case rates is shown in Table I.

Table I. Base Case Values for Economic Environment.

General Inflation	2.00%	
Incremental Escalation above General		
At-reactor costs	3.00%	
ISF costs	3.00%	
Transportation costs	0.00%	
Discount Rates		
	Real	Nominal
At-reactor costs	1.50%	3.50%
ISF costs	1.50%	3.50%
Transportation costs	1.50%	3.50%

Discount Rate

Per the US Government's Office of Management and Budget (OMB) Circular No. A-94, "Revised on Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs" [3], analyses should include comprehensive estimates of the expected benefits and costs to society based on established definitions and practices for program and policy evaluation. For simplicity and to more closely approximate the current economic environment, 2016 long-term discount rates of 1.5% real and 3.5% nominal from the revised Appendix C of Circular A-94 [4] were used for the base case (starting point) for this study and were simply applied to all cost elements. It should be understood that the base case represents a starting point for the sensitivity analyses, and it is recognized that the real and nominal discount rates may actually be higher based on Nuclear Waste Fund (NWF) and public investment considerations. Accordingly, a range of discount rates that envelopes the values discussed above are examined.

General Inflation Rate

General inflation in the US has been measured by the Department of Commerce since the Federal Reserve System was established in 1913. Prior to 1913, economists used various aggregated price indices for manufactured goods and agricultural commodities to arrive at an average inflation measure. From 1913 to 2015, inflation has averaged 3.27% per year. Chapter 2 and the appendices to the DOE's Fee Adequacy Report [5] contain a table with forecasts of inflation rates and interest rates. Based on the middle range of these data, a general US inflation rate of 2.0% per annum has been selected for the base case for this study.

Incremental Escalation Rate

Incremental escalation represents the average increase in project costs beyond that imposed by general inflation. The reasons for incremental escalation are usually specific to the nature of the project, such as project technology, the maturity of the technology, and project susceptibility to regulatory, legal, and project management difficulties. A paper on this subject entitled "Historical construction costs of global nuclear power reactors" [6] has been published in the journal *Energy Policy*. For dry storage projects (at reactor ISFSIs and an ISF) one would expect considerable learning to be achieved, especially with new less complex and certified dry cask designs available. Ideally, the actual escalation to be experienced will be more like that of the light water reactors in France, with only two or three standard designs for 59 light water reactors. In this case, 2–4% annual escalation was experienced for construction. ISFSI and ISF dry storage operations may potentially exhibit cost escalation behavior that is different from those of capital expenditures. An operating cost escalation rate was estimated from EIA reports on nuclear operating costs between 1974 and 2015 [7,8,9], and renormalized from a per-kilowatt basis to a per-reactor-year basis for each year using capacity factors, nuclear generating capacity, and the number of units in the fleet [10]. Costs were readjusted to 2016 dollars using the GDP implicit deflator [11]. Both the incremental escalation of capital costs and the incremental escalation of operating costs are gauged to be 3%, so in the interest of simplicity, the same incremental escalation rate is applied to both capital and operating costs in this study. Since transportation is a non-construction cost element and is likely to benefit quickly from learning, it is not judged to require any incremental escalation (0%) and will be subject only to general inflation.

ECONOMIC ENVIRONMENT RESULTS

It is possible to find the discount rate for which the ISF and no-ISF cases are equivalent in present value. This rate is sometimes called a *breakeven rate*. For the nominal discount rate, the breakeven rate is determined to be ~6.17%.

Breakeven Curves

Breakeven points vary depending on the prevailing economic environment. Thus, breakeven points for the ISF vs no-ISF cost comparison were determined for a range of cases with a focus on realistic economic environments for the next century.

ISF vs no-ISF breakeven for inflated, escalated, and discounted dollars is shown in Fig. 4. Various combinations of the inflation rate and the escalation rate were created, and the nominal discount rate at which breakeven occurs was determined. The inflation rate was varied from 0–7%, and escalation rates were varied from -5–10% to produce these combinations. The breakeven surface that results is flat, allowing it to be represented as a line in Fig. 4. The first variable (horizontal axis) is the sum of escalation and inflation, and the second variable (vertical axis) is the nominal discount rate. Because it is a one-dimensional representation of a two-dimensional surface, the breakeven curve is not sharply defined, as can be seen from the multiple breakeven points for each value along the horizontal axis.

