Cost Sensitivity Analysis for Consolidated Interim Storage of Spent Fuel: Evaluating the Effect of Economic Environment Parameters

Fuel Cycle Research & Development

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HISTORY OF CHANGE

Rev. 0 (Draft)	Initial Issuance on 06-30-2016.
Rev. 1	Revised to incorporate comments from Department of Energy.

EXECUTIVE SUMMARY

This report evaluates how the economic environment (i.e., discount rate, inflation rate, escalation rate) can impact previously estimated differences in lifecycle costs between an integrated waste management system with an interim storage facility (ISF) and a similar system without an ISF.

The costs analyzed in this report are based on the document entitled *Cost Implications of an Interim Storage Facility in the Waste Management System,* a systems study comparing the "constant dollar" future lifecycle costs of spent nuclear fuel (SNF) management system scenarios. The scenarios include (1) continuation of at-reactor SNF management, including onsite dry storage only, and (2) management of SNF at the reactor, supplemented by a centralized ISF located at a hypothetical site. A multi-laboratory team prepared cost and schedule estimates and used them in a variety of scenarios defined by parameters such as the opening dates for an ISF and the use of a geologic SNF repository at a hypothetical site. For the two selected scenarios, constant dollar annual cash flows were presented for the period from 2020 to 2110. Only SNF from today's decommissioned, shutdown, and operating domestic nuclear power plants was considered, for a total amount of approximately 142,000 metric tons of heavy metal (MTHM). While this analysis is based on the previous cost implications report, unit cost estimates from the initial 2015 calculations for an ISF were updated based on industry-led design efforts.

A sensitivity analysis of the economic environment parameters which could impact SNF management system costs for the two scenarios—with or without an ISF—was conducted. When setting an initial starting point and ranges for evaluation, historical and recent data, as well as future projections, were all considered. Factors evaluated include general inflation, incremental cost escalation of nuclear projects, and discounting. Breakeven curves were established to illustrate the impact of changing assumptions in discount rate, general interest rate, and incremental escalation rate on the cost difference between the two scenarios.

Potential cost savings for the scenario with an ISF were exhibited for low discount rate values, especially with an assumed incremental escalation rate. For higher discount rates, the scenario with an ISF was observed to cost more due to the larger near-term investment required for this option; however, the maximum cost difference remained less than $5 billion, even with increasing discount rates. It should be noted that this analysis did not assign a value to any benefits associated with clearing sites of SNF beyond that associated with discontinuation of direct storage costs, nor did it take into account discounting of any such benefits which, if positive, could favor the ISF-option due to shutdown reactor sites being cleared of SNF sooner than the no-ISF option. Future analysis work may include examining the impact of other parameters, including changes to certain technical parameters or programmatic assumptions.

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ACRONYMS

BRC	Blue Ribbon Commission
DOE	Department of Energy
DOE-NE	Department of Energy, Office of Nuclear Energy
GNEP	Global Nuclear Energy Partnership
IAEA	International Atomic Energy Agency
ISF	interim storage facility
ISFSI	independent spent fuel storage installation
kgHM	kilograms of heavy metal
MTHM	metric tons heavy metal
NPV	net present value
NWF	Nuclear Waste Fund
OCC	overnight capital cost
OMB	Office of Management and Budget
SNF	spent nuclear fuel
TMI	Three Mile Island

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1. INTRODUCTION

This report evaluates how the economic environment (as represented by discount rate, inflation rate, escalation rate) can impact previously estimated differences in lifecycle costs between an integrated waste management system with an interim storage facility (ISF) and a similar system without an ISF.

The document entitled *Cost Implications of an Interim Storage Facility in the Waste Management System* [1] is a systems study comparing the "constant dollar" future lifecycle costs of spent nuclear fuel (SNF) management system scenarios. The scenarios include (1) continuation of at-reactor SNF management, including onsite dry storage only, and (2) management of SNF at the reactor, supplemented by a centralized interim storage facility (ISF) located at a hypothetical site. A multi-laboratory team prepared cost and schedule estimates and used them in a variety of scenarios defined by parameters such as the opening dates for an ISF and the use of a geologic SNF repository at a hypothetical site. For various scenarios, constant dollar annual cash flows were presented for the period from 2020 to 2110. Only SNF from continued operation of today's decommissioned, shutdown, and operating domestic nuclear power plants is considered, for a total amount of approximately 142,000 metric tons of heavy metal (MTHM). While this analysis is based on the previous cost implications report [1], unit cost estimates the initial 2015 calculations for an ISF were updated based on industry-led design efforts [2].

2. SENSITIVITY OF ISF COST SAVINGS TO ECONOMIC ENVIRONMENT

Budget and funding planning for this long-term enterprise require financial figures-of-merit other than just lump sum constant dollar totals. 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 lump-sum total of the projected constant dollar cash flows. Inflated dollars are sometimes called escalated dollars, but it is important to understand that 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. Recent experience [3] shows that US nuclear projects typically experience such cost growth.

