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Comparative Cost Analysis of Spent Nuclear Fuel Management Alternatives

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ABSTRACT

This report presents a comparative analysis of spent nuclear fuel management options to support the U.S. Department of Energy (DOE). Specifically, a set of scenarios was constructed to represent a range of possible combinations of alternative spent fuel management approaches. Analyses were performed to provide simple and credible estimates of relative costs to the U.S. government and to the nuclear utilities for moving forward with each scenario.

The analyses of alternatives and options related to spent nuclear fuel management presented in this report are based on technical and programmatic considerations and do not include an evaluation of relevant regulatory and legal considerations (e.g., needs for new or modified regulations or legislation). This report has been prepared for informational and comparison purposes only and should not be construed as a determination of the legal permissibility of specific alternatives and options.

No inferences should be drawn from this report regarding future actions by DOE. To the extent this report conflicts with provisions of the Standard Contract, those provisions prevail.

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EXECUTIVE SUMMARY

Introduction

The national program for the long-term management and permanent disposal of spent nuclear fuel from commercial nuclear power plants has been stalled since licensing activities for the proposed repository at Yucca Mountain, Nevada, were suspended in 2010. Spent nuclear fuel continues to accumulate in temporary storage at all of the nation's operating nuclear power plants, and the total inventory of fuel awaiting disposal now exceeds the 70,000-metric-ton capacity of the Yucca Mountain repository defined in the Nuclear Waste Policy Act (NWPA). Projections indicate that by mid-century, when the current fleet of reactors will have been largely decommissioned, the total amount of spent nuclear fuel will be approximately 136,000 metric tons. Unless a repository becomes available, current practice indicates essentially all of this spent fuel will eventually be placed in dry storage in large steel canisters. Most of these large canisters are so-called "dual-purpose canisters" (DPCs), which are certified for both storage and transportation, but which are not designed for permanent disposal. In the absence of a repository or one or more consolidated interim storage (CIS) facilities, all of these storage canisters will remain at Independent Spent Fuel Storage Installations (ISFSIs) at the approximately 74 operating or shutdown nuclear power plant sites distributed across the U.S. The ever-increasing inventory of large storage canisters that are not designed for disposal may impact future spent nuclear fuel management options and processes. This report outlines those impacts and alternative strategies, presenting the current but suspended policy as the baseline against which alternatives and their costs are evaluated.

This report describes a comparative analysis of selected scenarios for the management of commercial spent nuclear fuel during the next century, focusing on the cost implications of delays in disposal and alternative choices about storage, transportation, and disposal practices. The proposed Yucca Mountain repository was considered as the basis for a final repository in all scenarios because it remains the option mandated for evaluation by the NWPA, and because the U.S. Department of Energy (DOE) completed a detailed "Total System Life Cycle Cost" (TSLCC) analysis for disposal at Yucca Mountain in 2008 (DOE 2008) that provides a suitable baseline for comparison. Most costs would be paid from the Nuclear Waste Fund created by the NWPA, but this analysis also includes estimates of the costs borne by taxpayers in the form of payments from the U.S. government "Judgment Fund" to nuclear utilities due to non-performance on Standard Contracts mandated by the NWPA that required the DOE to begin taking ownership of spent fuel in 1998.

Scenarios for Analysis

The baseline, or "Reference Case," scenario considered in this analysis is taken directly from the 2008 TSLCC (DOE 2008), with adjustments as described in Section 2 to consider the civilian (commercial) cost share only, to show costs in constant 2018 dollars, and to include costs of additional activities that will occur to some extent in all scenarios. Costs associated with treating, storing, transporting, and disposing of defense wastes are omitted from the Reference Case and the alternative scenarios to allow the analysis to focus exclusively on the impacts of decisions related to the management of commercial spent nuclear fuel.

The Reference Case (Scenario 1) serves as a useful baseline for comparison purposes by providing detailed cost estimates for what might have been had the project proceeded as planned, with initial waste receipt and start of emplacement operations in 2017. Future alternative scenarios are constructed around three representative dates for the first receipt of spent fuel at the repository: 2031, which corresponds to an early date for the opening of Yucca Mountain should licensing activities resume immediately (Scenario 2); 2041, which represents an additional ten-year delay in restarting Yucca Mountain (Scenario 3); and 2117, which represents a 100-year delay in the repository program (Scenario 4). These dates are chosen simply for the purpose of investigating relative cost impacts associated with delay and should not be interpreted as more or less likely than other dates. Variants within these scenarios examine the relative cost impacts of various decisions regarding repackaging of spent fuel from DPCs into the transportation, aging, and disposal (TAD) canisters specified in the Yucca Mountain Repository License Application (DOE 2009) and/or modifying repository operations (and licensing requirements) to allow for direct disposal of DPCs without repackaging. Cost impacts of having a federal CIS facility available in 2025, thereby reducing taxpayer liabilities paid through the Judgment Fund, are also considered.

The selected scenarios and variants are described in detail in Section 3. Summaries are provided below:

- Scenario 1 (Reference Case): Disposal at Yucca Mountain beginning in 2017, with loading of TADs at utilities starting in 2011 and repackaging of existing DPCs into TADs occurring at the repository.
- Scenario 2: Disposal at Yucca Mountain beginning in 2031, with loading of TADs at utilities starting in 2025 and repackaging of existing DPCs (loaded until 2025) into TADs occurring at the repository.
    - Scenario 2A: Loading TADs at utilities starting in 2025 but repackaging existing DPCs at utility sites instead of at the repository.
    - Scenario 2B: Loading TADs at utilities starting in 2025 but directly disposing of existing DPCs rather than repackaging into TADs.
    - Scenario 2C: Continue loading DPCs after 2025 and directly disposing of all spent fuel in DPCs rather than repackaging into TADs.
    - Scenario 2D: Loading TADs at utilities starting in 2025, transporting existing DPCs and TADs to a federal CIS facility beginning in 2025 and subsequently to the repository, and repackaging existing DPCs at the repository.
- Scenario 3: Disposal at Yucca Mountain beginning in 2041, with loading of TADs at utilities starting in 2035 and repackaging of existing DPCs (loaded until 2035) into TADs occurring at the repository.
    - Scenario 3A: Loading TADs at utilities starting in 2035, transporting existing DPCs and TADs to a federal CIS facility beginning in 2025 and subsequently to the repository, and repackaging existing DPCs at the repository.
- Scenario 4: Disposal beginning in 2117 at a repository with characteristics and costs equivalent to Yucca Mountain, with loading of spent fuel into DPCs after 2025 and repackaging of all DPCs occurring at the repository.

- Scenario 4A: Loading DPCs after 2025 and directly disposing of all spent fuel in DPCs rather than repackaging into TADs.
- Scenario 4B: Loading DPCs after 2025, transporting DPCs to a federal CIS facility beginning in 2025 and subsequently to the repository, and repackaging of DPCs into TADs at the repository.

Estimated future costs for each of the scenarios are summarized in Figure ES-1. Details and assumptions for these cost estimates are fully outlined in Section 4.

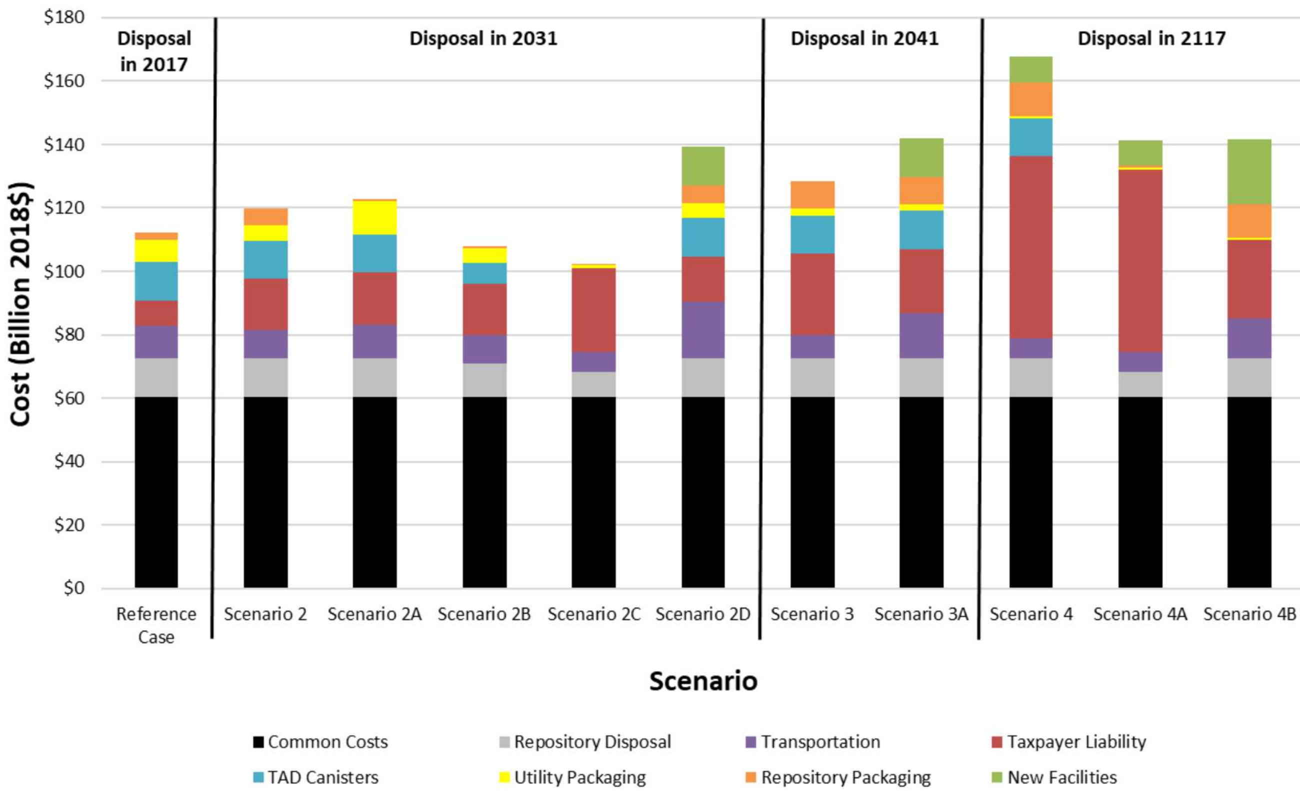


Figure ES-1. Estimated Costs of All Scenarios

All costs are reported in constant 2018 dollars. Measuring change in the same year constant dollars is a commonly accepted practice to measure real program cost growth because it removes the effects of inflation, which are beyond the control of individual programs. As a result, these cost estimates are considered representative for the purposes of comparative analysis between scenarios, but they should not be taken as formal projections of the life-cycle cost for any specific future scenario. In addition to not capturing the effects of inflation across scenarios with different time horizons, the bases for common costs from the TSLCC (DOE 2008) were not re-evaluated to consider new or updated information (e.g., changes in waste quantities), and the bases for the potentially discriminating costs, while citable, in many cases may not necessarily reflect the latest industry data and/or proprietary information.

Scenario Cost Estimates and Comparative Analyses

The results shown in Figure ES-1 are repeated in Figures ES-2 through ES-6, showing subsets of results as direct comparisons that support the major conclusions of the analysis.

Possible impacts of delay in repository opening

Figure ES-2 compares Scenarios 1, 2, 3, and 4, and shows that if all other factors are held constant, delay in the beginning of disposal operations results in a steady increase in overall program cost. Specifically, the adjusted Reference Case (Scenario 1) cost for disposal beginning in 2017 increases from $112.1 billion (2018$) to

- $120.0 billion (2018$) if disposal begins in 2031 (Scenario 2),
- $128.4 billion (2018$) if disposal begins in 2041 (Scenario 3), and
- $167.7 billion (2018$) if disposal is delayed to 2117 (Scenario 4).

These cost increases are primarily due to ongoing costs of continued storage of spent nuclear fuel at commercial sites and are paid by the U.S. taxpayer through the Judgment Fund.

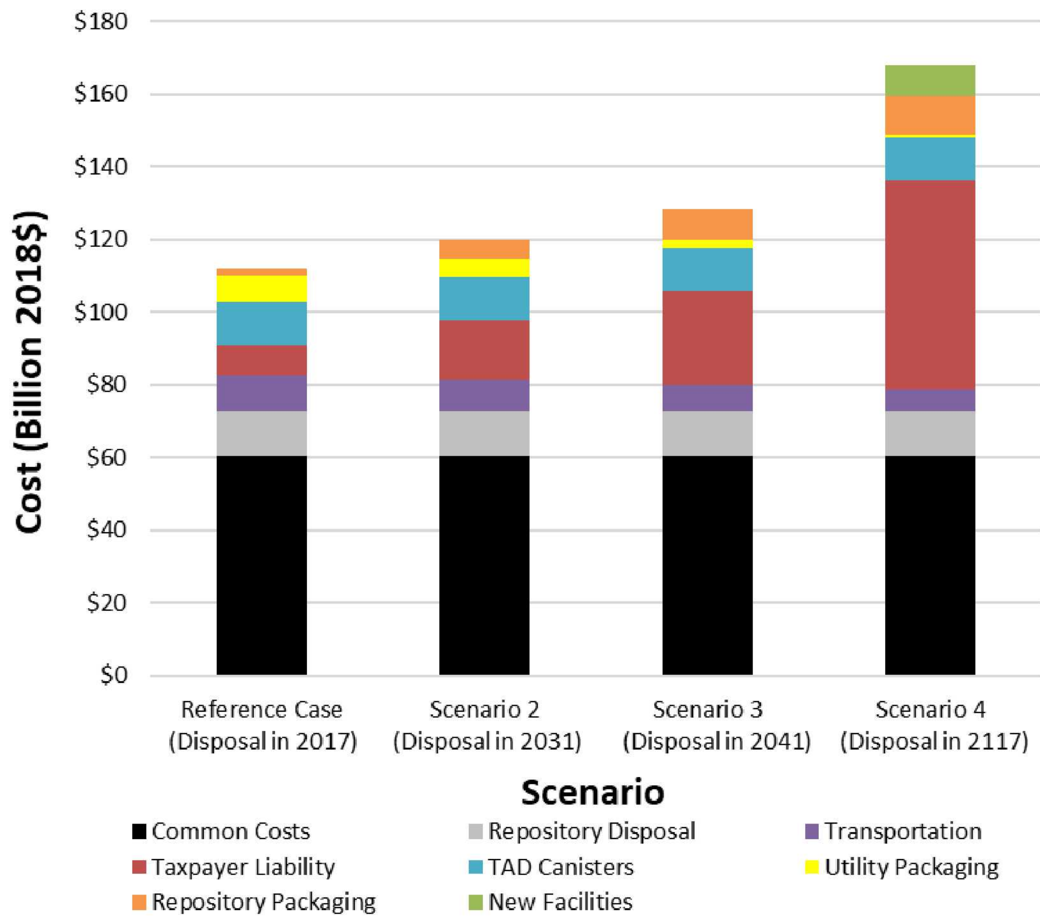


Figure ES-2. Comparison of Estimated Costs for Different Repository Opening Dates

Possible impacts from disposal of DPCs without repackaging

Figure ES-3 and Figure ES-4 show that total life-cycle costs can be reduced if some or all of the spent nuclear fuel can be disposed of in DPCs without repackaging. Specifically, Figure ES-3 compares costs for disposal operations that begin in 2031 with no disposal (full repackaging) of DPCs (Scenario 2), disposal only of the DPCs that exist as of 2025 (Scenario 2B), and disposal of all spent nuclear fuel in DPCs (Scenario 2C). Conclusions from Figure ES-3 are:

- Directly disposing of DPCs that exist as of 2025 has the potential to reduce costs for a repository that opens in 2031 by about $12 billion (2018$) as compared to full repackaging.
- Directly disposing of all spent fuel in DPCs has the potential to reduce costs for a repository that opens in 2031 by about $18 billion (2018$) as compared to full repackaging.

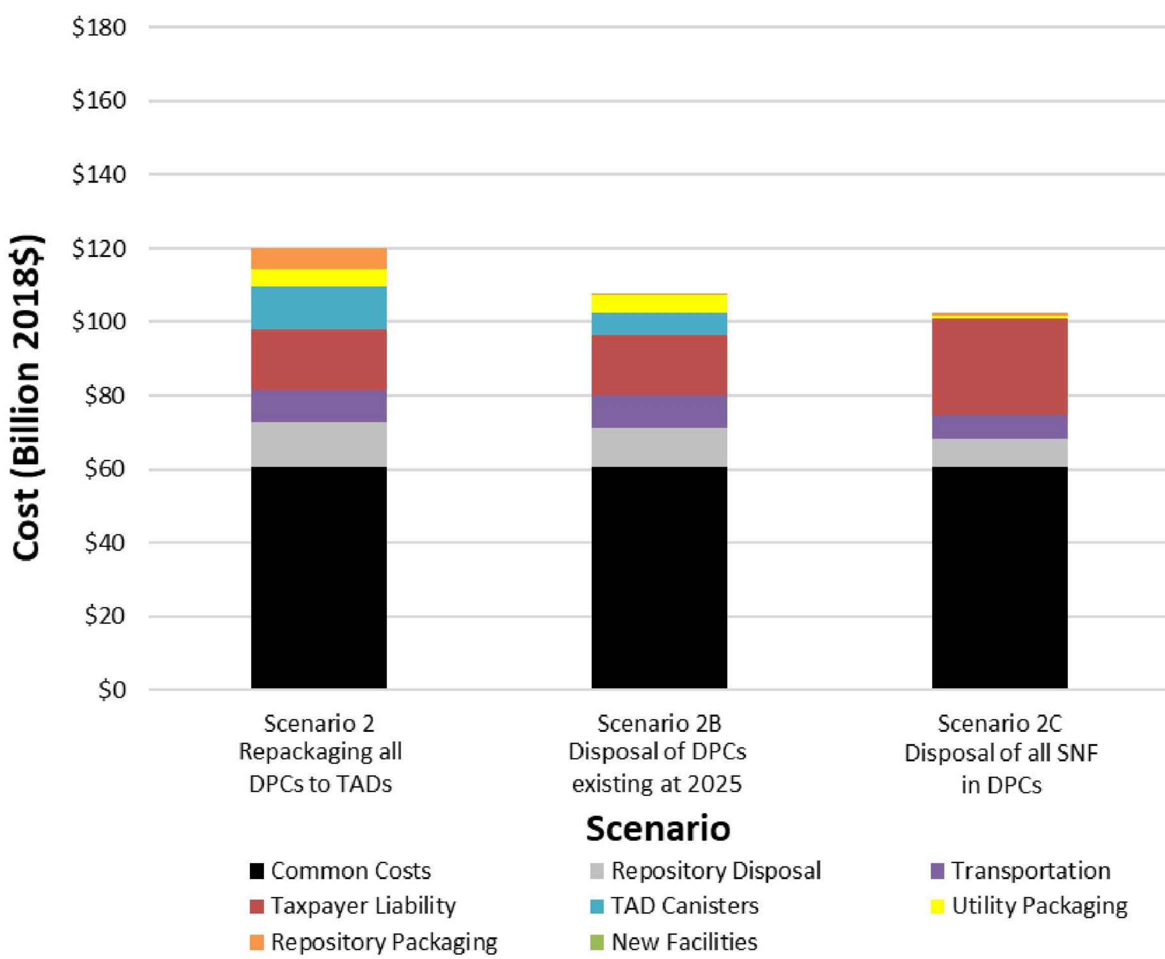


Figure ES-3. Comparison of Estimated Costs for Different DPC Disposal Options (Repository Opens in 2031)

Figure ES-4 shows a similar comparison for disposal operations that begin in 2117 for full repackaging of DPCs (Scenario 4) versus full disposal of DPCs (Scenario 4A).