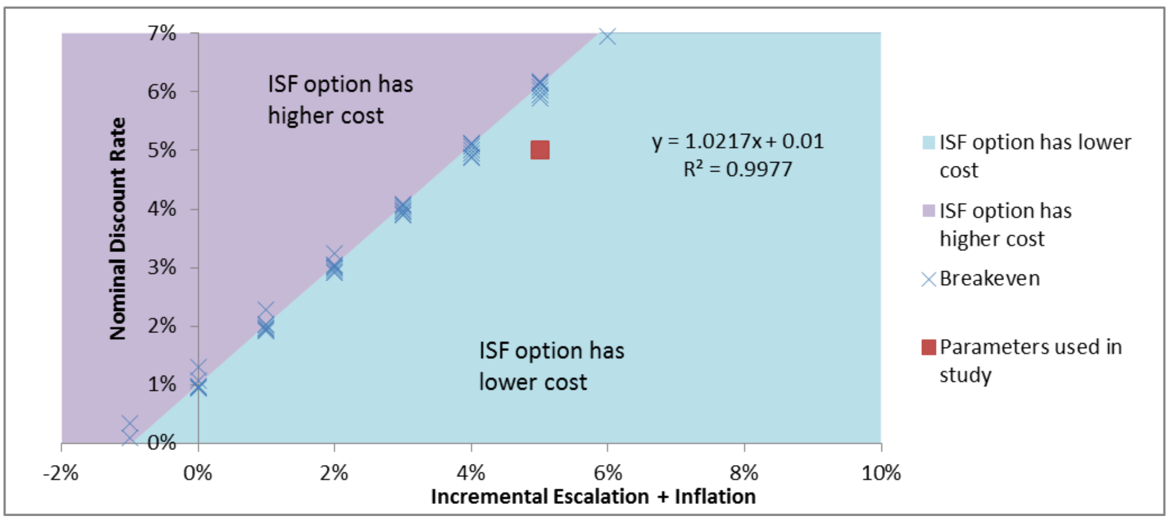

Fig. 4. Breakeven When Changing the Nominal Discount Rate, the Escalation Rate, and the Inflation Rate.

The trends revealed in this analysis are not surprising. The relative cost of the ISF option decreases as escalation and inflation increase. In the ISF option, sites are de-inventoried and SNF is transported sooner than in the no-ISF case. Because the ISF option shifts costs to the near term, escalation and inflation do not increase costs as much as in the no-ISF case. When discount rate is increased, it decreases the impact of delayed costs, so the no-ISF option becomes less expensive.

Next, ISF vs no-ISF breakeven curves were examined, holding the nominal discount rate constant. The ISF vs no-ISF breakeven curve is shown in Fig. 5 assuming a 0% nominal discount rate. As escalation and inflation increase, the ISF option becomes more attractive. Once the inflation rate reaches 5%, the ISF option always costs less.

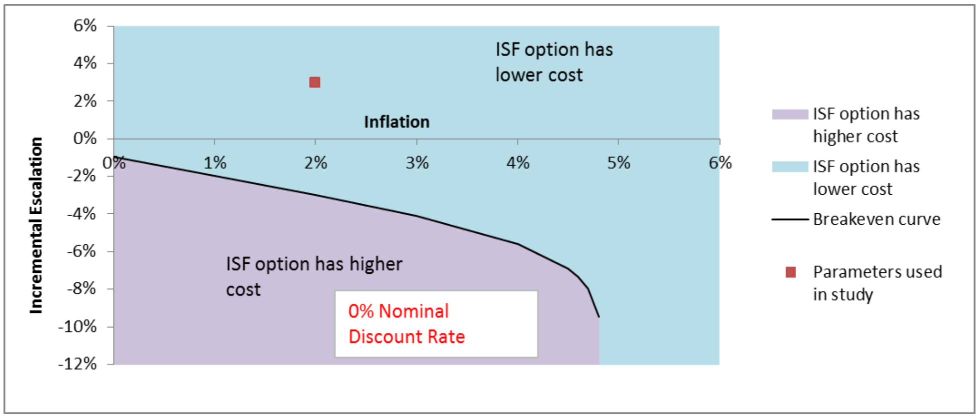

Fig. 5. The Breakeven Curve Assuming a 0% Nominal Discount Rate.

Figure 6 shows the effect of varying the discount rate on the difference in costs between the no-ISF option and the ISF option, excluding general inflation and incremental escalation. The curve in Fig. 6 shows that if general inflation and incremental escalation are neglected, the WMS scenario with an ISF results in cost savings for real discount rates less than about one percent, and for increasing discount rates, it would cost less than about $5 billion more than the no-ISF option. The observed behavior is due to the larger near-term investment required for the ISF-option, and the leveling off of the curve approximates the cost difference between the two scenarios integrated over the near-term timeframe.