Project planners and financiers are also required to evaluate deployment options in terms of discounted dollar sums for the cash flows. A dollar today could be invested at some rate of return (discount rate or interest rate), or it may be spent on a project. Therefore, future dollar cash flows spent on a project are discounted to reflect the fact that they are not earning interest if they are used to fund a project in those future years. This discounting quantifies a foregone opportunity cost. The usual figure-of-merit for discounting lifecycle costs is the sum of the discounted cash flows. This sum is always less than the sum of the undiscounted cash flows, whether the latter is in constant, inflated, or escalated dollars. The interest rate used to calculate discounted cash flows is called the "discount rate" and one must be cautious in selecting the appropriate rate.

This study applied various inflation, escalation, and discounting assumptions to the constant dollar cash flows for scenarios ***with an ISF*** and **without *an ISF*** to determine how the sums of the cash flows are affected in each scenario.

2.1 Methodology

Year-by-year cash flows in constant 2015 dollars were obtained for the with-ISF and no-ISF scenarios. (In Ref. 1, the with-ISF scenario was numbered *16*, and the no-ISF scenario was numbered *5*.) The cash flow data had over ten lifecycle project categories (project elements) which were grouped into the following subtotals, each of which could be a separate project.

At-reactor costs include costs associated with procuring and operating dry storage, including casks, of present and future projected SNF. These costs will continue to accrue until the SNF is removed from reactor sites, and the ISFSI is decommissioned

ISF costs are the lifecycle costs required to plan, design, construct, operate, and decommission a centralized storage facility capable of accepting dry casks from existing reactor sites' independent spent fuel storage installations (ISFSIs) and those constructed at reactor sites for future SNF. These costs are expected to be offset by a reduction in future at-reactor costs due to the ISF providing more efficient consolidated storage at a lower unit cost ($/kgHM) due to economy of scale.

Transportation costs are the costs of transporting SNF from the onsite ISFSIs to the ISF, from the on-site ISFSI to a repository, or from an ISF to a repository.

Cash flow streams for these three categories were extracted from the constant dollar data provided and were subjected to inflation, incremental escalation, and discounting, as described below. Each cash flow stream can carry different discount rates and incremental escalation rates. The general inflation rate is assumed to be the same for all three streams. Values for examination and ranges for analysis of these rates are discussed below.

2.1.1 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

$$(1 + i_d)^n,$$

where i is the discount rate and n is the number of years after the base year for constant dollar costing. For example, a constant dollar expenditure of $200M in 2025 (year n in this case) would have a value of

$$\frac{\$200M}{(1+0.05)^{(2025-2020)}} = \$156.7\text{M}$$

if the *real discount rate* i_d is 5% and 2020 the base year for discounting. *Real discount rates* are applied to constant dollar cash flow streams; *nominal discount rates* are applied to cash flow streams affected by inflation and/or incremental cost escalation.

The sum of all discounted cash flows over the project lifecycle is called the net present value, or NPV. Projects of long duration with significant out-year cash flows will have a lower NPV than a project costing the same amount in constant dollars but with nearer term future expenditures.

2.1.2 Escalation

Escalation reflects the fact 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 component dependent on 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 dollar cash flow for year n by the following compound interest term:

$$\left(1 + i_{inf}\right)^n,$$

where i_{inf} is the general inflation rate. For example, a constant dollar expenditure of $500M in 2025 (year n in this case) would have a value of

$$\$500M(1 + 0.02)^{(2025-2015)} = \$609.5\text{M}$$

if the *general inflation rate* i_{inf} is 2% and 2015 is the base year for constant dollar costing. Incrementally escalated dollars for a given year and cash flow are calculated by multiplying each cash flow for year n by the following compound interest term that includes the incremental escalation rate:

$$(1 + i_{inc\_esc})^n,$$

where i_{inc_esc} is the incremental escalation rate.

For example, a constant dollar expenditure of $500M in 2025 would have a value of $553.4 in 2015, assuming a general inflation rate of 2%, an incremental escalation rate of 3%, and a discount rate of 4%, as illustrated below:

$$\$500M \frac{(1 + i_{inf})^n (1 + i_{inc\_esc})^n}{(1 + i_d)^n} = \$500M \frac{(1 + .02)^{10}(1 + .03)^{10}}{(1 + .04)^{10}} = \$553.4 .$$

2.2 Discussion of Economic Parameters

The following is a discussion of the rationale for selection of economic parameters needed to define a base case and the ranges for study. Parameters discussed below include (1) discount rate, (2) general inflation rates, and (3) incremental escalation rate (above general inflation).

2.2.1 Discount Rate

Per the US Office of Management and Budget (OMB) Circular No. A-94, Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs [4], certain analyses should include comprehensive estimates of the expected benefits and costs to society based on established definitions and practices for program and policy evaluation. Social net benefits—not the benefits and costs to the federal government—should be the basis for evaluating government programs or policies that affects private citizens or other levels of government. Costs should reflect the opportunity cost of any resources used as measured by the return to those resources in their most productive application elsewhere.