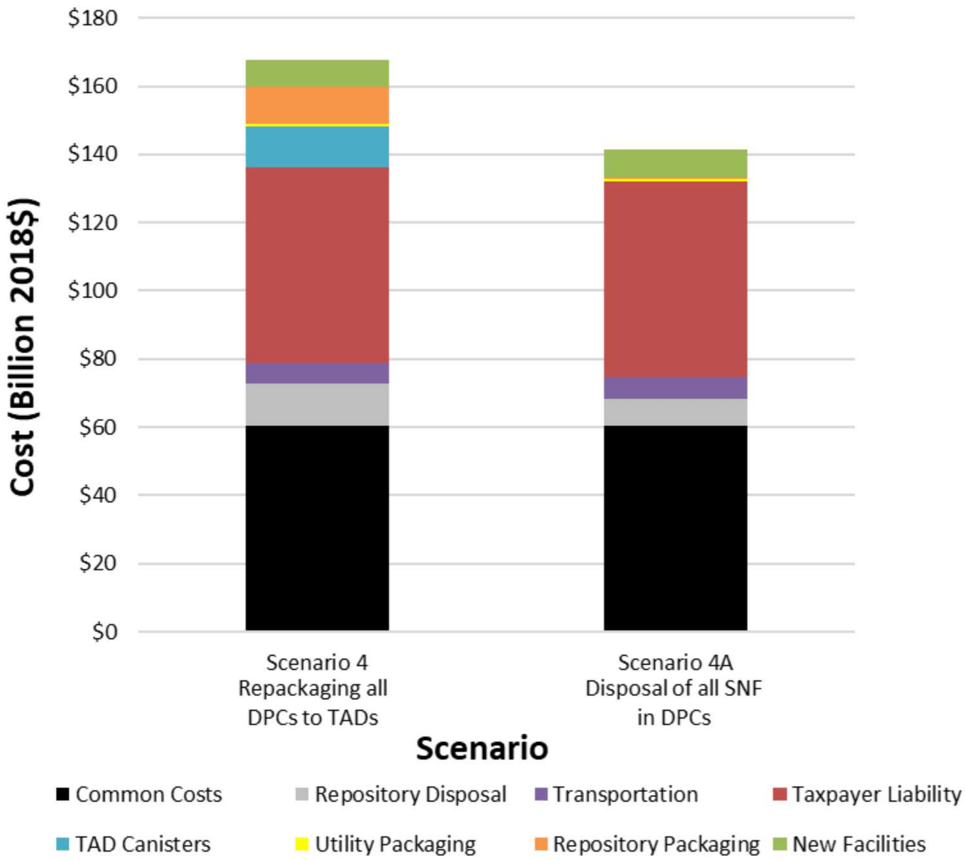


Figure ES-4. Comparison of Estimated Costs for Different DPC Disposal Options (Repository Opens in 2117)

Possible impacts from federal consolidated interim storage

Figure ES-5 shows the potential cost impacts of a federal CIS facility that is available in 2025, assuming disposal operations at a repository begin in 2031 (Scenario 2D), 2041 (Scenario 3A), and 2117 (Scenario 4B). The primary conclusion drawn from this comparison is that the relative cost impact of implementing CIS depends on the date at which the repository begins disposal operations.

- If the repository is available relatively soon after the CIS facility begins operations (e.g., Scenarios 2D and 3A), then the increased costs associated with construction, operation, and transportation for the CIS facility are greater than the savings associated with earlier termination of the Judgment Fund liabilities, resulting in an overall increase in scenario cost of as much as $20 billion (2018$).
- If disposal operations are delayed by 100 years (e.g., Scenario 4B), cost savings from the CIS facility, due primarily to early termination of the Judgment Fund liabilities, are estimated to be about $14 billion (2018$).

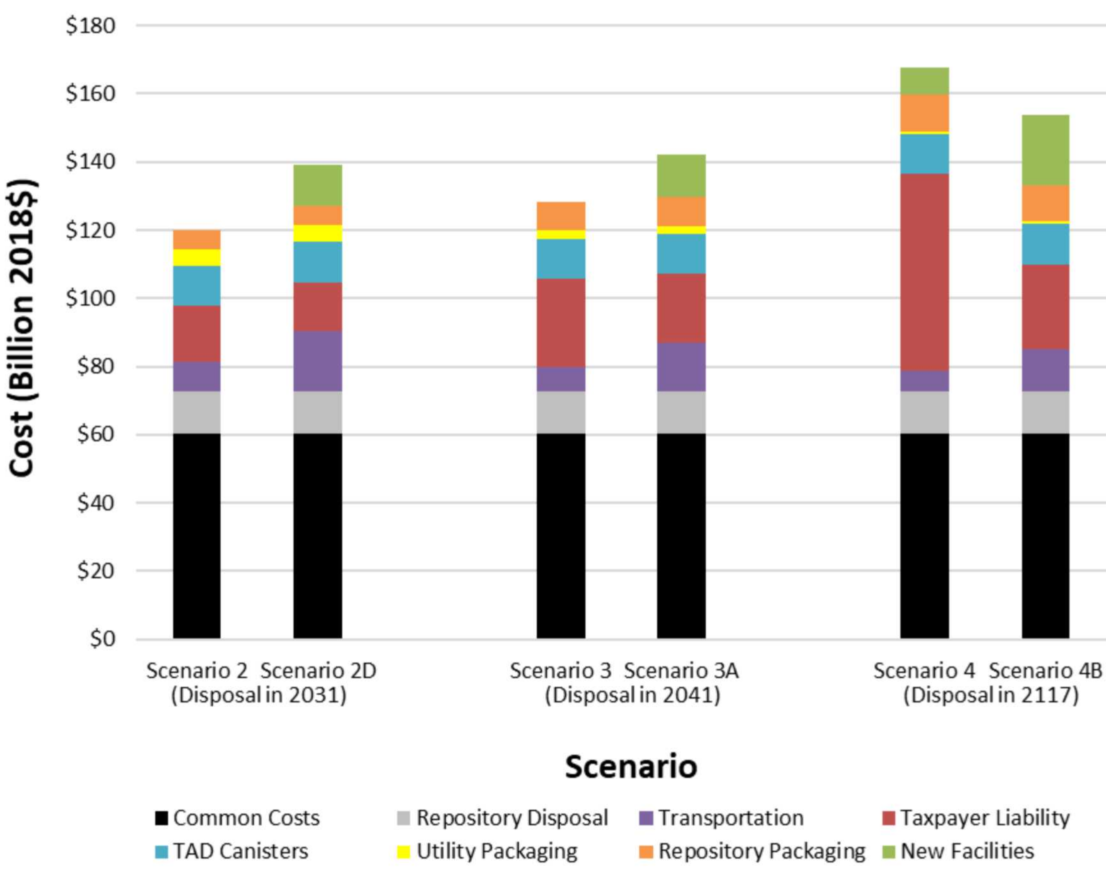


Figure ES-5. Comparison of Estimated Costs for Scenarios with CIS and Different Repository Opening Dates

Possible impacts of where spent nuclear fuel is repackaged

Figure ES-6 shows a comparison that addresses the relative impacts of assuming that repackaging of spent nuclear fuel occurs at the repository (Scenario 2) rather than at the commercial nuclear power plant sites (Scenario 2A). The primary conclusion drawn from Figure ES-6 is that, although there are significant changes in where in the system costs are incurred, the impact on the overall total life-cycle costs is less important than other factors considered in this analysis. Specifically:

- For a repository that begins disposal operations in 2031, repackaging spent nuclear fuel at the commercial nuclear power plant sites rather than at the repository results in an overall increase in total life-cycle cost of about $3 billion (2018$), primarily in increased transportation costs associated with the larger number of shipments required to move TADs rather than DPCs.

This cost comparison is shown only for a single date for the beginning of disposal operations (2031), but impacts can be inferred to be similar for other dates. Note that estimated costs of repackaging at either location do not include the cost of additional facility improvements that may be required to support operations.

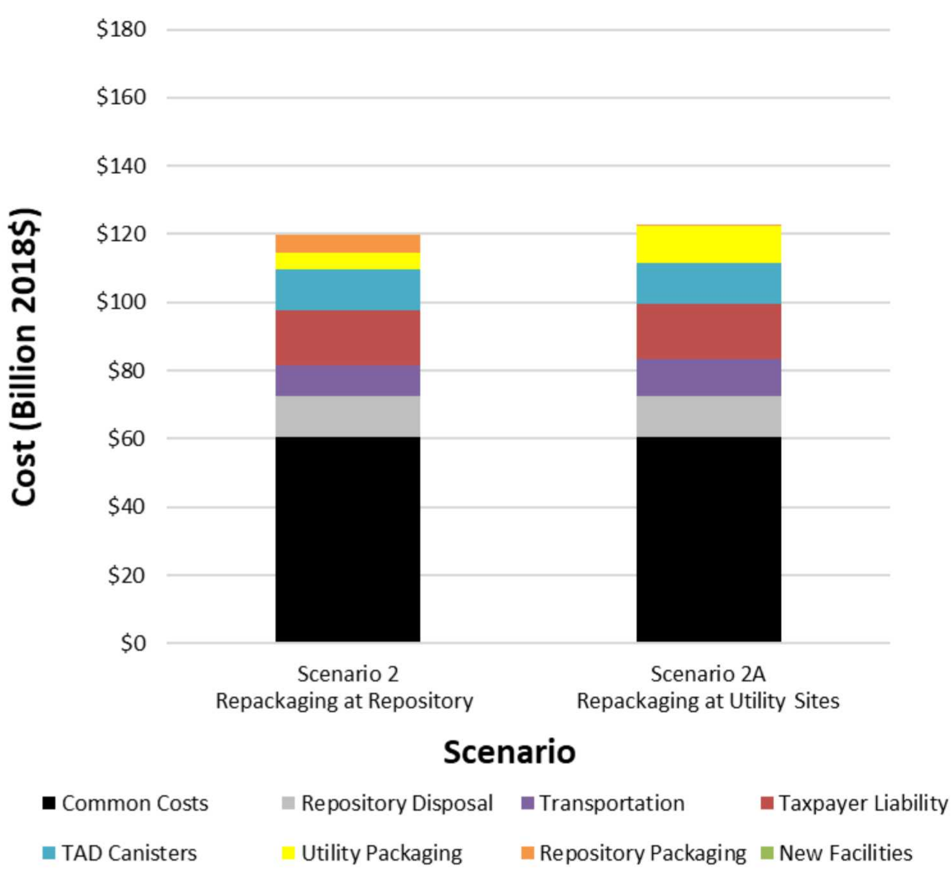


Figure ES-6. Comparison of Estimated Costs for Different DPC Repackaging Locations

Consideration of uncertainty in the analysis

An approach to evaluate the effects of uncertainty and/or variability in the total cost estimates is described in detail in Appendix D and summarized in Section 4.2. The effects of uncertainty in eleven key parameters were examined by assuming three different values for each parameter: a low estimate, a nominal estimate, and a high estimate. In general, the low estimate value is 75% of the nominal estimate value, and the high estimate value is 50% more than the nominal estimate value, consistent with industry project management accepted practices for rough-order-of-magnitude (ROM) cost estimates.

Figure ES-7 compares the low, nominal, and high cost estimates for each scenario. Scenarios 4 and 4A show the greatest difference between high estimate and low estimate values as compared to the other scenarios. This is due to the large increase in costs to taxpayers via payments from the Judgment Fund, which is driven by the large uncertainty (i.e., ratio of high estimate value to low estimate value) in annual operations costs at ISFSIs, both at shutdown (ISFSI-only) sites and at operating reactor sites. Other than this case, uncertainty in underlying costs does not discriminate among scenarios.

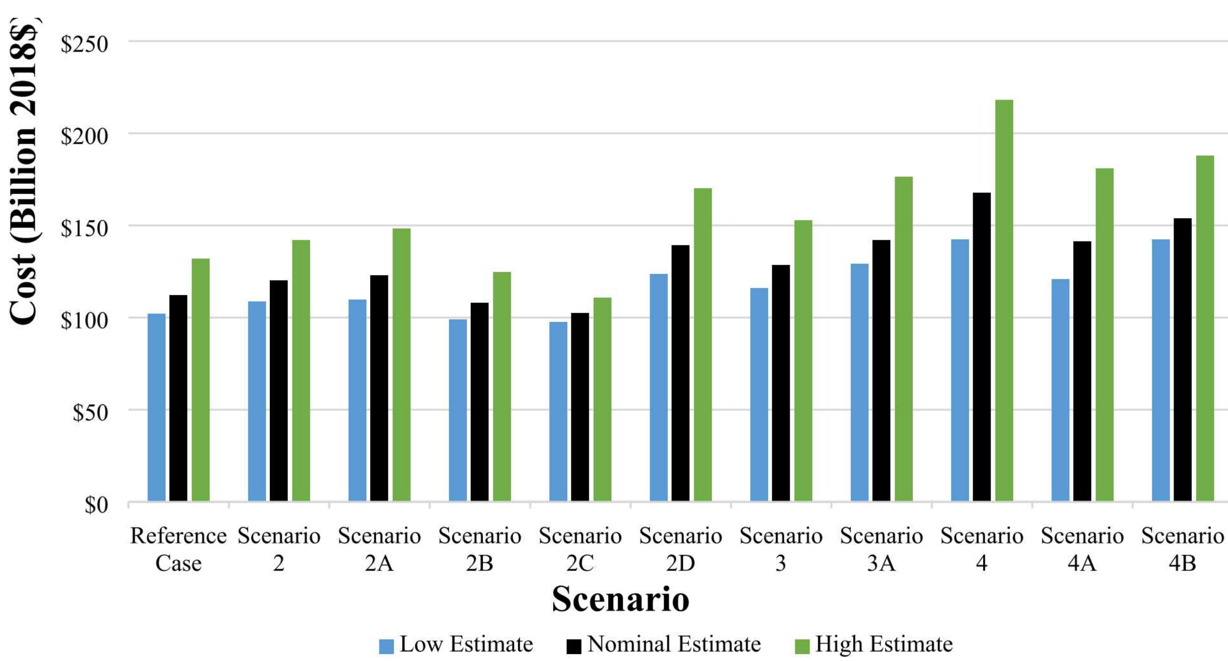


Figure ES-7. Estimated Costs with Uncertainty

Estimated costs grouped by funding source

As described in Section 2, possible funding sources for the various cost elements include: the Nuclear Waste Fund; Taxpayer Liability (Judgment Fund); and Other (costs for which funding sources are not yet identified or allocated, including low-level waste disposal, DPC treatment to facilitate disposal, repackaging of DPCs and loading of TADs at utility sites). A breakdown of the estimated costs for each scenario by funding source is shown in Figure ES-8, with details tabulated in Table 4-5 of Section 4.3.

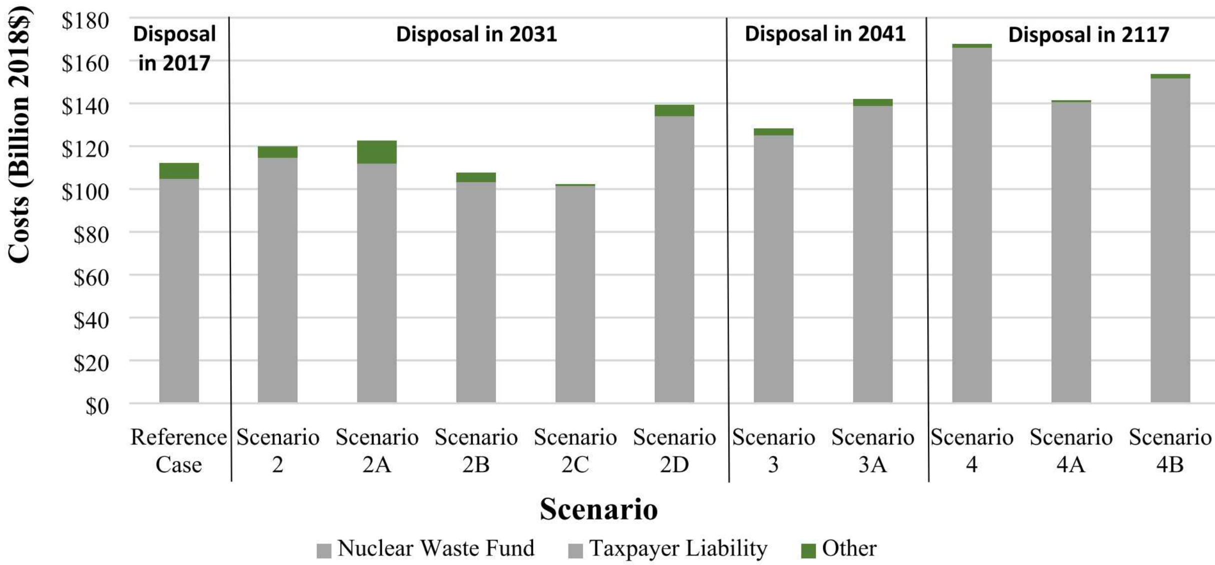


Figure ES-8. Estimated Costs by Funding Source

As shown in Figure ES-8, the primary funding source for all scenarios is the Nuclear Waste Fund. Nuclear Waste Fund costs are lowest in scenarios that include direct disposal of DPCs (Scenarios 2C and 4A) because fewer TAD canisters are required and significantly less repackaging is necessary. The larger capacity of DPCs relative to TADs also means there are fewer shipments of spent fuel, and fewer disposal overpacks needed. Nuclear Waste Fund costs are highest in scenarios where there are new facilities, such as costs associated with CIS (Scenarios 2D, 3A, and 4B).