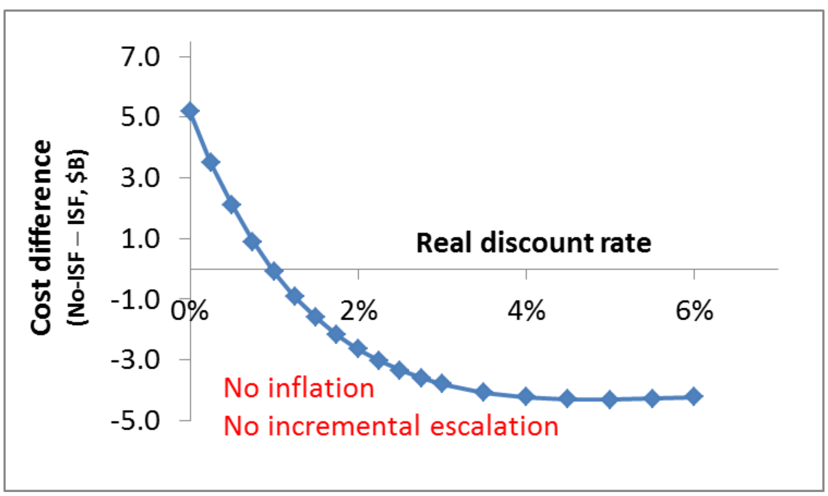

Fig. 6. System Scenario Cost Difference with Varying Real Discount Rate (Positive Values Represent Savings with ISF Option).

The effect of varying the nominal discount rate with general inflation and incremental escalation rates fixed at 2% and 3%, respectively, is shown in Fig. 7.

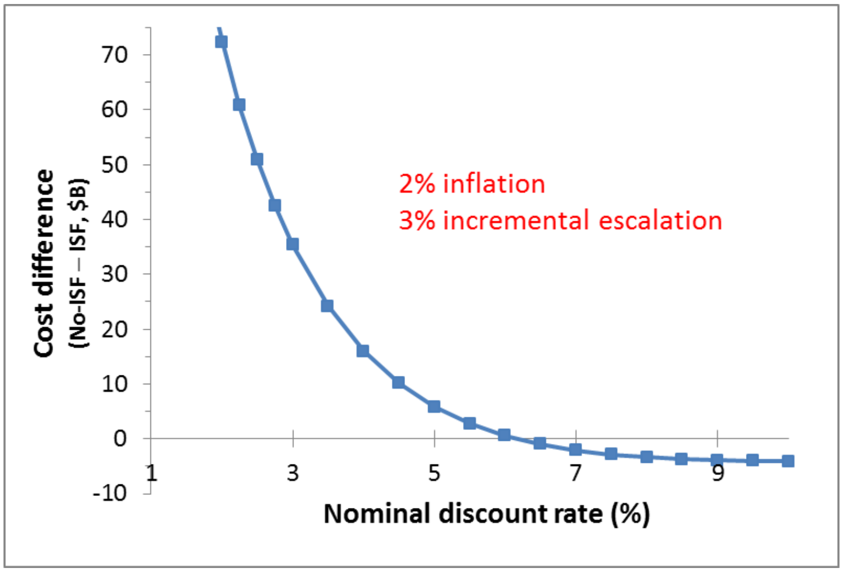

Fig. 7. System Scenario Cost Difference with Varying Discount Rate (Positive Values Represent Savings with ISF Option).

As mentioned previously, breakeven occurs at a nominal discount rate of approximately 6% (or real discount rate of 4%). For higher nominal discount rates, the ISF-option costs more than the no-ISF option, but the cost does not increase dramatically. Again, the curve levels out at higher discount rates because costs associated with future actions in the long-term are highly discounted and approach zero. If the plot were extended to include extremely high discount rates, the curve would reverse direction and approach the difference in cost between the two options near time zero. In contrast, as the nominal discount rate decreases below about 5% (or real discount rate < 3%), the cost savings realized by including an ISF with the specified incremental escalation rate become substantially larger than $5 billion. At a nominal discount rate of 4%, the real discount rate equals the general inflation rate, effectively negating each other, and the >$15 billion cost savings with the ISF-option is driven by the incremental escalation rate which favors near-term investment.

CONCLUSIONS

In conclusion, designing, licensing, and constructing an ISF will require a large near-term financial investment. However, reduced annual operating and maintenance costs for an IWMS with an ISF compared to a system without an ISF could eventually result in a system-wide (integrated) cost avoidance due to the reductions in at-reactor storage costs in the long term. The largest cost avoidances would not occur for multiple decades, so assumptions about inflation, escalation, and discount rates will have a significant effect on potential economic impacts of an ISF. It should be noted that other benefits associated with the investment of an

ISF, such as earlier removal of SNF from shutdown reactor sites, earlier prospects for site reutilization, and additional overall IWMS flexibility, were not addressed in this study.

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