In assessing the discount rate, it is assumed that each of the two main scenarios examined in the cost implications report—a waste management system with an ISF and a waste management system without an ISF—can both satisfy the fundamental waste management mission need, recognizing that the benefits and costs associated with each alternative will differ. The difference in opportunity cost between these scenarios is then measured by the return that could have otherwise accrued on the constant dollar cost difference between the two scenarios when integrated over time if the expenditures had not been required for the integrated waste management system. This particular study does not distinguish between how waste management system costs are paid, e.g. whether from Nuclear Waste Fund (NWF) resources paid into by a fee levied on commercial nuclear electricity generation or from Judgment Fund resources paid into by US taxpayers. Thus, the present sensitivity examines the effect of varying a single discount rate value for all waste management system costs and does not apply different rates to different types of costs.

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 [5] were used for the base case (starting point) for this study and were simply applied to all cost elements. However, the OMB Circular A-94 issued in 1992 states that “constant-dollar benefit-cost analyses of proposed investments and regulations should report net present value and other outcomes determined using a real discount rate of 7 percent,” which approximated the marginal pretax rate of return on an average investment in the private sector about the time the circular was issued. Updates to certain discount rates for lease-purchase and cost-effectiveness analysis are included in annual updates to Appendix C of OMB Circular A-94. It). It is typically assumed that the funds to be spent are appropriated by Congress and that funding alternatives are available within DOE’s overall budget. However, the NWF is invested in government securities – the nature and types of which are discussed in detail in the report entitled *Secretarial Determination of the Adequacy of the NWF Fee*, January 16, 2013 [6]. This report considered several economic forecasts having different real interest rates (from 0.51% to 3.73% as shown in Table 2 of Ref. 6). Additionally, some at-reactor costs are paid by the Judgment Fund which introduces an opportunity cost to US taxpayers. Therefore, the base case represents a starting point for the sensitivity analyses, and a range of discount rates that envelopes the values discussed above is examined in this study.

2.2.2 General Inflation Rate

General US inflation has been measured by the Department of Commerce since the 1913 establishment of the Federal Reserve System. Prior to 1913, economists used various aggregated price indices for manufactured goods and agricultural commodities to arrive at an average inflation measure. Figure 1 shows US general inflation from the years 1801 to 2015. Prior to 1936, deflation (negative inflation) was just as common as inflation. From 1913 to 2015, inflation has averaged 3.27% per year. Figure 1 shows that institution of the Federal Reserve System reduced the number of banking crises that led to "panics" or depressions and subsequent deflation from the number of crises that occurred between 1800 and 1912.

The government (Department of Commerce) and various private economic consulting firms periodically attempt to project a long-term average inflation rate. These forecasts project less than 50 years in the future. However, this planning exercise needs forecasts that project into the 22nd century. Chapter 2 and the appendices to the adequacy report [6] cited above 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 was selected for the base case for this study**. The graph shows that from the mid-1990s onward, the inflation rate has hovered around 2%/annum. This is in part due to the Federal Reserve Board taking a more active role in tempering fluctuations in the economy. A 2% inflation rate reflects relatively slow-to-moderate growth in the economy, which has been the case since 2008.

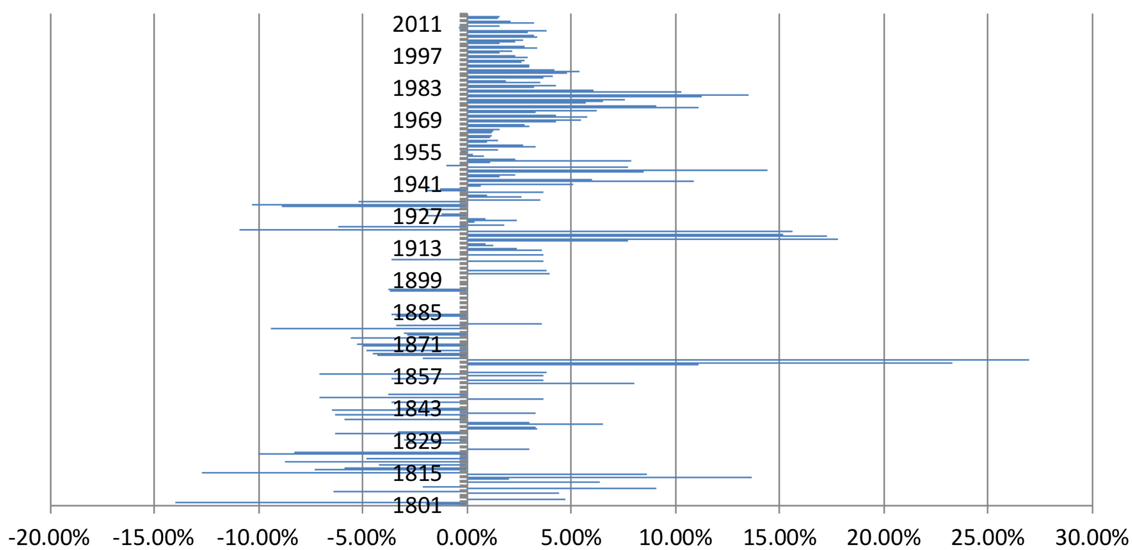

Figure 1. Annual inflation rate as a function of year.