Taxpayer liability, in the form of payments from the Judgment Fund, increases in scenarios where there is a delay in opening a repository and the utilities are required to maintain ISFSIs for a long time (Scenarios 4 and 4A).

Conclusions

Based on the comparative cost analyses summarized above and described in detail Section 4, the following conclusions are made:

- The adjusted Reference Case (Scenario 1), with disposal at Yucca Mountain in 2017, results in an estimated civilian (commercial) share of the total life-cycle cost of $112.1 billion (2018$).
- Scenarios that delay the beginning of disposal operations, with all other elements of the system unchanged, increase estimates of total life-cycle cost, to:
  - $120.0 billion (2018$) if disposal begins in 2031,
  - $128.4 billion (2018$) if disposal begins in 2041, and
  - $167.7 billion (2018$) if disposal is delayed to 2117.

  Doing nothing and delaying disposal for 100 years is the most expensive option, costing the taxpayers nearly $50 billion (2018$) in additional payments from the Judgment Fund. This increase includes about $15 billion (2018$) for loading more DPCs and about $35 billion

(2018$) for continued operation of ISFSIs at shutdown sites as compared to the Reference Case.

- Scenarios that allow for direct disposal of DPCs without repackaging to TADs reduce estimated total life-cycle costs. For a repository that opens in 2031:
  - Directly disposing of DPCs existing up to 2025, and loading TADs thereafter, has the potential to reduce costs by approximately $12 billion (2018$).
  - Directly disposing of all spent fuel in DPCs has the potential to reduce costs by approximately $18 billion (2018$).
- The relative cost impact of implementing a federal CIS facility depends on the date at which the repository begins disposal operations. If a repository is available relatively soon after the CIS facility begins operations, costs for construction and operation of the CIS facility and for related transportation are greater than the savings associated with the earlier termination of Judgment Fund liabilities. If disposal operations are delayed for a longer period, the earlier termination of Judgment Fund liabilities from a CIS facility can lead to overall cost savings.
- Decisions about where spent nuclear fuel is repackaged for disposal (i.e., at the commercial nuclear power plants or at the repository) result in significant changes in where in the system costs are incurred, but the impact on overall total life-cycle costs is less important than other factors considered in the analysis.
- Cost estimates are relatively insensitive to uncertainty in component costs. Uncertainty in costs to the taxpayer from Judgment Fund liabilities cause the costs associated with lengthy delays before disposal and prolonged ISFSI operations to increase more than those in other scenarios. Otherwise, uncertainty in costs is not a discriminator among the scenarios.
- The primary funding source for all scenarios is the Nuclear Waste Fund. Taxpayer liability, in the form of payments from the Judgment Fund, increases in scenarios where there is a delay opening a repository.

The analyses of alternatives and options related to spent nuclear fuel management presented in this report are based on technical and programmatic considerations. They do not include explicit evaluations of relevant regulatory and legal considerations (e.g., needs for new or modified regulations or legislation) or legal and political sensitivities (e.g., ongoing litigation between the U.S. government and utilities, government and public opinion towards nuclear waste and/or potential storage or disposal sites), although these considerations are likely to factor into decision making.

This report has been prepared for informational and comparison purposes only and should not be construed as a determination of the legal permissibility of specific alternatives and options. No inferences should be drawn from this report regarding future actions by DOE. To the extent this report conflicts with provisions of the Standard Contract, those provisions prevail.

ACRONYMS AND DEFINITIONS

Abbreviation	Definition
BWR	boiling water reactor
CIS	consolidated interim storage
CSNF	commercial spent nuclear fuel
DCSS	dry cask storage system
DOE	U.S. Department of Energy
DPC	dual-purpose canister
GTCC	greater-than-Class C (waste)
HLW	high-level radioactive waste
ISFSI	Independent Spent Fuel Storage Installation
LLW	low-level radioactive waste
MTHM	metric tons of heavy metal
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act of 1982
PWR	pressurized water reactor
SNF	spent nuclear fuel
TAD	transportation, aging, and disposal (canister)
TSLCC	*Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program, Fiscal Year 2007*, DOE/RW-0591
YM	Yucca Mountain

1. INTRODUCTION

1.1. Overview and Purpose

This report describes a comparative analysis of possible approaches, or scenarios, for the management of spent nuclear fuel (SNF) from commercial nuclear power plants during the next century. The selected scenarios represent plausible variants of, or conceptual alternatives to, the Yucca Mountain Project; all scenarios include eventual disposal either at Yucca Mountain or at an alternative repository with equivalent costs. The analyses describe the fundamental features of each alternative scenario and provide simple and credible cost estimates for comparative evaluations. The objective is to inform the U.S. Department of Energy (DOE) in future decision making and policy development that can optimize the management of commercial SNF.

The selected set of scenarios represents a range of possible combinations of alternative spent fuel management approaches that are considered to be generally representative; however, they are not necessarily comprehensive. DOE completed a detailed Total System Life Cycle Cost (TSLCC) analysis in 2008 for transportation and disposal activities associated with a repository at Yucca Mountain (DOE 2008) that provides a suitable baseline for the cost estimates for, and comparisons between, scenarios. The alternative scenarios are evaluated in terms of the timing, options, and costs for waste packaging, storage, transportation, and disposal at the proposed Yucca Mountain repository or an equivalent repository. Most costs would be paid from the Nuclear Waste Fund, but this analysis also includes estimates of the costs borne by taxpayers in the form of payments from the U.S. government “Judgment Fund” to nuclear utilities due to non-performance on Standard Contracts (per 10 CFR Part 961).

None of the selected scenarios include cost estimates for repository concepts and/or rock types different from Yucca Mountain or for fundamentally different waste disposal strategies. Uncertainties associated with the cost of alternative repository concepts are larger than those associated with alternative spent fuel management practices, and insufficient information is available to provide reliable comparisons to the full suite of activities in the TSLCC report (DOE 2008).

The analyses of the various scenarios are intended to help answer questions such as:

> *“What will it cost if we do nothing for another generation?”*
>
> *“Does Yucca Mountain still make sense economically even if it can’t be in operation until the early 2030s?”*
>
> *“Do the economics and timing of other alternatives compare more or less favorably to the baseline?”*
>
> *“What are the relative costs of continuing to load SNF into large dual-purpose canisters compared to loading SNF into packages specifically designed for permanent disposal?”*

The analyses of alternatives and options related to spent nuclear fuel management presented in this report are based on technical and programmatic considerations. They do not include explicit evaluations of relevant regulatory and legal considerations (e.g., needs for new or modified regulations or legislation) or legal and political sensitivities (e.g., ongoing litigation between the U.S. Department of Justice and utilities, government and public opinion towards nuclear waste and/or potential storage or disposal sites), although these considerations are likely to factor into decision making. This report has been prepared for informational and comparison purposes only and should not be construed as a determination of the legal permissibility of specific alternatives and options.

1.2. Background

1.2.1. History

Since the early 1940s, the U.S. has been generating spent nuclear fuel and high-level radioactive waste (HLW). By the time the first commercial power plant came into service in the U.S. in 1957, the National Academy of Sciences/National Research Council had already anticipated that deep geologic disposal would be the best option for final disposal of the radioactive wastes they would generate (NAS 1957). That conclusion would develop into an international consensus on deep geologic disposal that remains to the present day (NAS 2001; NWTRB 2011). Although much progress on siting and development of geologic repositories has been made, no nation is yet operating a deep geologic disposal facility for commercial SNF and HLW.

In 1982, Congress passed the Nuclear Waste Policy Act of 1982 (Public Law 97-425; 96 Stat. 2201) (NWPA), recognizing the need for a clear national policy regarding wastes from both commercial and defense-related nuclear enterprises. The NWPA assigned responsibility for permanent disposal of all spent nuclear fuel and high-level radioactive waste to the federal government, requiring the DOE to evaluate multiple repository sites and to license and construct a disposal facility that would begin operations in 1998. The NWPA limited this first repository to a disposal inventory of 70,000 metric tons of heavy metal (MTHM), either in the form of spent nuclear fuel or an equivalent quantity of high-level radioactive waste. To accommodate additional wastes, the NWPA called for a second repository to be licensed and constructed three years after the first. Private utilities would pay a fee of $0.001/kWh into the Nuclear Waste Fund to finance the federal repository and would retain responsibility for storing and managing spent nuclear fuel until the DOE took title to the material for transport to the repository. DOE and the utilities entered into the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (10 CFR Part 961), which called for utilities to load spent nuclear fuel assemblies into DOE-provided casks, made DOE responsible for transportation of the loaded casks to the repository site, and required DOE to begin taking ownership of the spent nuclear fuel by January 31, 1998. A timeline of important actions driving spent nuclear fuel management in the U.S., from the NWPA in 1982 to the present, is shown in Figure 1-1.

In 1987, Congress passed the Nuclear Waste Policy Amendments Act of 1987 (Public Law 100-203, 101 Stat. 1330), which amended the NWPA to identify Yucca Mountain, Nevada, as the only site for further evaluation as a repository, to defer action on a second repository, and to preclude site-specific activities associated with any location other than Yucca Mountain without specific Congressional authorization. The provisions of the NWPA, as amended, remain in effect today, but all of what the law envisioned has not yet come to pass.

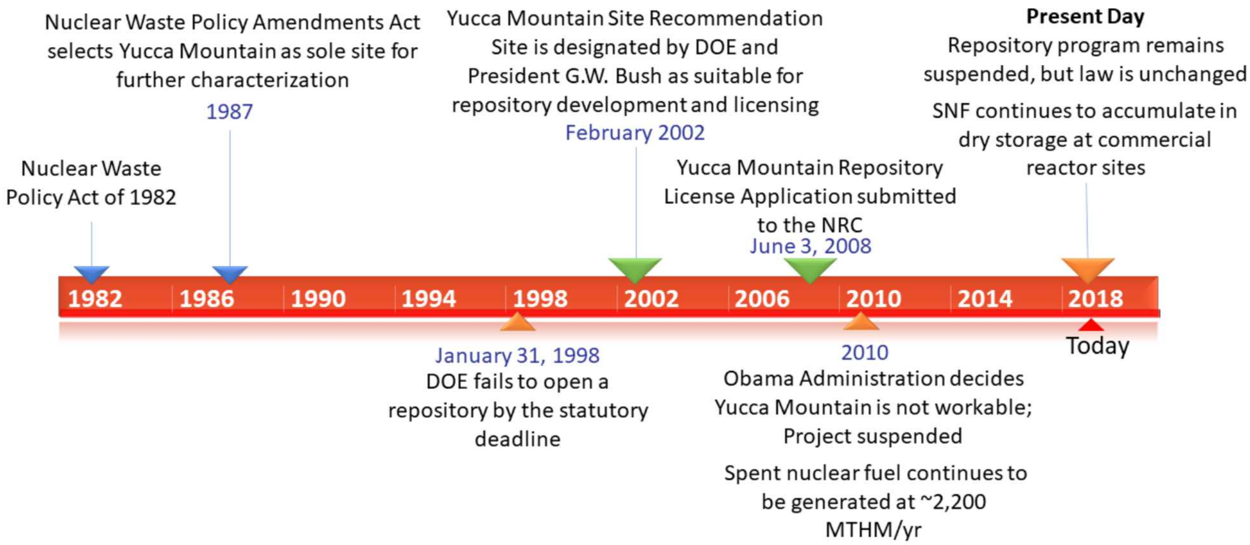


Figure 1-1. U.S. Spent Nuclear Fuel Management Timeline

Spent fuel, upon being removed from the reactor core, was expected to be held in spent fuel pools at nuclear power plants until it had cooled sufficiently and then transported for reprocessing or disposal. In the early years of the commercial nuclear fleet, on-site storage times for spent fuel were anticipated to be on the order of one year or less before spent fuel would be sent for reprocessing, and most reactor storage pools were originally designed to hold one full core plus one or two refueling discharges (NRC 2014a, Section 2.1.2). However, by the late 1970s when reprocessing ceased to be a national policy objective, utilities began reconfiguring reactor pools and storage practices to accommodate substantially more fuel assemblies. As pools approached the revised capacity limits in the 1990s, and as it became clear that the proposed Yucca Mountain repository would not open in 1998, utilities moved forward with implementing on-site dry storage systems, the first of which had been loaded in 1986.

When the DOE failed to open the repository in 1998 and did not begin taking title of spent nuclear fuel, as required by the NWPA, the utilities sued the DOE for breach of contract and were eventually awarded ongoing damages and penalties that taxpayers continue to pay to the present day.

Subsequently, DOE submitted a License Application for Yucca Mountain to the U.S. Nuclear Regulatory Commission (NRC) in 2008 (Sproat 2008; DOE 2009), but the DOE withdrew support for the project in 2010, and Congress suspended funding for the licensing process.

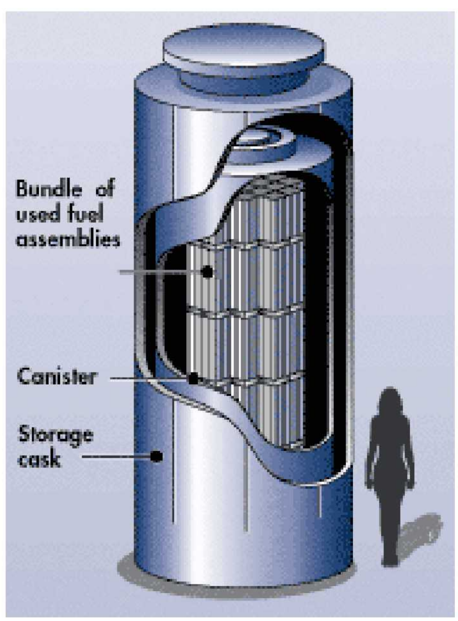
The NRC staff completed its review of the Yucca Mountain Repository License Application in January 2015 by issuing the five-volume Safety Evaluation Report (NRC 2015), concluding that, although certain land ownership and water rights requirements have not yet been met, the repository meets its requirements for preclosure and postclosure safety. However, the Yucca Mountain repository licensing process remains suspended as of the date of publication of this report.

The future of commercial spent nuclear fuel management in the U.S. remains uncertain, with few options available other than continued on-site storage at power plants. Congress has made no change to the law, and the U.S. government is considering no other sites for disposal. Spent nuclear fuel continues to accumulate in storage at reactor sites, about 80,000 MTHM in pools and dry storage at commercial reactor sites as of December 2017, and taxpayers continue to pay utilities for costs of on-site management of spent nuclear fuel. Both federal and private sector consolidated interim storage (CIS) facilities have been contemplated that could accommodate some spent fuel from both decommissioned and operating sites. The private sector CIS sites are not yet NRC-licensed and their economic viability is uncertain. The viability of a federal CIS site is also unlikely without modifications to the portions of the NWPA that link federal interim storage to repository licensing and operation.

Neither existing on-site dry storage nor the proposed CIS approaches are optimized for eventual transportation or disposal; both may require repackaging and handling of spent nuclear fuel in the future and may impact disposal options and processes. This report outlines those impacts and alternative strategies, presenting the current but suspended policy as the baseline against which alternatives and their costs are evaluated.

1.2.2. Dry Storage Systems for SNF

Numerous dry cask storage system (DCSS) designs are in use in the U.S. today. Most systems place spent fuel assemblies in a sealed inner stainless-steel canister, which is then placed in a concrete or steel storage cask or overpack (Figure 1-2). In most DCSSs, the sealed inner canister is a large-diameter dual-purpose canister (DPC) that is certified by the NRC for both storage and transportation of SNF. For transportation, the DPC is removed from the storage cask/overpack and placed in a shielded transportation cask. Multiple vendors provide NRC-certified dry storage systems to utilities. Some of the older-design inner canisters are NRC-certified for storage only, and not for transportation; many are not proximal to spent fuel pools or other fuel handling facilities. The existence of storage-only canisters complicates the task of eventually transporting the spent fuel in them to a CIS site or to a disposal facility.



(Source: NRC 2019)

Figure 1-2. Spent Fuel in a Dry Cask Storage System

Individual specifications vary, but typical DPCs are approximately 2 m in diameter and 5 m in length, and the largest currently in use in the U.S. accommodates up to 37 pressurized water reactor (PWR) fuel assemblies or 89 boiling water reactor (BWR) fuel assemblies (Bonano et al. 2018). Fully loaded DPCs weigh between 25 and 53 metric tons (Rechard et al. 2015, Section 2.1.2.2; Greene et al. 2013, Table 2); a shielded transportation cask/overpack may increase the weight to 150 metric tons (Bonano et al. 2018).

The most common type of dry storage system is a vertical DCSS. Vertical DCSSs can be constructed both above grade on concrete pads (Figure 1-3a) and below grade (Figure 1-3b); horizontal systems with canisters emplaced in modular concrete storage "vaults" are also in use (Figure 1-3c). Some older fuel is also stored as uncanistered (i.e., "bare") fuel in casks with bolted lids; few sites continue to load these systems.