2.2.3 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: the type of technology, the maturity of the technology, and its susceptibility to regulatory, legal, and project management difficulties. Incremental escalation can result from construction cost overruns, project execution schedule slippages, and operational cost overruns. History indicates that private and

Government nuclear projects in the US have been experiencing escalation well beyond that due to general inflation.

ISF lifecycle costs and the costs associated with multiple at-reactor ISFSIs are subject to nuclear project incremental escalation. The transportation portion of the project consists of railroad operations requiring additional security. Most containers to be used in this work have already been certified or are in the process of being certified. Railcar certification and manufacturing should also be relatively straightforward once the design is approved. Therefore, no incremental escalation is applied to transportation.

To determine the most likely average incremental escalation rate, the average increase for nuclear power plants built since the 1960s until the present was considered. A paper on this subject, *Historical Construction Costs of Global Nuclear Power Reactors* [3] was published in the journal *Energy Policy.* Historical specific overnight capital costs for nuclear power plants, expressed in year 2010$ per kW_e of capacity, are studied for the US, France, Germany, Canada, Japan, South Korea, and India, as shown in Table 1. Russian and Chinese data are sparse, and treatment of costs in socialist countries differs markedly from western costing practices. In this report, the effects of general inflation are removed by adjusting all as-then historical dollars by applying the country's experienced implicit price deflator. Therefore, all experienced overnight cost increases (or decreases) represent incremental escalation. Each country's reactor construction timeline is divided into eras representing particular reactor types and particular events such as the US reactor accident at Three Mile Island (TMI), the costs of reactors already under construction, and whether the reactor designs were domestic or imported. The most recent eras were the focus of this study. As shown in Table 1 from Lovering et al. [3], the US and West Germany experienced the highest overnight construction cost escalation. Part of the increase is due to US and German reactors having the least standardized designs, with each project having some first-of-a-kind attributes. Thus, the beneficial cost effect of learning was reduced. The US and Germany also experienced the most intervention and regulatory ratcheting of all countries listed. For dry storage projects at reactor ISFSIs and an ISF are substantially less complex than reactor systems. The goal is for the actual escalation to be more like that of the light water reactors in France, which have only 2 to 3 standard designs for 59 light water reactors and only 2 to 4% annual escalation. Therefore, a midrange value of 3% per year has been selected as the base case value for at-reactor and ISF cost elements[a].

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[a] 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 Energy Information Administration 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 gross domestic product implicit deflator [11]. The incremental escalation rate was gauged using an exponential regression yielding a rate of approximately 3%. Since both the incremental escalation of capital costs and the incremental escalation of operating costs are gauged to be 3%, in the interest of simplicity, the same incremental escalation rate was applied to both capital and operating costs in this study.

Table 1. Summary of nuclear plant overnight capital cost (OCC) escalation trends by country [3].

COUNTRY	Era (defined by time period in which reactors began construction)	Annualized rate of change in OCC (%/yr)**	Total change in OCC by era (%)
USA	1954–1968: 18 demonstration reactors	−14%	−81%
	1964–1967: 14 turnkey reactors	−13%	−33%
	1967–1972: 48 reactors completed pre-TMI	23%	190%
	1968–1978: 51 reactors completed post-TMI	+5 to +10%	+50 to +200%
FRANCE	1957–1966: 7 gas-cooled reactors	−17%	−82%
	1971–1991: 59 light water reactors	+2 to +4%	+50 to +100%
CANADA	1957–1974: 6 reactors	−8%	−77%
	1971–1986: 18 reactors	4%	60%
W. GERMANY	1958–1973: 8 reactors	−6%	−63%
	1973–1983: 18 reactors	12%	200%
JAPAN	1960–1971: 11 imported reactors	−15%	−82%
	1970–1980: 13 foreign designs	8%	100%
	1980–2007: 30 domestic reactors	−1% to +1%	−17% to +33%
INDIA	1964–1972: 5 imported reactors	−7%	−38%
	1971–1980: 8 domestic reactors	5%	150%
	1990–2003: 6 domestic reactors + 2 imported	−1%	−10%
S. KOREA	1972–1993: 9 foreign designs	−2%	−25%
	1989-2008: 19 domestic reactors	−1%	−13%
	**General inflation has been removed		

2.2.4 Summary of Base Case Economic Parameters

Based on the discussion above, the selected economic parameters for the base case shown in Table 2 will be used to conduct the sensitivity analyses (discussed in the next section) to understand how variations in these parameters can affect the results.

Table 2. Base case values for economic environment.

General Inflation Rate	2.00%	
Incremental Esc above General Inflation		
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%

Table 3[b] compares scenarios with and without an ISF, with net present values (NPVs) evaluated in the year 2020.