(a) Vertical Above Grade
(Maine Yankee, Wiscasset, ME)

(b) Vertical Below Grade
(Humboldt Bay, Eureka, CA)

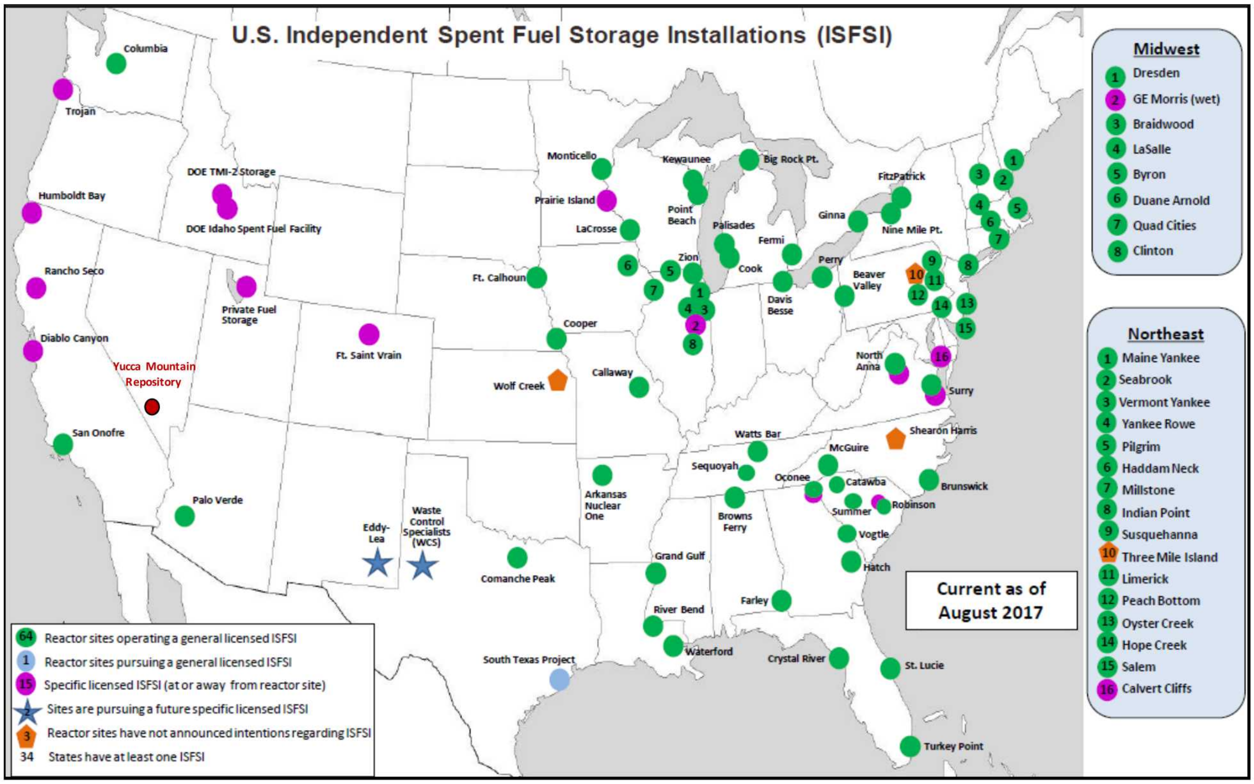
(c) Horizontal
(Rancho Seco, Herald, CA)

(Source: Rechard et al. 2015, Figure 3)

Figure 1-3. Types of Dry Cask Storage Systems

Dry storage systems are certified by NRC for use at Independent Spent Fuel Storage Installations (ISFSIs) licensed under 10 CFR Part 72. An ISFSI may be licensed for up to 40 years with options to renew in up to 40-year increments. Recent NRC findings for "Continued Storage of Spent Nuclear Fuel" (NRC 2014b), formerly known as the "Waste Confidence Decision," suggest that spent fuel can be stored safely for at least 60 years beyond the licensed life for operation, which could result in storage times of at least 100 years.

ISFSIs are most commonly co-located at sites with operating reactors. At the end of 2017, there were 99 operating reactors at 60 sites (NEI 2018a; NEI 2018b). At the 60 sites with operating reactors, there are 60 licensed ISFSIs at 56 sites (four of the sites have dual licenses); the other four sites do not yet have on-site dry storage (NEI 2018b; NEI 2018c). There are also currently ISFSIs at 14 "shutdown" sites where there is no longer an operating reactor; the SNF at these sites is referred to as "stranded" waste (NEI 2018d). ISFSIs at sites where the reactor is no longer operating and has been decommissioned can be more expensive to operate because they cannot take advantage of cost sharing (e.g., for security) with reactor operations. As operating reactors continue to shut down, the number of ISFSIs at shutdown sites will increase. Figure 1-4 shows the locations of the ISFSIs at operating reactors (60), shutdown reactors (14), and away-from-reactor sites (5).



(Source: NRC 2017)

Figure 1-4. Independent Spent Fuel Storage Installations (ISFSIs) as of August 2017

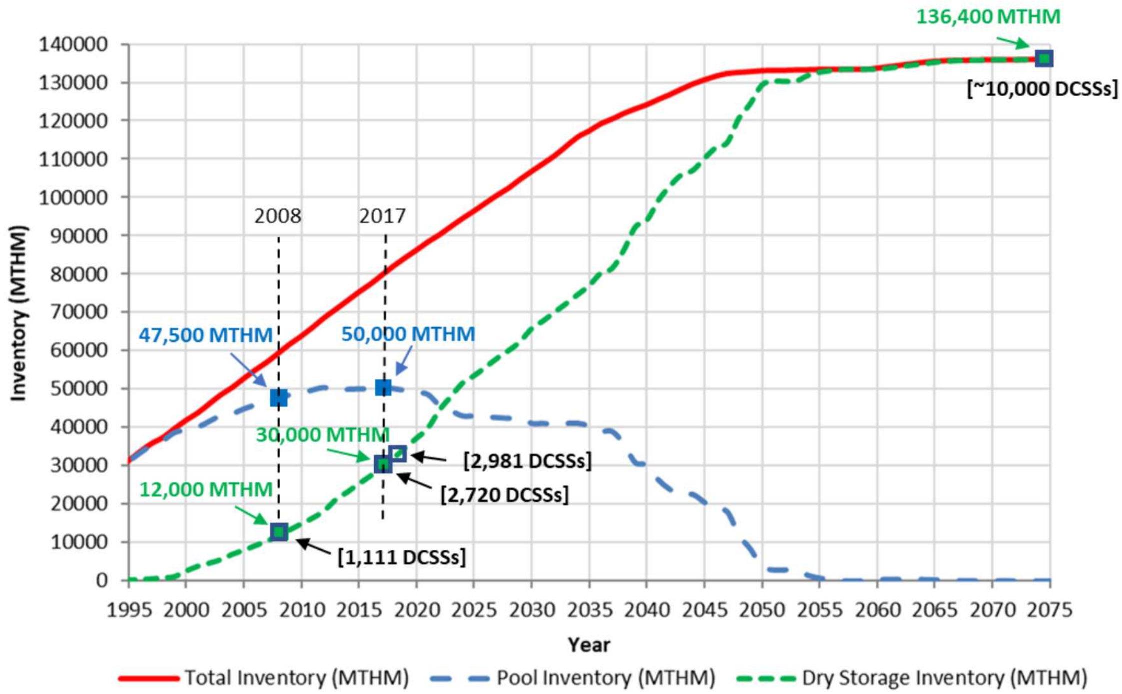
1.2.3. Commercial SNF Inventory Projections

Estimates of future U.S. commercial SNF (CSNF) inventory were developed by Vinson and Metzger (2017, Section 2.2). The estimates used a "No Replacement Nuclear Power Generation" scenario for future nuclear power generation in the U.S., comprising the following assumptions[1]:

- No new reactors are constructed (i.e., no replacement).
- 93 of the 99 reactors operating at the end of 2017 are assumed to have one 20-year extension and will be decommissioned after 60 years of operation.
- 6 operating reactors that have announced shutdown dates continue operating until those dates.
- No CSNF is reprocessed.
- There are no options for permanent disposal and all CSNF remains in storage.

[1] These assumptions and estimates were developed in 2017 and assumed a shutdown of the Oyster Creek Nuclear Generating Station in 2019. Oyster Creek was shut down prematurely in September 2018, leaving 98 currently operating reactors.

Under these assumptions, all currently operating reactors shut down by 2055, except for Watts Bar 2, which was licensed in 2015 and is assumed to shut down in 2075. Figure 1-5 shows the projected inventory of U.S. CSNF under the “no replacement” scenario through 2075. It also shows the projected number of DCSSs at the end of 2008 (StoreFuel 2008), 2017 (StoreFuel 2018), 2018 (StoreFuel 2019), and 2075 (estimated).



Note: Projections assume:

1. **(1) 93 of the 99 reactors operating at end of 2017 receive license renewals and are decommissioned after 60 years of operation,**
2. **(2) the 6 existing reactors that have announced shutdown dates continue operating until those dates,**
3. **(3) no new reactors are constructed,**
4. **(4) no CSNF is reprocessed, and,**
5. **(5) there are no options for permanent disposal and all CSNF remains in storage.**

Figure 1-5. Projected Inventory of Commercial SNF in Storage

Key observations, under the “no replacement” scenario include:

- Approximately 80,000 MTHM of CSNF were in storage in the U.S. as of December 2017 (Figure 1-5; Vinson and Metzger 2017, Table 1-2).
  - Approximately 30,000 MTHM in dry storage at reactor sites. Of the 2,720 total DCSSs, 2,487 contain canistered commercial spent fuel (e.g., DPCs) (StoreFuel 2018); the remainder contain uncanistered “bare” fuel or greater-than-Class C (GTCC) waste.
  - Approximately 50,000 MTHM in pools, mainly at reactors
- Approximately 2,200 MTHM of CSNF are generated nationwide each year, resulting in 160 to 200 new storage canisters (i.e., DPCs) being loaded annually.
- Most reactor pools in the U.S. have been filled to capacity since approximately 2012, and pool storage of newly discharged CSNF at most locations now requires transferring older and cooler fuel to dry storage.
- The total mass of CSNF generated by the existing U.S. reactor fleet by mid-century will be about 136,400 MTHM (Figure 1-5; Vinson and Metzger 2017, Table 2-9), which is nearly twice the limit established by the NWPA for the proposed Yucca Mountain repository. If existing practices continue, this inventory will be in ~10,000 DPCs.
- The DOE is in partial breach of the Standard Contracts requiring it to take title to spent nuclear fuel, and the U.S. government pays utilities for storage as a result of settlements and penalties associated with lawsuits.
  - Payments to the utilities are a taxpayer liability that come from the U.S. Treasury via a “Judgment Fund” rather than from the Nuclear Waste Fund or DOE-appropriated funds.

As more spent nuclear fuel is put in dry storage, the increased inventory in DPCs and the reduced inventory remaining in pools will eventually start to limit future disposal options. Impacts may include the need for repackaging of stored spent nuclear fuel assemblies, limiting design options for future repositories, and/or increased use of long-term dry storage. Therefore, waste management options become progressively more constrained over time. The flexibility in the system for the NWPA-sanctioned repository can be defined as the inventory of unpackaged CSNF (e.g., in pools and still to be discharged from reactors), which remains available to be directly loaded into repository-specific disposal canisters. With respect to the NWPA-specified inventory for the proposed Yucca Mountain repository, this flexibility is retained until ~2037, which is the latest projected date at which 63,000 MTHM[2] of the total projected future inventory will not yet be in DPCs in dry storage. Therefore, the options and scenarios outlined in this report may be foreclosed or limited over time by the quantity of spent nuclear fuel in dry storage.

[2] To achieve the 70,000 MTHM inventory limit for Yucca Mountain as specified in the NWPA, DOE allocated 10% of the mass (i.e., 7,000 MTHM) to DOE-managed SNF and HLW, leaving a 63,000 MTHM capacity for CSNF (Lytle 1995; DOE 2009).

1.2.4. Observations on Current Practice

Current practice using existing dry storage systems is safe and secure, though assurance of continued safety and security over extended service lifetimes requires additional research regarding canister integrity, fuel integrity, and aging management practices. Although the recent NRC findings for "Continued Storage" (NRC 2014b) suggest that spent fuel can be stored safely for 100 years, dry storage systems are not designed, constructed, or licensed for use in perpetuity and would probably require periodic remediation or replacement. Current practices are optimized for reactor site operations including efficiency of reactor operations, maintaining cost-effective on-site safety, and minimizing occupational dose. These reactor-site priorities for dry storage do not optimally support transportation and disposal; for example, thermal loading, package size, and package design do not necessarily align with transportation requirements and disposal design assumptions. Those requirements and assumptions were based primarily on transferring spent fuel from the pools directly into standardized transportation, aging, and disposal (TAD) canisters as described in the Yucca Mountain repository design in the License Application (DOE 2009). Placing spent fuel in dry storage in DPCs commits the U.S. to some combination of three options.

- Repackaging spent fuel in the future to accommodate existing or future repository designs
- Constructing one or more repositories that can accommodate DPCs
- Storing spent fuel at surface facilities indefinitely, repackaging as needed

Each option is technically feasible, but none reflects original planning, and all have implications for cost, safety, and disposal schedule.

1.3. Scope and Organization of the Report

Section 2 describes the baseline Reference Case scenario.

Section 3 describes the set of alternative scenarios.

Section 4 describes the cost analyses for the selected scenarios.

Section 5 provides the overall conclusions of the report.

Appendices provide details of the cost estimates.

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2. REFERENCE CASE SCENARIO FOR MANAGEMENT OF SNF

The baseline, or Reference Case, scenario derives from the transportation and disposal activities described in the TSLCC report (DOE 2008) and the associated cost elements. The baseline Reference Case provides a comparison basis for the representative alternative scenarios described in Section 3.

The TSLCC report provides a cost estimate for the prospective repository life cycle (design, engineering, licensing, construction, surface and subsurface operations, and decommissioning) and transportation activities based on the system described in the *Draft Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE 2007). The TSLCC cost estimate (DOE 2008, Section 1) includes the project-specific TAD-canister-based system design used for the License Application that was subsequently submitted by the DOE to the NRC for authorization to construct a repository at Yucca Mountain. The TSLCC estimate includes historical (sunk) costs starting from 1983 and projected costs through an assumed closure date of 2133 (DOE 2008, Section 1).

The TSLCC cost estimate is based on the following schedule milestones from the then-current baseline schedule (DOE 2008, Sections 1.3 and 2.2):

- Submittal of the License Application for construction to the NRC in 2008
- Repository Construction Authorization by the NRC in 2011
- Utilities stop loading CSNF into DPCs and start loading it into TADs in 2011
- Submittal of the License Application to receive and possess to the NRC in 2013
- Initial waste receipt and start of repository surface and subsurface operations in 2017
- End of 57-year period of waste emplacement in 2073
- End of 50-year period of monitoring with drift ventilation in 2123 (drip shields are emplaced from 2113 to 2123)
- End of 10-year period of closure operations in 2133.

A detailed breakdown of the TSLCC costs is provided in Appendix A. Specific cost estimates include:

- TSLCC Total (in 2007$) of $96.18 billion – The cost for transportation and disposal of commercial and defense wastes at the Yucca Mountain repository, estimated as of May 2007.
- TSLCC Civilian Share (in 2007$) of $77.38 billion – The civilian (commercial) cost share allocation, representing costs for the disposal of commercial SNF and HLW and which is to be paid from the Nuclear Waste Fund, is 80.4%. The remainder, 19.6%, is the total government allocation, representing costs for the disposal of DOE-managed waste and which is to be paid by annual appropriations.
- TSLCC Civilian Share (in 2018$) of $96.22 billion – The escalation of the commercial cost share allocation to constant 2018 dollars, based on an average annual inflation rate of 2% from 2007 to 2018 (BLS 2018).

The cost estimate used here considers only the commercial cost share. Costs associated with treating, storing, transporting, and disposing of defense wastes are omitted from the Reference Case and the alternative scenarios to allow the analysis to focus exclusively on the impacts of decisions related to the management of commercial spent nuclear fuel. The TSLCC commercial cost share estimate is based on the following assumptions about repository operations (see Appendix A):

- A projected inventory of 109,300 MTHM of CSNF. Disposal is for 12,983 TAD-based waste packages (7,978 with PWR assemblies and 5,005 with BWR assemblies). This includes:
  - 10,989 TAD canisters loaded and sealed at the utility sites and shipped to the repository. The TAD canisters, with capacities of 21 PWR or 44 BWR assemblies, would be provided to the utilities by the DOE. Upon receipt at the repository, DOE would remove the TAD canisters from transportation casks/overpacks and place them in waste package overpacks suitable for disposal underground.
  - 1,994 TAD canisters loaded at the repository; 1,410 come from 920 DPCs shipped from the utility sites (~1.53 TADs/DPC) and 584 come from spent fuel in other types of containers (e.g., casks of uncanistered "bare" fuel) shipped from the utility sites.

The TSLCC commercial cost share estimate is based on the following assumptions about transportation (see Appendix A):

- The preferred mode of transportation to the repository is "mostly rail" using dedicated rolling stock (100 cask cars, 37 buffer cars, and 18 escort cars). Waste pickup uses the "Oldest Fuel First" acceptance priority in the Standard Contract for CSNF acceptance. Nominal acceptance rates for CSNF are 3,000 MTHM/year.
- The fleet of transportation casks and overpacks required includes 12,983 TAD canisters, 42 CSNF overpacks, 31 CSNF medium/small casks, 30 CSNF truck casks, and 30 DOE rail casks.
- A total of 11,909 shipments – The commercial allocation for transportation costs is assumed to be based on the rail shipments (10,989 TADs and 920 DPCs). A shipment consists of one loaded canister (TAD or DPC) in a cask/overpack transported on a single rail car.

To produce a baseline Reference Case that provides a common comparison basis for the alternative scenarios in Section 3 and is consistent with current knowledge, cost adjustments to the TSLCC commercial share were necessary. These cost adjustments included (1) updating the number of DPCs loaded in 2011 assumed in the TSLCC and revising the affected cost elements, and (2) adding costs of additional activities that were not included in the TSLCC but that are potentially discriminating costs between scenarios. The details of these two cost adjustments are described in the following paragraphs.

First, the TSLCC cost estimate assumed that utilities would stop loading CSNF into DPCs in 2011 and was based on a projection that 920 DPCs would be loaded by 2011. The actual number of DPCs loaded through May 2011 was 1,224 (StoreFuel 2011). Due to more CSNF being loaded into DPCs, there is also a corresponding decrease of 465 TADs projected to be loaded at the utility sites. Consideration of these additional 304 DPCs and 465 fewer TADs results in revisions to the following cost elements:

- Transportation (Operations and Infrastructure) – There are 161 fewer canisters (more DPCs but fewer TADs) to be transported, corresponding to 161 fewer rail shipments.
- Repository Operations (Repackaging DPCs to TADs) – This includes costs for (1) unloading DPCs, and (2) loading TADs. There are an additional 304 DPCs to be repackaged at the repository, beyond the 920 DPCs (and SNF from the uncanistered "bare" fuel casks) included in the TSLCC cost estimate.

Second, the following costs, which were not part of the TSLCC estimate but which may be potentially discriminating between scenarios, are added to the escalated (2018$) TSLCC commercial costs:

- Utility/ISFSI Operations (TAD Loading/DPC Transport Preparation) – These include costs for (1) loading TADs at utility sites, and (2) transferring DPCs to transportation casks/overpacks at utility sites.
- Low-Level Radioactive Waste (LLW) Disposal – This includes the cost of disposing of the DPC shells as LLW after the spent fuel has been transferred to TADs. Due to the increased usage of DPCs by utilities, LLW disposal at both the utility sites and the repository has become an important and somewhat variable cost input.
- Taxpayer Liability (Judgment Fund) – Funds paid to utilities through litigation or settlement agreements, colloquially known as "Judgment Funds" (31 CFR Part 256; 31 CFR Section 1304) are managed through the U.S. Court of Claims and the U.S. Department of Justice and are paid from the U.S. general fund (i.e., a taxpayer liability) as opposed to appropriated DOE funds or the Nuclear Waste Fund. These costs, primarily associated with dry storage, include payments to the utilities for the cost of loading DPCs, the annual costs of ISFSI administration and maintenance, and associated ISFSI costs for up to 10 years following availability of a repository.

The resulting Reference Case scenario is shown graphically in Figure 2-1. The Reference Case cost estimate of $112.084 billion (2018$), with the adjustments, is summarized in Table 2-1.

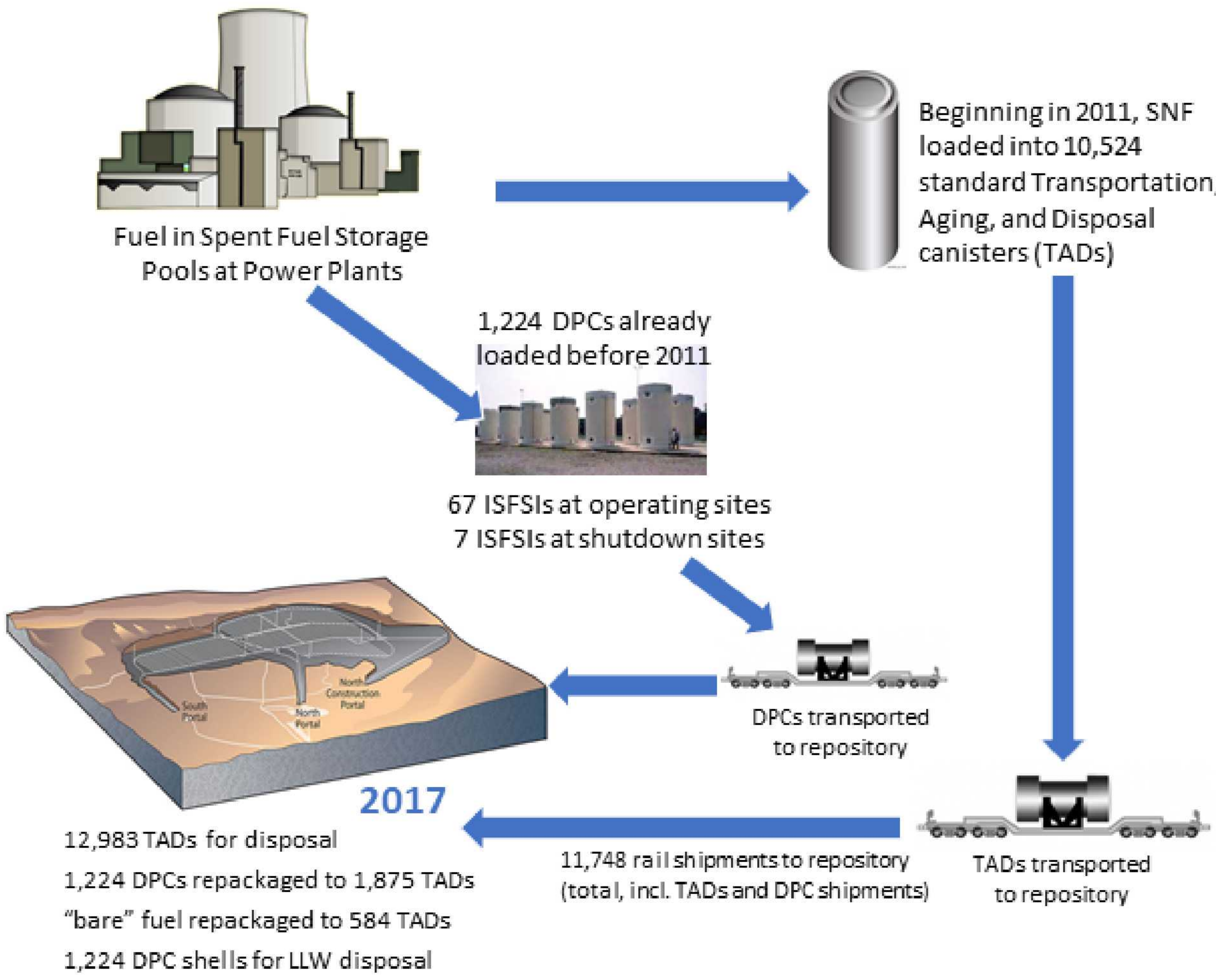

Figure 2-1. Reference Case (Scenario 1): Repository in 2017, Load TADs in 2011, Repackage DPCs at Repository

Table 2-1. Summary of Reference Case Scenario Costs (Billions of 2018$)

COST ELEMENT		TSLCC COMMERCIAL SHARE (2018$)	REFERENCE CASE SCENARIO (2018$)
REPOSITORY COSTS	**Development and Evaluation (1983-2002)**	**8.099**	**8.099**
	Engineering, Procurement, and Construction (2003-2053)	**17.628**	**17.628**
	Repository Emplacement Operations (2017-2073)	**25.990**	**24.507**
	Waste Package Fabrication (12,983 disposal overpacks)	12.232	12.232
	Repository Operations and Infrastructure	13.758	12.276[a]
	Monitoring (2074-2123)	**9.869**	**9.869**
	Closure (2124-2133)	**1.352**	**1.352**
	REPOSITORY COSTS TOTAL	**62.938**	**61.455**
TRANSPORTATION COSTS	**Transportation Operations and Infrastructure (11,748 shipments)**	**10.159**	**10.022** [b]
	TAD Canister Fabrication (12,983 TADs)	**11.922**	**11.922**
	TRANSPORTATION COSTS TOTAL	**22.081**	**21.944**
BALANCE OF PROGRAM COSTS		**11.196**	**11.196**
COST ADJUSTMENTS FOR REFERENCE CASE	**Repository Operations (DPC Repackaging)**	**0.000**	**1.829**
	Utility Site/ISFSI Operations (TAD Loading/DPC Transport Preparation)	**0.000**	**7.226**
	LLW Disposal	**0.000**	**0.214**
	Taxpayer Liability (Judgment Fund)	**0.000**	**8.219**
	COST ADJUSTMENTS TOTAL	**0.000**	**17.488**
TOTAL COSTS		***96.216***	***112.084***

Notes: Column totals may not add due to rounding

[a] The cost for repackaging 1,224 DPCs is included as a Cost Adjustment. In the TSLCC, the cost for repackaging 920 DPCs was included as part of Repository Operations and Infrastructure.

[b] The cost for Transportation Operations is lower in the Reference Case because the extra 304 DPCs result in fewer overall canisters (more DPCs, but fewer TADs) resulting in fewer overall shipments.

The use of 109,300 MTHM as the CSNF inventory for the Reference Case scenario, and for alternative scenarios, warrants further discussion.

The NWPA, as amended, limits the amount of SNF and HLW in Yucca Mountain to 70,000 MTHM (~63,000 MTHM CSNF) prior to the start of operations at a second repository. However, the TSLCC estimate included the entire future U.S. inventory for disposal, projected at the time (in 2008) to be 109,300 MTHM of CSNF. The TSLCC assumption was appropriate because (1) no basis for cost information for a second repository existed, and (2) then-proposed legislation was being considered to remove the 70,000 MTHM limit. As shown in Figure 1-5, current (made at the end of 2017) projections estimate a future total of 136,400 MTHM of CSNF, with 109,300 MTHM CSNF in inventory by about 2032 and 109,300 MTHM CSNF in dry storage by 2043. These projections could also change; decreasing in the case of premature reactor shut downs or increasing in the case of new builds or further license extensions.

Due to the uncertainties in future inventory projections, and to be consistent with the TSLCC estimate and allow comparison with it as a baseline, all the scenarios considered in this report assume an inventory of 109,300 MTHM of CSNF is disposed of in a repository similar to Yucca Mountain.

This report does not consider costs associated with construction of a second repository to accommodate CSNF in excess of 109,300 MTHM. Given that the purpose of this report is to compare costs of spent fuel management options, assumptions about a second repository (or any repository other than Yucca Mountain) would (1) introduce unresolvable questions about siting, licensing, and costing a second repository that are beyond the scope of this analysis, (2) be the same for all scenarios, and/or (3) mimic the first repository results, with the second repository in each scenario assumed to be a duplicate of the first (e.g., using same treatment of DPCs, etc.). This would not support a focused analysis of differences between spent fuel management alternatives.

To further provide a complete common basis for comparison for alternative scenarios, the Reference Case scenario costs are grouped in two ways. First, costs are categorized as either:

- Common Costs – Costs that are common to all scenarios. While there may be uncertainty and/or variability in some of these cost elements, it is expected to be similar for all scenarios. Therefore, for the purposes of this simple cost analysis, these common costs are fixed across all scenarios.
- Potentially Discriminating Costs – Costs that may differ across scenarios. These costs, and the uncertainty in the input parameters that control them, are the focus of the cost analyses in Section 4 of this report. Some potentially discriminating costs were identified previously in this section; more are identified in Section 3.

Second, costs are allocated by their likeliest source of funding. The source of funding depends on a number of variables, most importantly the location (e.g., at the utility sites or at the repository site) and timing (before or after DOE begins to take receipt of the CSNF) of the activities. The funding sources include:

- Nuclear Waste Fund – This fund, established by the NWPA, collects or accrues payments from the utilities based on nuclear electricity generation (i.e., at a rate of $0.001/kWh). The utilities in turn collect these funds from their ratepayers. In 2014, in response to a finding by the U.S. Court of Appeals, the rate (ongoing fee) was reduced to zero (OIG 2018, p. 6). Prospective Nuclear Waste Fund expenditures are reflected in the TSLCC; they are primarily related to transportation and repository activities. In Fiscal Year 2017, the Nuclear Waste Fund had a balance of $37.7 billion (DOE 2017, pp. 31 and 81), which included interest from investments in U.S. Treasury securities of approximately $1.3 billion for the year (OIG 2018, p. 20), without any additional fees being collected.
- Taxpayer Liability (Judgment Fund) – As described previously, these are funds paid from the U.S. Treasury Judgment Fund (a taxpayer liability) to the utilities as a result of litigation or settlement agreements due to breach of the Standard Contract. Taxpayer liabilities are primarily related to utility site/ISFSI storage activities and, in addition to being dependent on the time at which DOE takes receipt of the CSNF, are also dependent on the time at which reactors at shutdown sites are decommissioned (at which point annual ISFSI

maintenance costs increase). As of 2017, $6.9 billion had been paid from the Judgment Fund, with a remaining liability estimated to be $27.2 billion (DOE 2017, p. 78).

- Other – These are costs that are not currently identified as either being paid by the Nuclear Waste Fund or the Judgment Fund (i.e., taxpayer liabilities). They include LLW disposal, DPC treatment to facilitate disposal, repackaging of DPCs at utility sites, and loading of TADs at utility sites. The loading of TADs at utility sites is a cost that was not previously included in the TSLCC, but which will contribute to the total cost of spent fuel management. Utilities presently get compensated from the Judgment Fund for loading DPCs. Loading TADs will have similar operational impacts on the utilities, but it is not clear at this point if such costs will be covered by the Nuclear Waste Fund (as opposed to the Judgment Fund).

The Reference Case scenario costs by category are summarized in Table 2-2.

Table 2-2. Reference Case Scenario Cost Categorization (Billions of 2018$)

	NUCLEAR WASTE FUND	TAXPAYER LIABILITY	OTHER	TOTAL
COMMON COSTS	**60.420**	**0.000**	**0.000**	**60.420**
Repository (Development and Evaluation)	8.099			8.099
Repository (Engineering, Procurement, and Construction)	17.628			17.628
Repository (Operations and Infrastructure)	12.276			12.276
Repository (Monitoring)	9.869			9.869
Repository (Closure)	1.352			1.352
Balance of Program	11.196			11.196
POTENTIALLY DISCRIMINATING COSTS	**36.005**	**8.219**	**7.440**	**51.664**
Repository (WP Fabrication)	12.232			12.232
TAD Canister Fabrication	11.922			11.922
Transportation (Operations and Infrastructure)	10.022			10.022
Repository (DPC Repackaging)	1.829			1.829
Utility/ISFSI (TAD Loading/DPC Preparation)			7.226	7.226
LLW Disposal			0.214	0.214
Taxpayer Liability (Judgment Fund)		8.219		8.219
TOTAL COSTS	**96.425**	**8.219**	**7.440**	**112.084**

Notes: Column totals may not add due to rounding.

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3. ALTERNATIVE SCENARIOS FOR MANAGEMENT OF SNF

A set of scenarios was developed to represent a range of possible combinations of alternative spent fuel management approaches. The set of alternative scenarios comprise a range of possible combinations of the timing, options, and costs for waste packaging, storage, transportation, and disposal. While not necessarily comprehensive, the alternative scenarios span a representative range of spent fuel management options and therefore provide useful information for comparative cost analyses.

The Reference Case (Scenario 1), described in Section 2, serves as a useful baseline for comparison purposes by providing detailed cost estimates for what might have been had the project proceeded as planned, with initial waste receipt and start of emplacement operations in 2017. Future alternative scenarios are constructed around three representative dates for the first receipt of spent fuel at the repository: 2031, which corresponds to an early date for the opening of Yucca Mountain should licensing activities resume immediately (Scenario 2); 2041, which represents an additional ten-year delay in restarting Yucca Mountain (Scenario 3); and 2117, which represents a 100-year delay in the repository program (Scenario 4). These dates are chosen simply for the purpose of investigating relative cost impacts associated with delay and should not be interpreted as more or less likely than other dates.

Some of the alternative scenarios also include "one-off" sub-scenarios or variants. These variants examine the relative cost impacts of various decisions regarding repackaging of spent fuel from DPCs into TAD canisters and/or modifying repository operations (and licensing requirements) to allow for direct disposal of DPCs without repackaging. Cost impacts of having a federal CIS facility available in 2025 (thereby reducing Judgment Fund liabilities) are also considered. Table 3-1 summarizes the alternative scenarios and their variants.

Details of the alternative scenarios are described in Sections 3.1 through 3.3 and are also provided in Appendix B. Assumptions common to the alternative scenarios are summarized in Section 3.4.