Table 3. Cash flows using base case values for economic environment.

With ISF	Undiscounted constant dollars ($M)	Constant dollars discounted ($M)	Constant dollars inflated ($M)	Constant dollars inflated and escalated ($M)	Constant dollars inflated, escalated, and discounted ($M)
At-reactor site costs	34,233	23,116	62,633	184,421	53,560
ISF costs	14,710	9,939	29,037	119,336	24,129
Transportation costs	5,437	3,221	12,572	12,572	3,252
TOTAL	**54,380**	**36,277**	**104,242**	**316,329**	**80,941**
Without ISF	**Undiscounted constant dollars ($M)**	**Constant dollars discounted ($M)**	**Constant dollars inflated ($M)**	**Constant dollars inflated & escalated ($M)**	**Constant dollars inflated, escalated, and discounted ($M)**
At-reactor costs	55,425	32,659	128,310	582,756	103,039
ISF costs	0	0	0	0	0
Transportation costs	4,144	2,017	11,594	11,594	2,044
TOTAL	**59,569**	**34,676**	**139,903**	**594,350**	**105,083**
Difference (*With* minus *Without*)	**Undiscounted constant dollars ($M)**	**Constant dollars discounted ($M)**	**Constant dollars inflated ($M)**	**Constant dollars inflated & escalated ($M)**	**Constant dollars inflated, escalated, and discounted ($M)**
At-reactor costs	-21,192	-9,543	-65,677	-398,335	-49,479
ISF costs	14,710	9,939	29,037	119,336	24,129
Transportation costs	1,293	1,205	978	978	1,207
TOTAL (negative favors ISF)	**-5,189**	**1,601**	**-35,661**	**-278,021**	**-24,143**

Table 3 represent various successive applications of discounting, inflation, and incremental escalation. The difference between the *with ISF* and *without ISF* totals is negative in four of the five columns, thus favoring the scenario ***with*** an ISF. In the second column, which shows discounting of the constant dollar cash flows, the difference is positive, thus favoring the *without-ISF* case.

2.3 Searching for the Breakeven Discount Rates

By trial and error or successive iteration, it is possible to find the discount rate for which the *with ISF* and *without -ISF* cases are equivalent in present value. This rate is sometimes called a *breakeven rate*. For the real discount rate, the breakeven rate is 0.98%. Column 2 of Table 4 shows the near-zero NPV difference when the breakeven discount rate (also known as the internal rate of return) is found.

[b] The ISF life cycle cost presented in this report is based on one alternative scenario of many from Ref. [1]. This assumed cost represents a starting point for economic environment comparisons and should not be confused with a definitive ISF cost basis.

Table 4. Breakeven cost breakdown using discounted dollars.

WITH ISF	Undiscounted constant dollars ($M)	Constant dollars discounted using real discount rates ($M)
At-reactor site costs	34,233	26,344
ISF lifecycle costs	14,710	11,278
Transportation costs	5,437	3,824
TOTAL	**54,380**	**41,447**
WITHOUT ISF	**Undiscounted Constant Dollars ($M)**	**Constant Dollars discounted Using Real Discount Rates ($M)**
At-reactor site Costs	55,425	38,869
ISF Life Cycle Costs	0	0
Transportation Costs	4,144	2,578
TOTAL	**59,569**	**41,447**
DIFF (With minus without)	**Undiscounted Constant Dollars ($M)**	**Constant Dollars discounted Using Real Discount Rates ($M)**
At-reactor site Costs	-21,192	-12,525
ISF Life Cycle Costs	14,710	11,278
Transportation Costs	1,293	1,247
TOTAL (negative favors ISF)	**-5,189**	**0**

The same iterative procedure can be applied to the "nominal" discount rate. The breakeven rate is determined to be ~6.17% (see Table 5).

Table 5. Breakeven nominal discount rate given a 2% inflation and 3% incremental escalation rate.

General inflation rate	2.00%
Incremental escalation above general inflation rate	
At-reactor costs	3.00%
ISF costs	3.00%
Transportation costs	0.00%
Discount rates:	
	Nominal
At-reactor costs	6.17%
ISF lifecycle cost	6.17%
Transportation costs	6.17%

The last column of Table 6 below shows the zero NPV difference.

Table 6. Breakeven cost breakdown assuming 2% inflation and 3% incremental escalation rates.

WITH ISF	Undiscounted constant dollars ($M)	Constant dollars discounted ($M)	Constant dollars inflated ($M)	Constant dollars inflated & incremental escalated ($M)	Constant dollars inflated, incremental escalated, and discounted ($M)
At-reactor costs	34,233	13,140	62,633	184,421	25,832
ISF costs	14,710	5,989	29,037	119,336	11,063
Transportation costs	5,437	1,597	12,572	12,572	1,625
TOTAL	**54,380**	**20,726**	**104,242**	**316,329**	**38,520**
WITHOUT ISF	**Undiscounted constant dollars ($M)**	**Constant dollars discounted ($M)**	**Constant dollars inflated ($M)**	**Constant dollars inflated & escalated ($M)**	**Constant dollars inflated, escalated, and discounted ($M)**
At-reactor costs	55,425	15,826	128,310	582,756	37,861
ISF costs	0	0	0	0	0
Transportation costs	4,144	638	11,594	11,594	660
TOTAL	**59,569**	**16,464**	**139,903**	**594,350**	**38,520**
DIFFERENCE (with ISF minus without ISF)	**Undiscounted constant dollars ($M)**	**Constant dollars discounted ($M)**	**Constant dollars inflated ($M)**	**Constant dollars inflated & incremental escalated ($M)**	**Constant dollars inflated, incremental escalated, and discounted ($M)**
At-reactor costs	-21,192	-2,686	-65,677	-398,335	-12,029
ISF costs	14,710	5,989	29,037	119,336	11,063
Transportation costs	1,293	959	978	978	966
TOTAL (negative favors ISF)	**-5,189**	**4,262**	**-35,661**	**-278,021**	**0**

2.4 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.

The ISF vs. No-ISF breakeven for inflated, incrementally escalated, and discounted dollars is shown in Figure 2. Various combinations of the inflation rate and the incremental escalation rate were created, and the nominal discount rate at which breakeven occurs was determined. The inflation rate was varied from 0% to 7% and escalation rates were varied from -5% to 10% to produce said combinations. The breakeven surface that results is flat, allowing it to be represented as a line in Figure 2. The first variable (horizontal axis) is the sum of escalation and inflation, and the second variable (vertical axis) is nominal discount rate. Because it is a 1D representation of a 2D surface, the breakeven curve is not sharply defined, as can be seen from the multiple breakeven points for each value along the horizontal axis. Nominal discount rates over 7% are not shown, as these are unlikely to exist over a sustained period. In the figures in this subsection, the *parameters used in study* refers to the assumed base case economic assumed parameters detailed in Table 2.

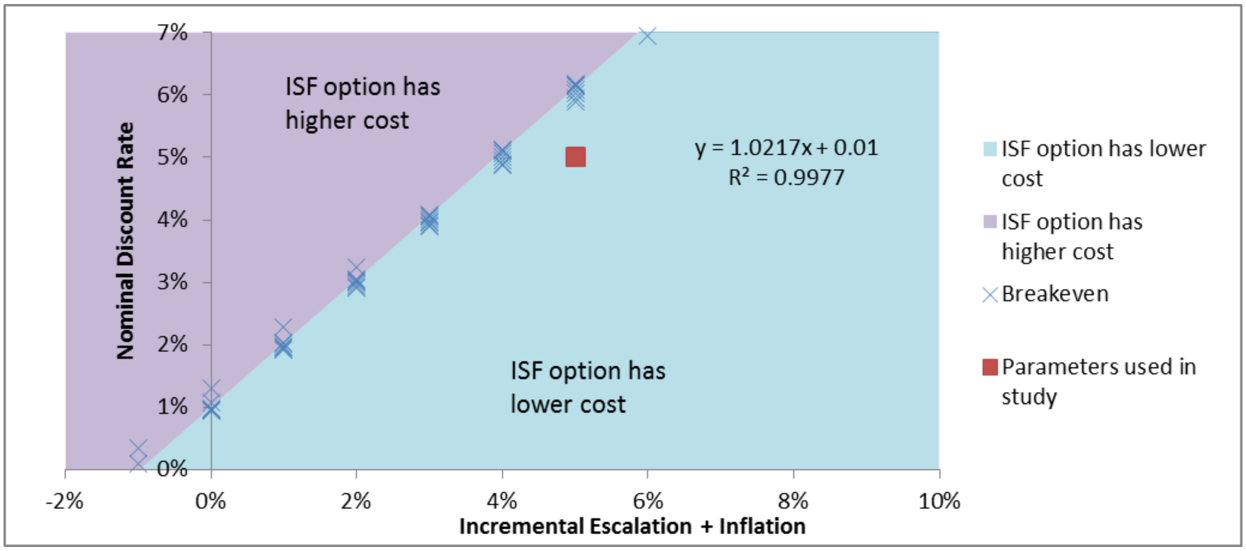

Figure 2. Breakeven when changing the nominal discount rate, incremental escalation rate, and the inflation rate.

The trends revealed here 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, incremental escalation and inflation do not increase costs as much as in the no-ISF case. When the discount rate is increased, it decreases the impact of delayed costs so that 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 Figure 3 assuming a 0% nominal discount rate. Again, as incremental escalation and inflation increase, the ISF option becomes more attractive. Once the inflation rate reaches 5%, the ISF option always costs less. The asymptote was not included in the 3-parameter study; as such, an economic environment is unlikely to occur over a sustained period of time.