The Reference Case cost estimate (Table 2-2) included common costs and the following potentially discriminating costs:

- TAD Canister Fabrication
- Repository Disposal (WP Overpack Fabrication)
- Transportation (Infrastructure and Operations)
- Repository Packaging (Repackaging DPCs to TADs)
- Utility/ISFSI Packaging (TAD Loading/DPC Transport Preparation)
- LLW Disposal
- Taxpayer Liability (Judgment Fund)

Table 3-1. Summary of Scenarios and Variants

NO.	SCENARIO	UTILITIES	REPOSITORY
Disposal at Yucca Mountain (YM) in 2017 (Reference Case)			
1	**YM Baseline (Adjusted TSLCC)** • 109,300 MTHM CSNF • Start loading TADs in 2011 • Repackage DPCs at repository • Taxpayer liability (DPCs) to 2011 • Taxpayer liability (ISFSIs) to 2027	• 1,224 DPCs loaded ≤ 2011 • 10,524 TADs loaded ≥ 2011 • 11,748 rail shipments to repository • 67 ISFSIs at operating sites • 7 ISFSIs at shutdown sites	• 12,983 TADs for disposal • 0 DPCs for disposal • "bare" fuel repackaged to 584 TADs • 1,224 DPCs repackaged to 1,875 TADs • 1,224 DPC shells for LLW disposal
Disposal at Yucca Mountain (YM) in 2031			
2	**YM Delayed to 2031** • Start loading TADs in 2025 • Repackage DPCs at repository • Taxpayer liability (DPCs) to 2025 • Taxpayer liability (ISFSIs) to 2041	• 3,900 DPCs loaded ≤ 2025 • 6,423 TADs loaded ≥ 2025 • 10,323 rail shipments to repository • 46 ISFSIs at operating sites • 28 ISFSIs at shutdown sites	• 12,983 TADs for disposal • 0 DPCs for disposal • "bare" fuel repackaged to 584 TADs • 3,900 DPCs repackaged to 5,976 TADs • 3,900 DPC shells for LLW disposal
2A	**Variant of Scenario 2** • Repackage DPCs at utility sites	• 3,900 DPCs repackaged to 5,976 TADs • 12,399 rail shipments to repository • 3,900 DPC shells for LLW	• 0 DPC shells for LLW disposal
2B	**Variant of Scenario 2** • Directly dispose DPCs loaded ≤ 2025	[same as Scenario 2]	• 7,007 TADs for disposal • 3,900 DPCs for disposal • 3,900 DPCs modified for disposal • 0 DPC shells for LLW disposal
2C	**Variant of Scenario 2B** • Continue loading DPCs ≥ 2025 • Larger DPCs ≥ 2025 • Directly dispose DPCs loaded ≤ 2043 • Taxpayer liability (DPCs) to 2043	• 7,305 DPCs loaded • 0 TADs loaded • 7,305 rail shipments to repository	• 7,649 DPCs for disposal • "bare" fuel repackaged to 344 DPCs • 7,305 DPCs modified for disposal • 0 DPC shells for LLW disposal
2D	**Variant of Scenario 2** • CIS available in 2025 • Store DPCs and TADs at CIS • Taxpayer liability (ISFSIs) to 2035	• 10,323 rail shipments to CIS • 10,323 rail shipments to repository • 55 ISFSIs at operating sites • 19 ISFSIs at shutdown sites	[same as Scenario 2]
Disposal at Yucca Mountain (YM) in 2041			
3	**YM Delayed to 2041** • Larger DPCs ≥ 2025 • Start loading TADs in 2035 • Repackage DPCs at repository • Taxpayer liability (DPCs) to 2035 • Taxpayer liability (ISFSIs) to 2051	• 5,812 DPCs loaded ≤ 2035 • 2,534 TADs loaded ≥ 2035 • 8,346 rail shipments to repository • 31 ISFSIs at operating sites • 43 ISFSIs at shutdown sites	• 12,983 TADs for disposal • 0 DPCs for disposal • "bare" fuel repackaged to 584 TADs • 5,812 DPCs repackaged to 9,865 TADs • 5,812 DPC shells for LLW disposal
3A	**Variant of Scenario 3** • CIS available in 2025 • Store DPCs and TADs at CIS • Taxpayer liability (ISFSIs) to 2035	• 8,346 rail shipments to CIS • 8,346 rail shipments to repository • 55 ISFSIs at operating sites • 19 ISFSIs at shutdown sites	[same as Scenario 3]

NO.	SCENARIO	UTILITIES	REPOSITORY
Disposal at Yucca Mountain (YM) in 2117 (Extended Storage)			
4	**YM-Like Repository in 2117** • Continue loading DPCs ≥ 2025 • Larger DPCs ≥ 2025 • Repackage DPCs at repository • Taxpayer liability (DPCs) to 2043 • Taxpayer liability (ISFSIs) to 2127	• 7,305 DPCs loaded • 0 TADs loaded • 7,305 rail shipments to repository • 0 ISFSIs at operating sites • 74 ISFSIs at shutdown sites	• 12,983 TADs for disposal • 0 DPCs for disposal • “bare” fuel repackaged to 584 TADs • 7,305 DPCs repackaged to 12,399 TADs • 7,305 DPC shells for LLW disposal
4A	**Variant of Scenario 4** • Directly dispose DPCs loaded ≤ 2043	[same as Scenario 4]	• 7,649 DPCs for disposal • “bare” fuel repackaged to 344 DPCs • 7,305 DPCs modified for disposal • 0 DPC shells for LLW disposal
4B	**Variant of Scenario 4** • CIS available in 2025 • Store DPCs at CIS • Taxpayer liability (ISFSIs) to 2035	• 7,305 rail shipments to CIS • 7,305 rail shipments to repository • 55 ISFSIs at operating sites • 19 ISFSIs at shutdown sites	[same as Scenario 4]

The alternative scenarios introduce the following additional potentially discriminating costs:

- Utility/ISFSI Packaging (Repackaging DPCs to TADs) – This includes costs for unloading DPCs (the cost of loading TADs is captured above)
- Repository Disposal (Disposal of DPCs) – These include (1) added costs for modifying DPCs for direct disposal (i.e., added criticality controls), and (2) reduced costs for fewer WP overpacks because there are fewer waste packages if CSNF is disposed in DPCs rather than TADs.
- New Facilities – This includes (1) costs for construction and operation of a federal CIS facility (Scenario 2D, 3A, and 4B), and (2) re-incurred costs for repository development and evaluation 100 years in the future (Scenarios 4, 4A, and 4B).

These costs and cost elements are discussed further in Section 4.

3.1. Scenario 2 and Variants: Repository Opens in 2031

Alternative Scenario 2, shown in its basic form in Figure 3-1, considers variations associated with the disposal of 109,300 MTHM of commercial SNF at the Yucca Mountain repository (Yucca Mountain) in 2031. This is assumed to be the earliest plausible date a repository could open at Yucca Mountain if a decision were made today to restart the licensing process. This effectively delays the TSLCC-based Reference Case timeline by 14 years, leading to the following assumed schedule milestones:

- Repository Construction Authorization by the NRC in 2025
- Utilities stop loading CSNF into DPCs and start loading it into TADs in 2025, which is assumed to be the earliest plausible date that TADs could be available if a decision were made today.
- Initial waste receipt and start of repository surface and subsurface operations in 2031
- End of 57-year period of waste emplacement in 2087
- End of closure operations in 2147

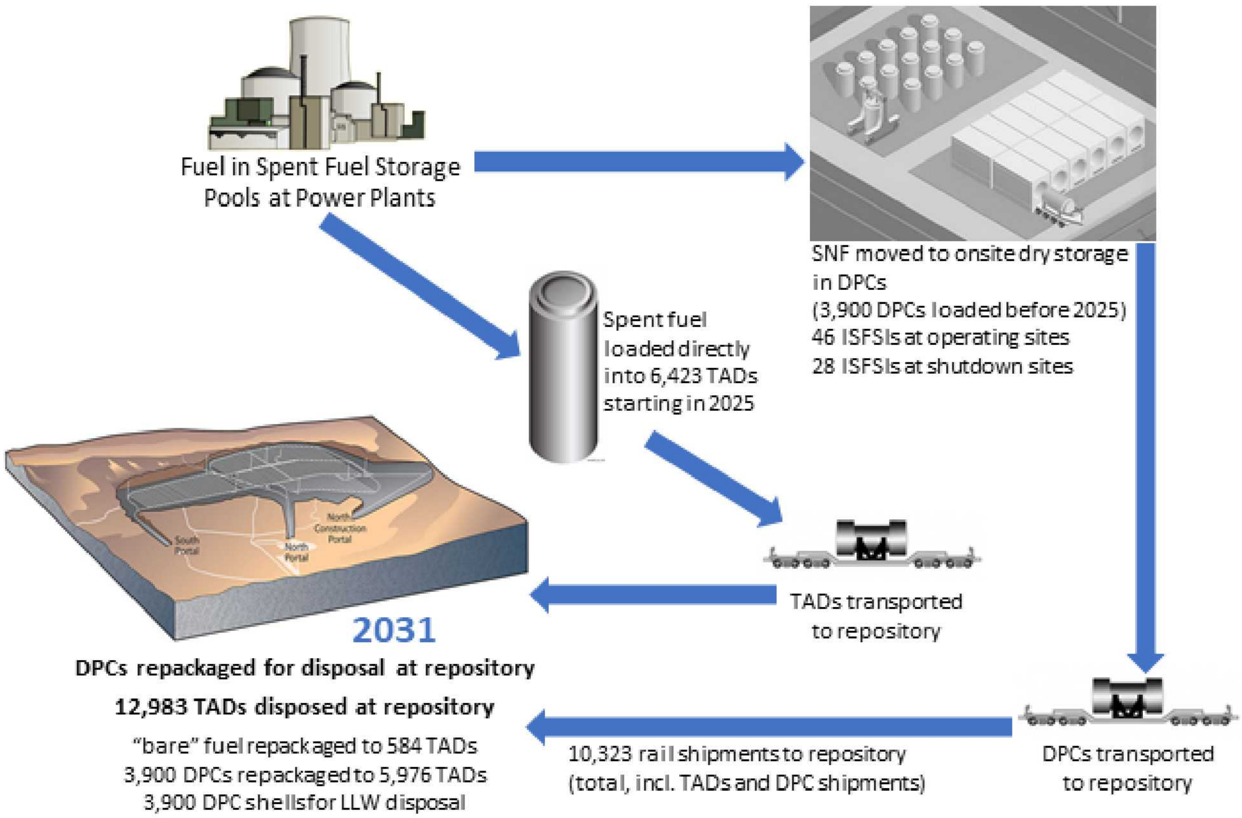

Figure 3-1. Scenario 2: Repository in 2031, Load TADs in 2025, Repackage DPCs at Repository

Based on details provided in Appendix B, the following projections apply to Scenario 2:

- Canister loading at the utility sites includes 3,900 DPCs (loaded until 2025) and 6,423 TADs (loaded from 2025 onward, until a total of 109,300 MTHM of CSNF has been loaded, which is projected to be in 2043). It also includes loading uncanistered "bare" fuel from casks to TADs.
- Transportation includes 10,323 rail shipments (3,900 DPCs and 6,423 TADs) and the bare fuel casks.
- Repackaging of the 3,900 DPCs into 5,976 TADs is done at the repository. Along with the 584 TADs from the bare fuel casks, a total of 6,560 TADs are loaded at the repository.
- Disposal is for 12,983 TAD-based waste packages.
- Taxpayer liability (Judgment Fund) continues until 2025 for settlement costs for loading DPCs and until 2041 for ISFSI operating costs.

The variant scenarios further examine (1) options for loading, repackaging, and/or disposing of the DPCs (Scenarios 2A, 2B, and 2C), and (2) the option of storage at a federal CIS facility (Scenario 2D).

Scenario 2A, illustrated in Figure 3-2, considers the implications of repackaging fuel from DPCs to TADs at the utility sites instead of repackaging at the repository. In this scenario, the 3,900 DPCs are repackaged into 5,976 TADs at the utility sites. Only the 584 TADs from bare fuel casks are loaded at the repository. Transportation includes 12,399 rail shipments (all TADs) and the bare fuel casks. Disposal is for 12,983 TAD-based waste packages.

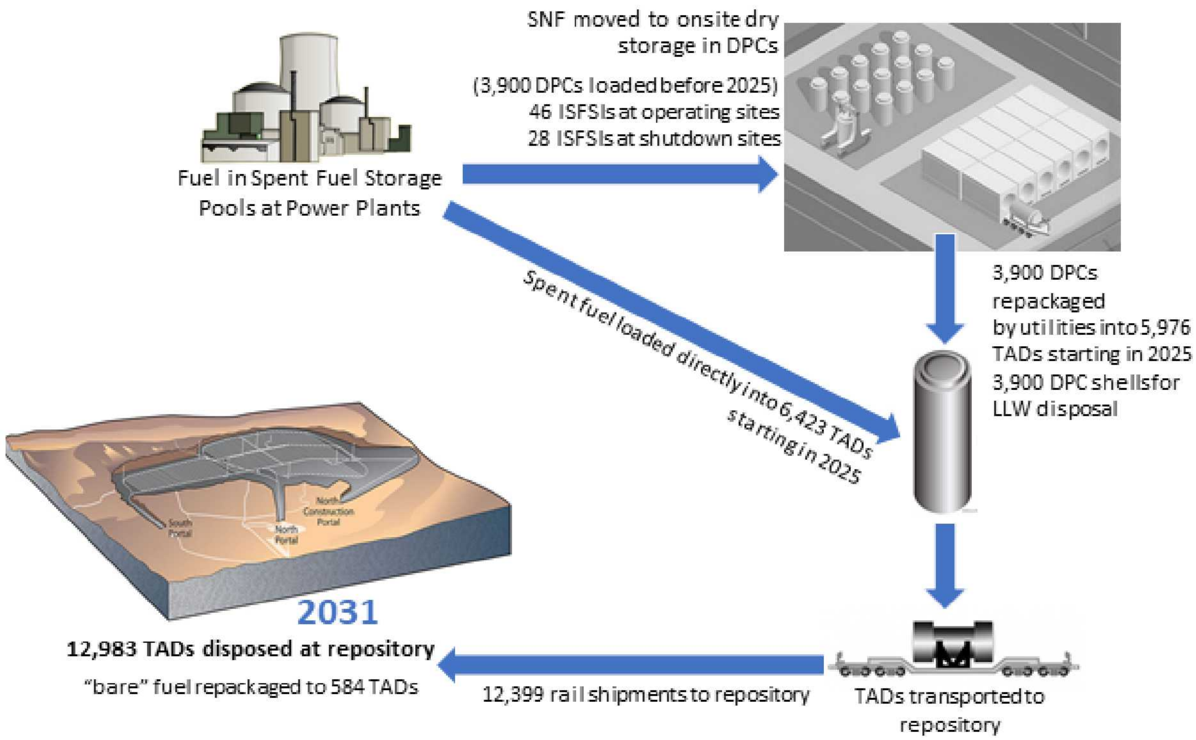

Figure 3-2. Scenario 2A: Repository in 2031, Load TADs in 2025, Repackage DPCs at Utility Sites

Scenario 2B, shown in Figure 3-3, considers the implications of direct disposal of existing DPCs (loaded until 2025) and loading TADs at the utility sites going forward. In this scenario, utilities begin loading and transporting TADs when they're available in 2025, and the 3,900 DPCs already loaded are directly disposed at the repository, without repackaging. Only the 584 TADs from bare fuel casks are loaded at the repository. Transportation includes 10,323 rail shipments (3,900 DPCs and 6,423 TADs) and the bare fuel casks. Disposal is for 7,007 TAD-based waste packages and 3,900 DPC-based waste packages.

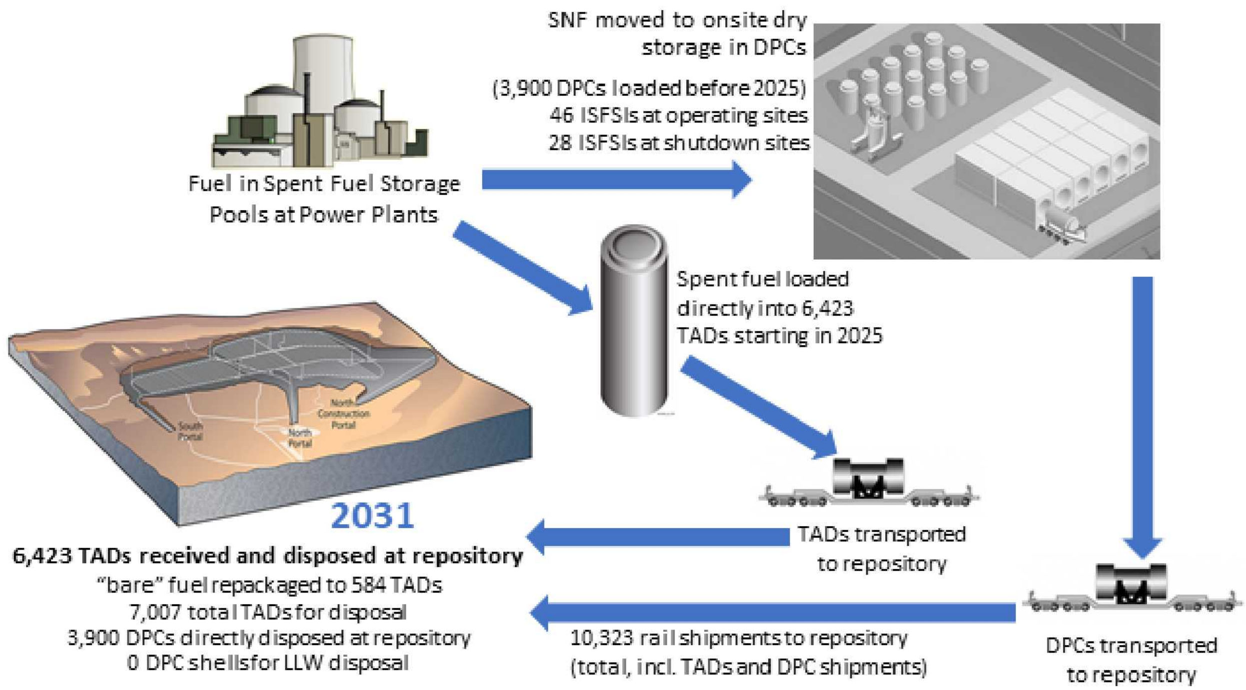

Figure 3-3. Scenario 2B: Repository in 2031, Load TADs in 2025, Dispose DPCs in Repository

Scenario 2C, shown in Figure 3-4, considers the implications of continuing to load all CSNF into DPCs and relying on direct disposal of DPCs rather than repackaging fuel into TADs. In this scenario, CSNF continues to be loaded in DPCs at the utility sites, even after 2025, resulting in a total of 7,305 DPCs. The 7,305 DPCs are directly disposed at the repository, without repackaging. The bare fuel casks are repackaged into 344 DPCs (rather than TADs) for disposal at the repository. Transportation includes 7,305 rail shipments (all DPCs) and the bare fuel casks. Disposal is for 7,649 DPC-based waste packages.