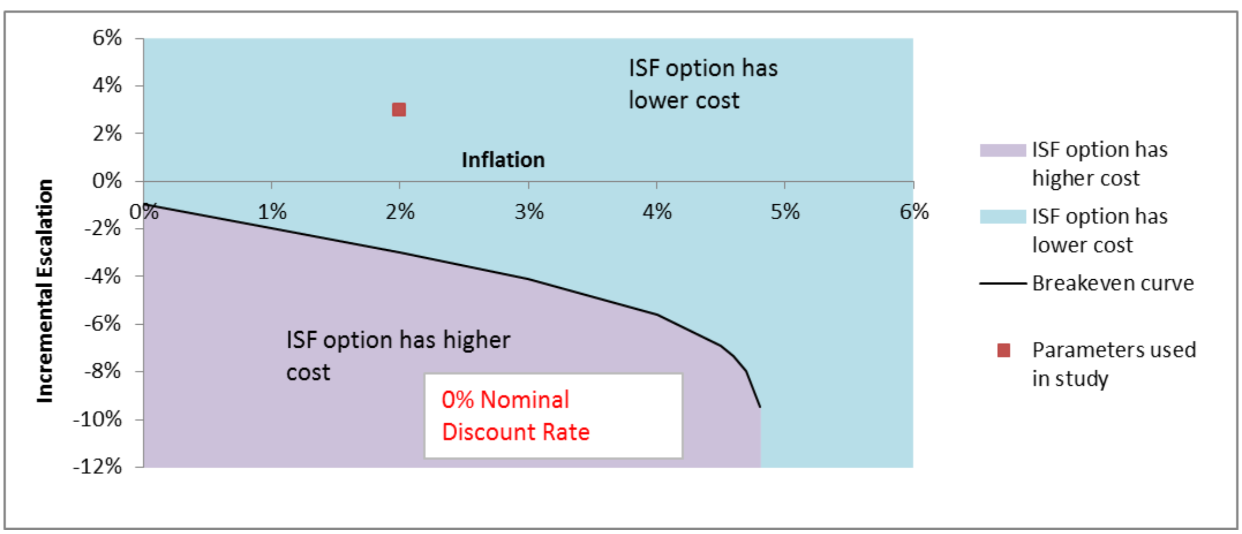

Figure 3. The breakeven curve assuming a 0% nominal discount rate.

An alternative situation with a non-zero nominal discount rate may also be of interest. In Figure 4, the nominal discount rate is increased to 3.5%. The relative cost of the no-ISF option decreases because a higher discount rate makes delayed purchases (de-inventory and transportation) more attractive. Once the inflation rate reaches 8.5%, the ISF option always costs less. Again, the asymptote was not included in the 3-parameter study, as it does not occur in a realistic, long-term economic environment.

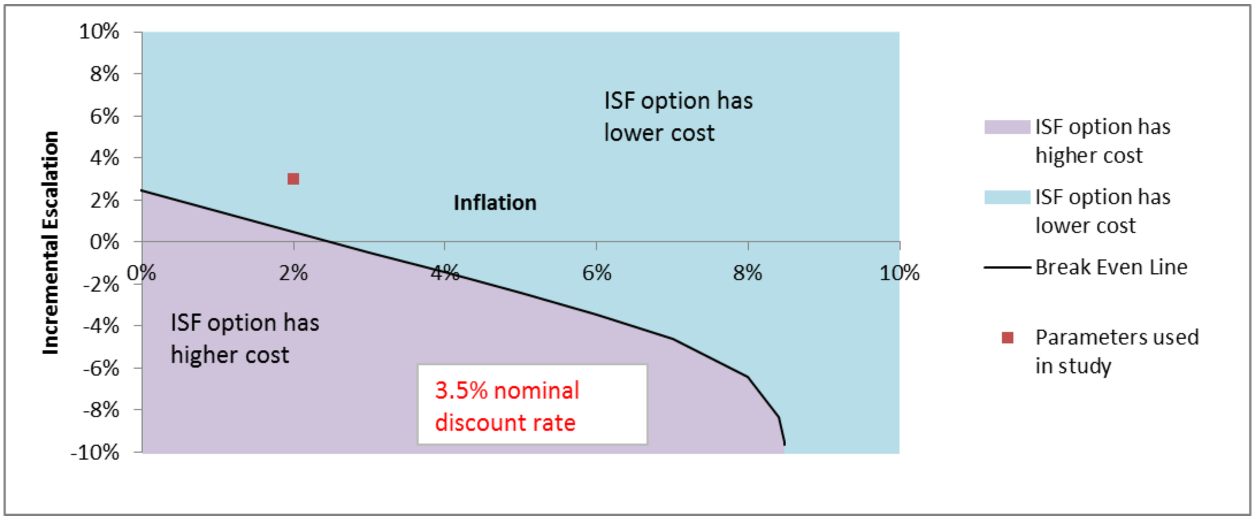

Figure 4. Breakeven curve assuming 3.5% nominal discount rate.

2.5 Effect of Economic Environment on System Scenario Cost Differences

Figure 5 shows the effect of a varying discount rate on the difference in costs between the No-ISF option and the ISF option, excluding general inflation and incremental escalation. In this graphic and the one that follows, the order of computing the difference was reversed from that used for Tables 3 and 6, so positive values favor the ISF-option in Figures 5 and 6. The curve in Figure 5 shows that if general inflation and incremental escalation are neglected, the waste management system scenario with an ISF results in a 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.