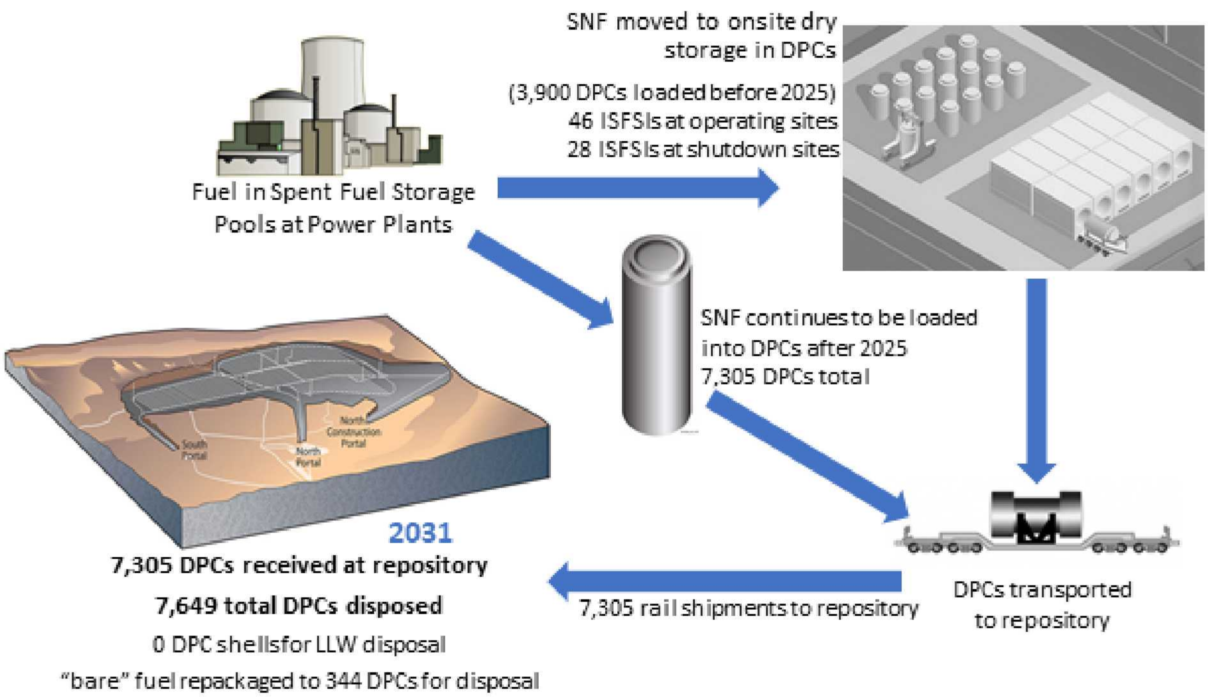

Figure 3-4. Scenario 2C: Repository in 2031, Never Stop Loading DPCs, Dispose DPCs in Repository

Scenario 2D, shown in Figure 3-5, considers the implications of using a federal CIS facility for centralized management of SNF prior to permanent disposal. In this scenario, a CIS facility is constructed and available starting in 2025 and operates until 2087, which corresponds to the end of waste emplacement operations at the repository. This scenario is similar to Scenario 2 except that that the number of rail shipments doubles (utility sites to CIS, then CIS to repository) and the ISFSIs can be closed in 2035 rather than in 2041.

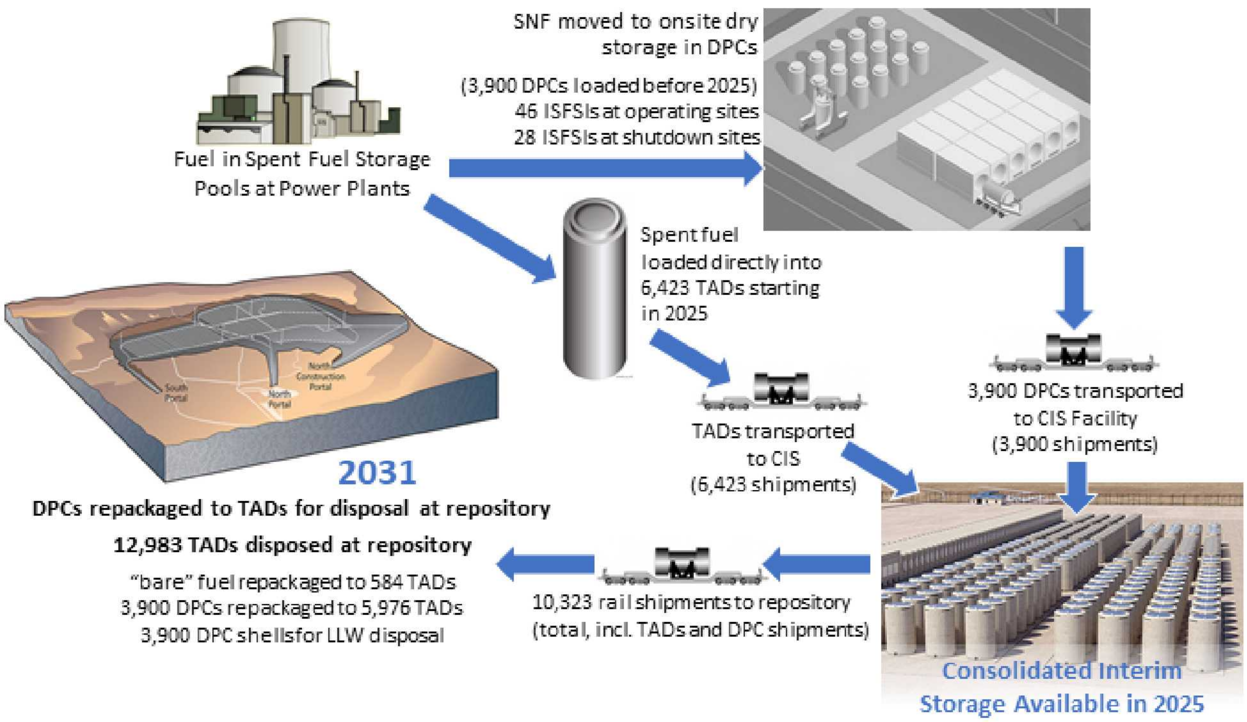

Figure 3-5. Scenario 2D: Repository in 2031, CIS in 2025, Load TADs in 2025, Repackage DPCs at Repository

3.2. Scenario 3 and Variant: Repository Opens in 2041

Scenario 3, illustrated in Figure 3-6, is similar to Scenario 2 except that the repository is assumed to open in 2041, rather than 2031. This is a further 10-year delay from the TSLCC-based Reference Case timeline, resulting in the following assumed schedule milestones:

- Repository Construction Authorization by the NRC in 2035
- Utilities stop loading CSNF into DPCs and start loading it into TADs in 2035
- Initial waste receipt and start of repository surface and subsurface operations in 2041
- End of 57-year period of waste emplacement in 2097
- End of closure operations in 2157

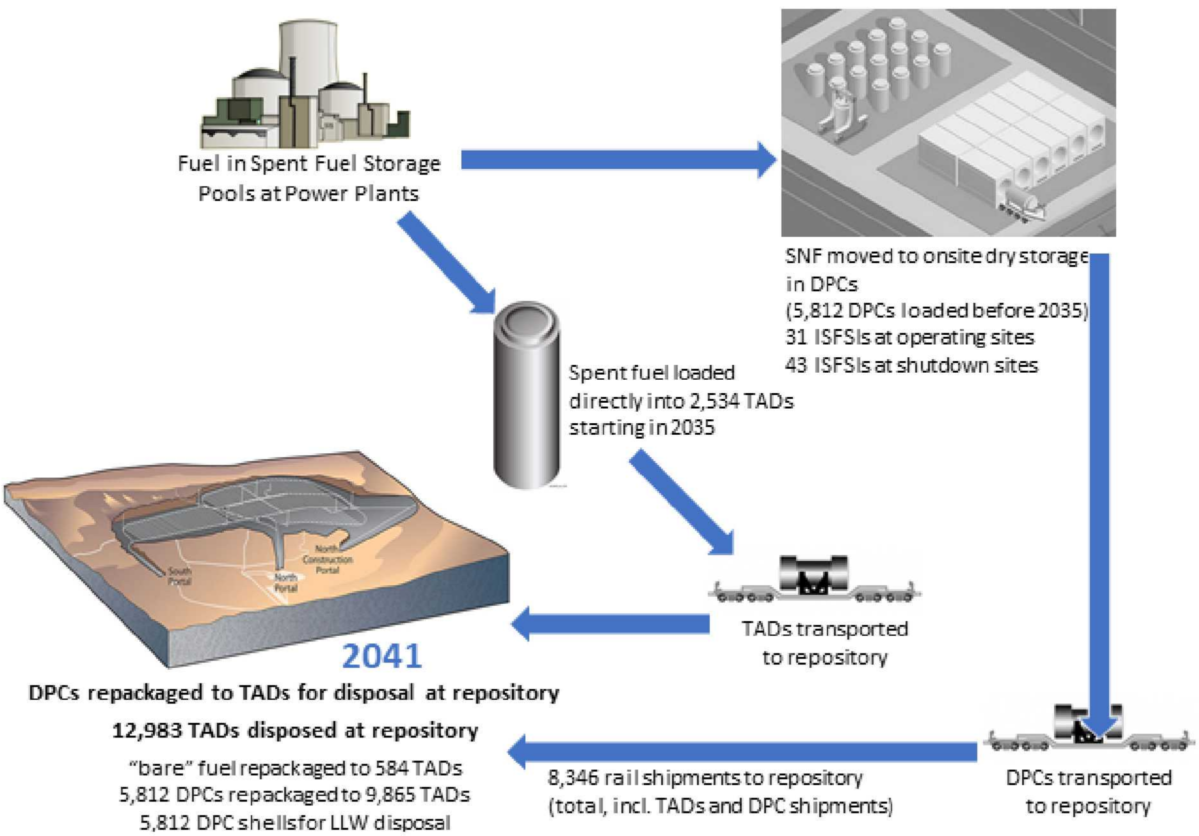

Figure 3-6. Scenario 3: Repository in 2041, Load TADs in 2035, Repackage DPCs at Repository

Based on the details provided in Appendix B, the following projections apply to Scenario 3:

- Canister loading at the utility sites includes 5,812 DPCs (loaded until 2035) and 2,534 TADs (loaded from 2035 onward, until a total of 109,300 MTHM of CSNF has been loaded, which is projected to be in 2043). It also includes loading uncanistered "bare" fuel from casks to TADs.

- DPCs loaded are assumed to be 32 PWR/68 BWR up to 2025, and 37 PWR/89 BWR thereafter.
- Transportation includes 8,346 rail shipments (5,812 DPCs and 2,534 TADs) and the bare fuel casks.
- Repackaging of the 5,812 DPCs into 9,865 TADs is done at the repository. Along with the 584 TADs from the bare fuel casks, a total of 10,449 TADs are loaded at the repository.
- Disposal is for 12,983 TAD-based waste packages.
- Taxpayer liability (Judgment Fund) continues until 2035 for settlement costs for loading DPCs and until 2051 for ISFSI operating costs.

One variant scenario (Scenario 3A), shown in Figure 3-7, evaluates the impact of a federal CIS facility that begins operations in 2025 and operates until 2097, which corresponds to the end of waste emplacement operations at the repository. This scenario is similar to Scenario 2D except that TAD loading starts in 2035 (rather than 2025), disposal operations begin in 2041 (rather than 2031), and the CIS facility operates for 10 more years. In Scenario 3A, the number of rail shipments doubles as compared to Scenario 3 and the ISFSIs can be closed in 2035 rather than in 2051.

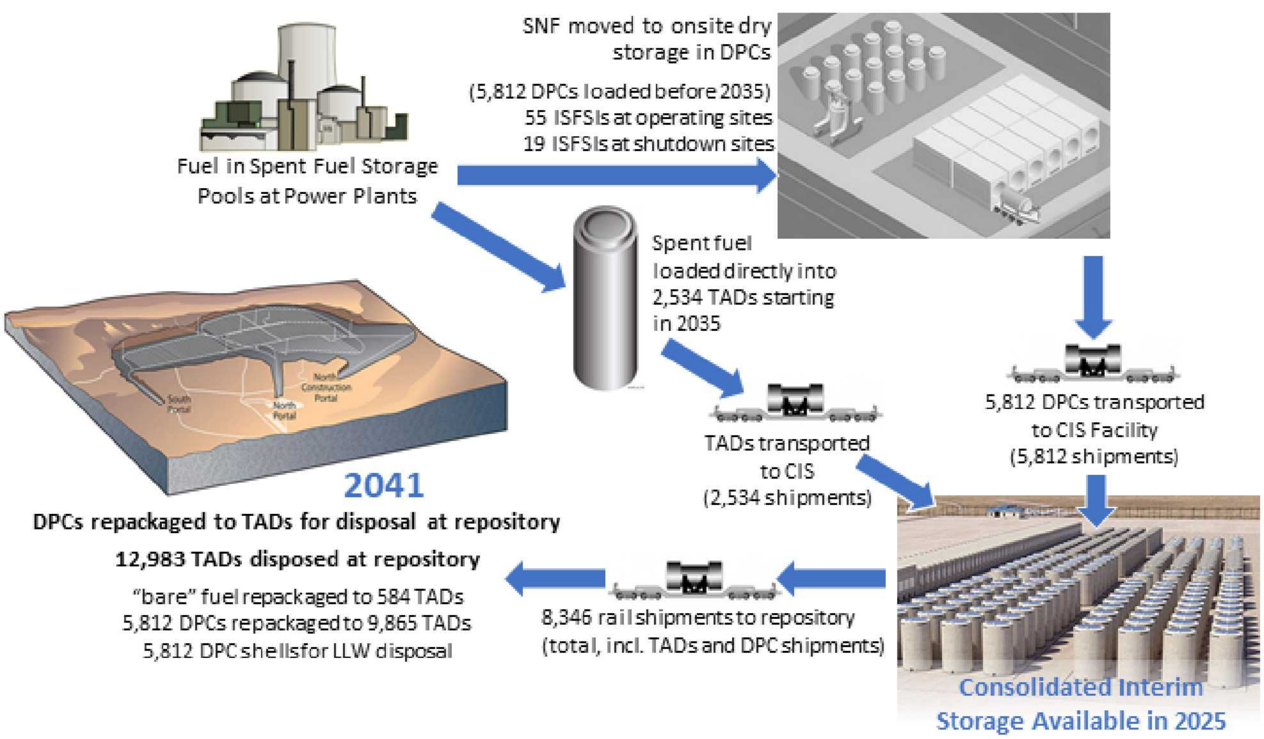

Figure 3-7. Scenario 3A: Repository in 2041, CIS in 2025, Load TADs in 2035, Repackage DPCs at Repository

3.3. Scenario 4 and Variants: Repository Opens in 2117

Scenario 4, shown in Figure 3-8, assumes a 100-year delay from the TSLCC-based Reference Case timeline, resulting in the following assumed schedule milestones:

- Repository Construction Authorization by the NRC in 2111
- Initial waste receipt and start of repository surface and subsurface operations in 2117
- End of 57-year period of waste emplacement in 2173
- End of closure operations in 2233.

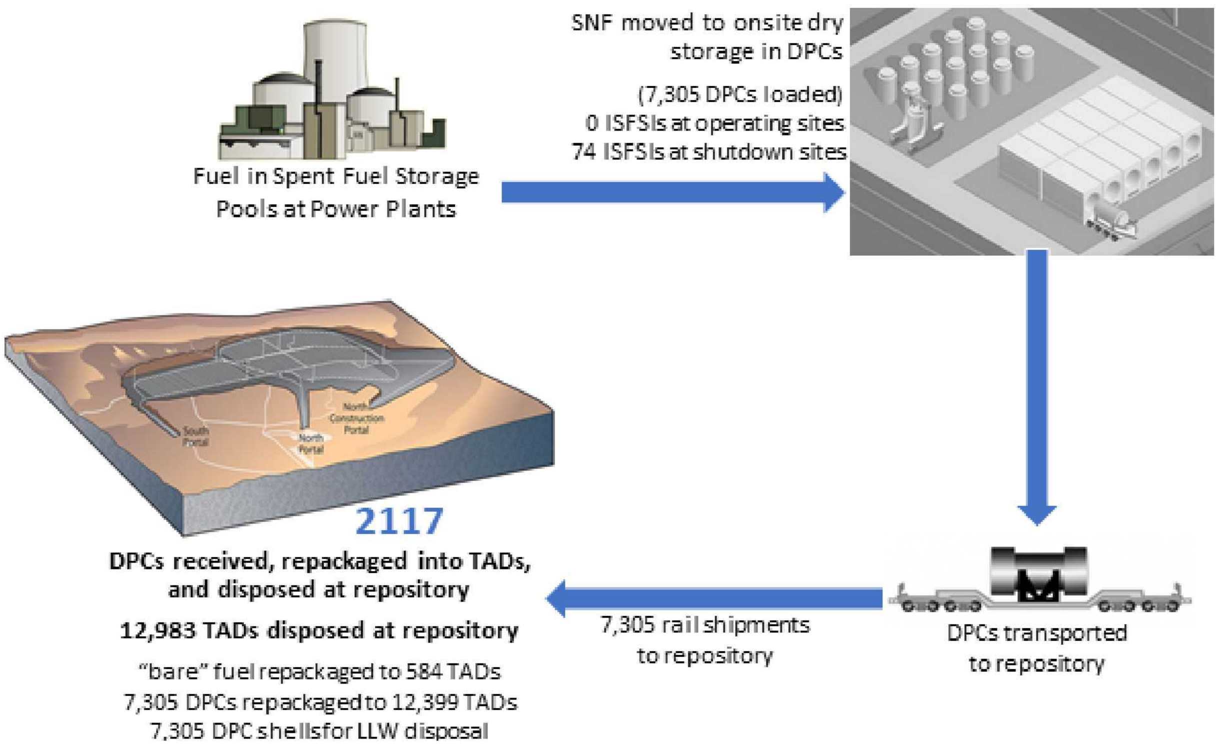

Figure 3-8. Scenario 4: Repository in 2117, Never Stop Loading DPCs, Repackage DPCs at Repository

With this timeline, all of the CSNF will be loaded into DPCs at the utility sites before a repository is available; those DPCs will all be subsequently transported to the repository where they will be repackaged into TADs for disposal.

Based on the details provided in Appendix B, the following projections apply to Scenario 4:

- Due to the 100-year delay, repository development and evaluation costs (see Table 2-1) are re-incurred.
- Canister loading at the utility sites includes 7,305 DPCs, which occurs until a total of 109,300 MTHM of CSNF has been loaded, which is projected to be in 2043. It also includes loading uncanistered "bare" fuel from casks to TADs.
- DPCs loaded are assumed to be 32 PWR/68 BWR up to 2025, and 37 PWR/89 BWR thereafter.