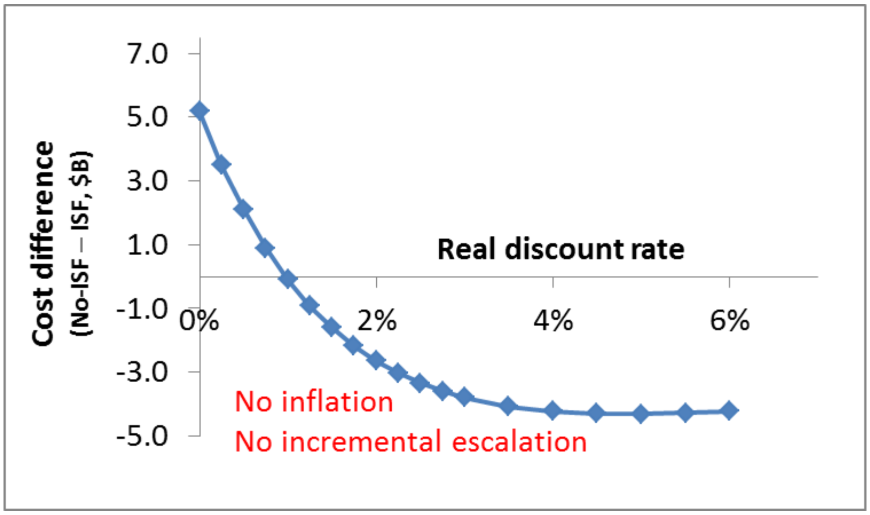

Figure 5. System scenario cost difference with varying real discount rate. (positive values represent savings with ISF option)

The effect of varying the nominal discount rate with general inflation and incremental escalation rates fixed at 2% and 3%, respectively, is shown in Figure 6.

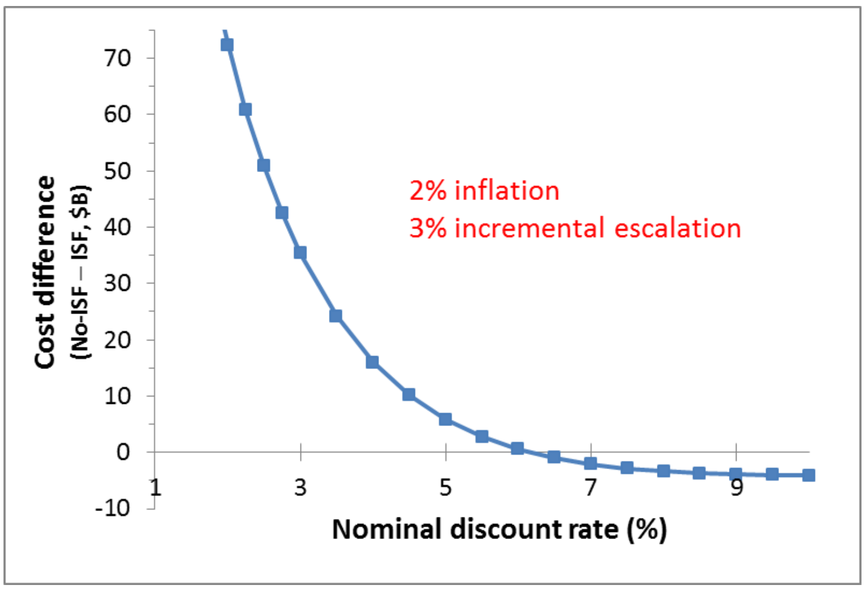

Figure 6. System scenario cost difference with varying discount rate. (positive values represent savings with ISF option)

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.

3. SUMMARY

A sensitivity analysis of the economic environment parameters which could impact SNF management system costs associated with two scenarios, with and without an ISF, was conducted. Historical and recent data and future projections were considered when setting an initial starting point and determining the ranges for evaluation of general inflation, incremental cost escalation of nuclear projects, and discounting. Breakeven curves were established to illustrate the impact of changing assumptions in discount rate, general interest rate, and incremental escalation rate on the cost difference between scenarios. Potential cost savings for the scenario with an ISF were exhibited for low discount rate values, especially with an assumed incremental escalation rate. For higher discount rates, the scenario with an ISF was observed to cost more due to the larger near-term investment required for this option; however, the maximum cost difference remained less than $5 billion, even with increasing discount rates. It should be noted that this analysis did not assign a value to any benefits associated with clearing sites of SNF beyond that associated with discontinuation of direct storage costs, nor did it consider discounting of any such benefits which, if positive, could favor the ISF-option due to shutdown reactor sites being cleared of SNF sooner than the No-ISF option. Future sensitivity analysis may include examining the impact of varying other parameters, including changes to certain technical parameters or programmatic assumptions.

4. REFERENCES

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