- Transportation includes 7,305 rail shipments (7,305 DPCs and 0 TADs) and the bare fuel casks.
- Repackaging of the 7,305 DPCs into 12,399 TADs is done at the repository. Along with the 584 TADs from the bare fuel casks, a total of 12,983 TADs are loaded at the repository.
- Disposal is for 12,983 TAD-based waste packages.
- Taxpayer liability (Judgment Fund) continues until 2043 for settlement costs for loading DPCs and until 2127 for ISFSI operating costs.

The variant scenarios examine (1) direct disposal of the DPCs at the repository, rather than repackaging the CSNF into TADs for disposal (Scenario 4A), and (2) the option of storage at a federal CIS facility (Scenario 4B).

In Scenario 4A, illustrated in Figure 3-9, the 7,305 DPCs are directly disposed at the repository, without repackaging. The bare fuel casks are repackaged into 344 DPCs (rather than TADs) at the repository. Disposal is for 7,649 DPC-based waste packages. This is similar to Scenario 2C, but with delayed repository availability.

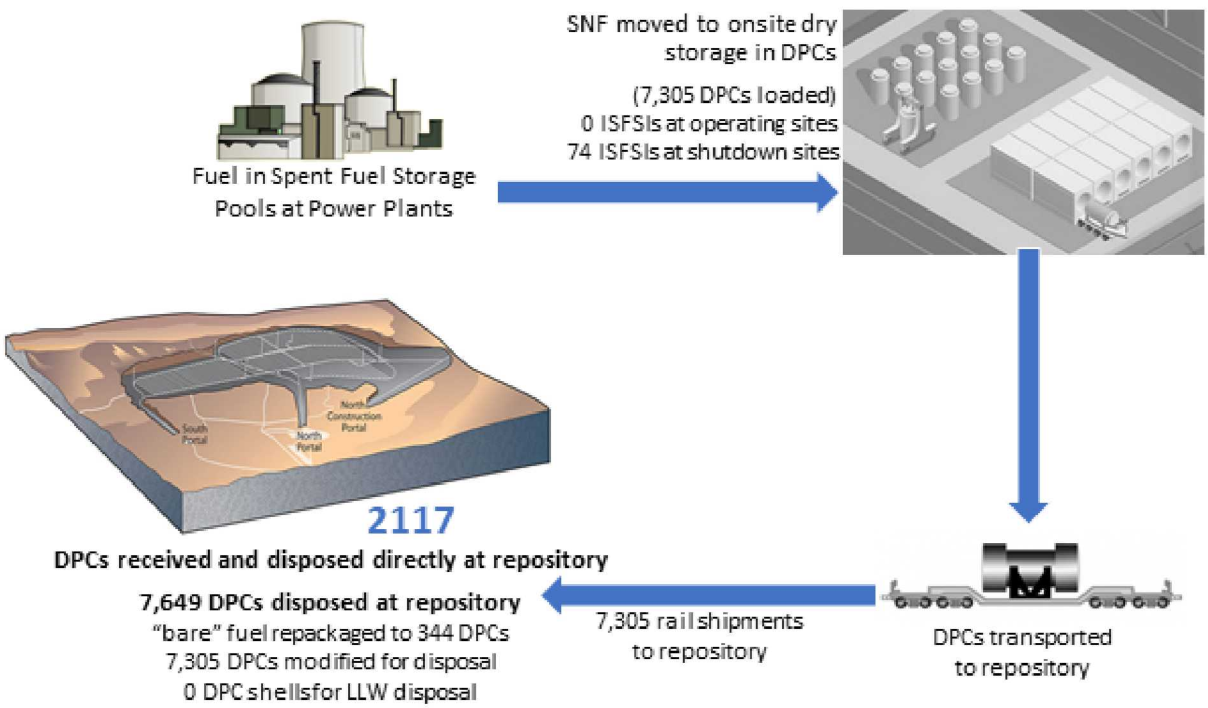

Figure 3-9. Scenario 4A: Repository in 2117, Never Stop Loading DPCs, Dispose DPCs in Repository

Scenario 4B, shown in Figure 3-10, evaluates the impact of a federal CIS facility that begins operations in 2025 and operates until 2173 (see assumptions in Section 3.4), which corresponds to the end of waste emplacement operations at the repository. Scenario 4B is similar to Scenarios 3A and 2D, except that (1) disposal operations begin in 2117, (2) the CIS facility operates longer, and (3) all CSNF is initially loaded and stored in DPCs. The DPCs are transported to the CIS facility and subsequently to the repository; repackaging of DPCs into TADs occurs at the repository.

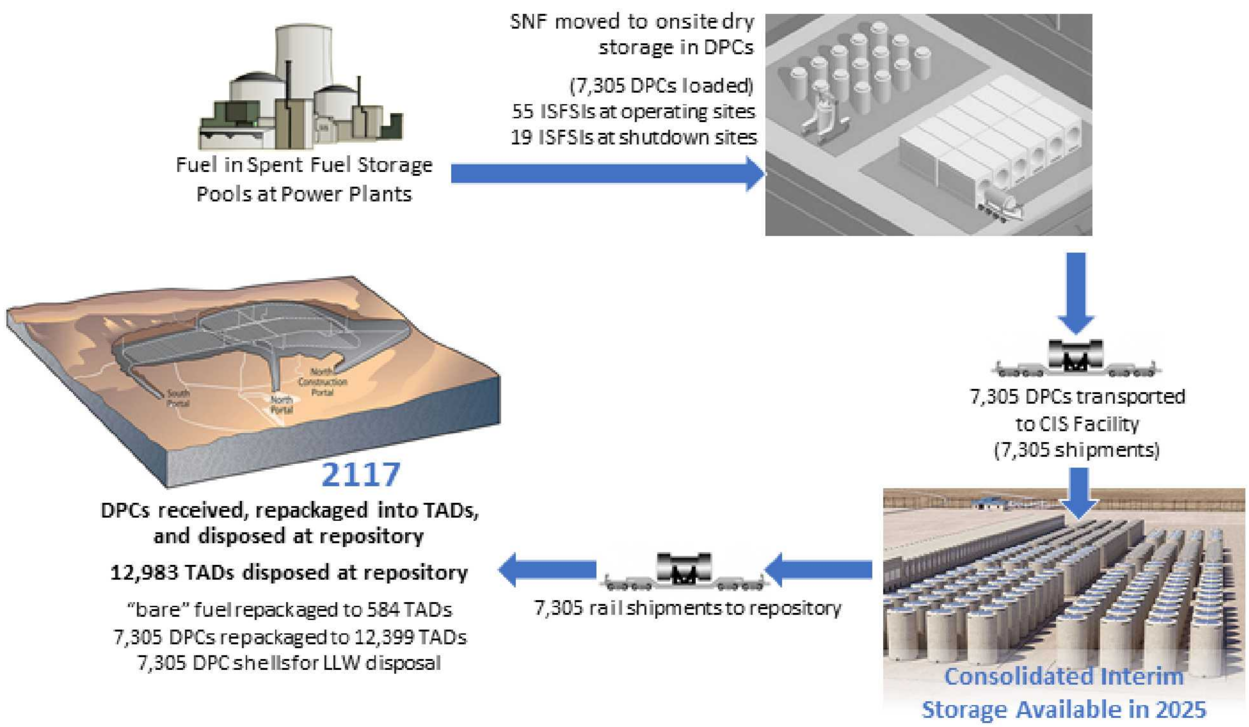

Figure 3-10. Scenario 4B: Repository in 2117, CIS in 2025, Never Stop Loading DPCs, Repackage DPCs at Repository

3.4. Assumptions

In addition to the assumptions for the Reference Case scenario listed in Section 2, the following assumptions apply to the cost estimates for the alternative scenarios described in Sections 3.1 through 3.3:

- None of the alternative scenarios explore repository geologies or designs other than the Yucca Mountain design outlined in the TSLCC (DOE 2008). Scenarios 4 and 4A include some extra costs for "redevelopment" of the Yucca Mountain design and licensing basis that would likely be necessary following a 100-year delay.
- For scenarios that are inconsistent with Yucca Mountain repository design in the License Application (DOE 2009) and/or the NWPA, as amended, such as those with disposal of DPCs, the cost estimates do not include the cost of amending the License Application.

- The repository footprint is the same for all alternatives. The number of drifts, drift lengths, and associated drip shields are the same for each alternative because they are a function of thermal load, not number of waste packages.
- The cost for a TAD disposal overpack is the same as that for a DPC disposal overpack.
- Additional costs that may be associated with extended storage up to 100 years (e.g., remediation or replacement of storage system components) are not included.
- All DPCs can be transported; there are no additional costs to make storage-only DPCs transportable, or to transport DPCs after extended storage.
- The cost for a rail shipment for a TAD is the same as that for a DPC. A shipment consists of one loaded canister (TAD or DPC) in a cask/overpack transported on a single rail car.
- The cost for a shipment of stranded fuel from an ISFSI at a shutdown site is the same as for a shipment from an ISFSI at a site with an operating reactor. No additional cost is allotted for developing transportation systems for stranded fuel.
- DPCs existing as of 2025 have capacities of 32 PWR or 68 BWR assemblies. DPCs loaded from 2025 onward have capacities of 37 PWR or 89 BWR assemblies.
- TADs have capacities of 21 PWR or 44 BWR assemblies.
- Waste transfers and repackaging are done in a pool, both at the utility sites and at the repository. All scenarios involve repackaging "bare" fuel into 584 TADs at the repository.
- Costs associated with modifications that may be required to existing or planned wet handling facilities for spent fuel at utility sites or the repository are not included.
- In scenarios where DPCs are repackaged, used DPC shells and baskets are disposed of as LLW, not decontaminated and recycled.
- There is no loss of spent fuel capacity from modifying or treating DPCs to make them suitable for direct disposal.
- Costs for a federal CIS facility include design, construction, staging pads, overpacks, storage modules, maintenance, operations, and security (see Appendix C). Transportation of TADs and/or DPCs to and from the CIS facility are captured as part of the transportation cost element. The CIS costs are based on an operational lifetime of 40 years, which is consistent with a 40-year initial license for an ISFSI. For scenarios where the CIS facility lifetime exceeds 40 years, additional annual operating costs are applied, and license renewals in 40-year increments are assumed.
- Costs for a federal CIS facility are based on estimates for a commercial CIS facility (Jarrell et al. 2015), which may or may not be reflective of costs for a federal CIS facility. However, the estimated CIS costs are considered adequate for the purposes of this comparative analysis.
- For the scenario with the CIS facility operating lifetime exceeding 100 years, it is assumed that aging DPCs can be repackaged to TADs at the CIS facility (rather than at the repository), with no change in overall system cost.

4. SCENARIO COST ESTIMATES AND COMPARATIVE ANALYSES

The scenarios identified in Section 3 were analyzed to provide simple and credible cost estimates; these estimates were compared to the Reference Case scenario to identify the relative costs to the U.S. government and to the nuclear utilities for moving forward with each scenario.

The quantitative and comparative evaluations of the total life-cycle costs for each scenario used information from the TSLCC report (DOE 2008) as foundational cost inputs, with adjustments for inflation and changes in quantities (e.g., DPCs), similar to what was done for the Reference Case scenario (Section 2). Additional cost inputs beyond those included in the TSLCC were selected from published, citable sources and likewise adjusted for quantities and inflation. Input parameters supporting the alternative scenarios are listed in Appendix C.

The comparative cost evaluations of the Reference Case and alternative scenarios include the common costs and the potentially discriminating costs identified in Sections 2 and 3. For the comparative analyses, the individually calculated potentially discriminating costs are grouped into the following seven cost elements:

- TAD Canisters
  - Cost of TAD canisters
- Utility/ISFSI Packaging[3]
  - Cost of loading CSNF from a pool into a TAD
  - Cost of unloading CSNF already stored in a DPC and loading it into a TAD
  - Cost of storage overpack for TAD
  - Cost of transferring a TAD or a DPC from a storage cask to a transportation cask
- Transportation
  - Cost of rail shipments
- Repository Packaging
  - Cost of unloading DPCs
  - Cost of loading TADs
  - LLW disposal cost (in Scenario 2A, this occurs at the utility/ISFSI sites rather than at the repository)
- Repository Disposal
  - Cost of modifying DPCs to facilitate disposal
  - Cost of disposal overpacks (waste packages)
- Taxpayer Liability (Judgment Fund)
  - Cost of loading CSNF into DPCs
  - Annual operations cost per ISFSI-only (shutdown) site
  - Annual operations cost per ISFSI at operating reactor site

[3] These costs are not covered by payments from the Judgment Fund

- New Facilities
  - Cost of a federal CIS facility (Scenario 2D)
  - Cost of developing and evaluating a new repository (Scenarios 4 and 4A)

Specific details of these costs and how they are calculated from the input parameters are provided in Appendix C.

Additional considerations associated with alternative scenarios that could also be potentially discriminating include factors such as: (1) other repository options; (2) inflation beyond 2018 (i.e., the future value of money); (3) political and social costs of delays; (4) public perception, acceptance, and social angst associated with certain aspects of spent fuel management; (5) impact of a future nuclear-related accident (e.g., Fukushima); and (6) legislative alternatives. These additional considerations, while important to decision-makers, are subject to intangible factors that make quantification of their effects impractical and were therefore not included in the cost estimates or the associated uncertainties.

Initial cost computations for the scenarios were made using a single, nominal (i.e., best-estimate) value for each input parameter; these estimated costs are presented for each scenario in Section 4.1. Possible variations in scenario costs due to uncertainty in the potentially discriminating costs were examined using a range of parameter input values. These cost variations are presented in Section 4.2. The breakdown of estimated costs by category (Nuclear Waste Fund, Taxpayer Liability, or Other) is presented in Section 4.3.

All costs are reported in constant 2018 dollars. Measuring change in the same year constant dollars is a commonly accepted practice to measure real program cost growth because it removes the effects of inflation, which are beyond the control of individual programs (DOE 2008). As a result, these cost estimates are considered credible and representative for the purposes of comparative analysis between scenarios, but they should not be taken as formal projections of the life-cycle cost for any specific future scenario. In addition to not capturing the effects of inflation across scenarios with different time horizons, the bases for common costs from the TSLCC were not re-evaluated to consider new or updated information (e.g., changes in waste quantities), and the bases for the potentially discriminating costs, while citable, in many cases may not necessarily reflect the latest industry data and/or proprietary information.

4.1. Cost Analyses

Estimated costs for all of the scenarios are shown in Figure 4-1. This figure shows the cost allocation between those costs that are common to all scenarios (i.e., Common Costs) and the seven potentially discriminating cost elements. Details of the costs for each scenario are discussed below.

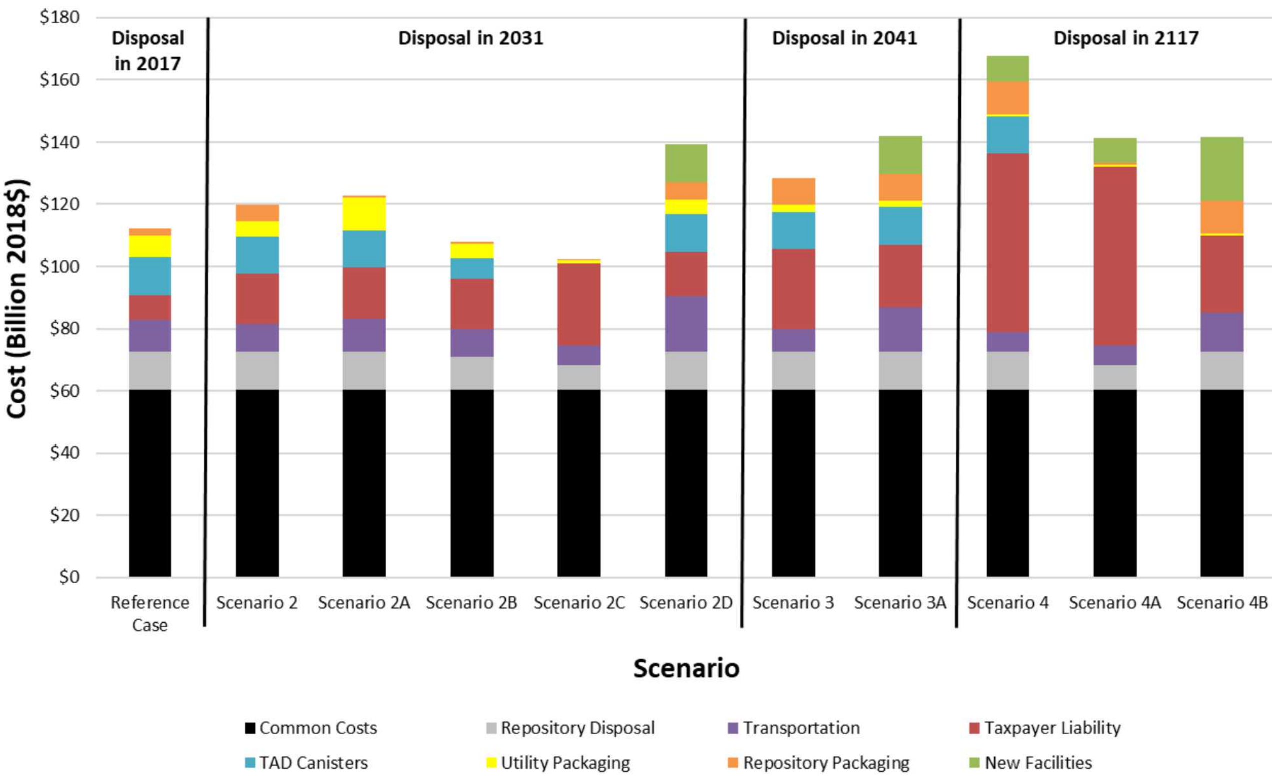

Figure 4-1. Costs and Cost Allocation of All Scenarios

4.1.1. Scenario 2 and Variants: Repository Opens in 2031

As discussed in Section 3.1, Scenario 2 and all of its variants (2A, 2B, 2C, and 2D) are based on the assumption that the repository opens in 2031. Figure 4-2 and Table 4-1 show the relative contributions of each cost element to the overall cost for Scenario 2 and its variants. Cost elements for the Reference Case are provided for comparison.

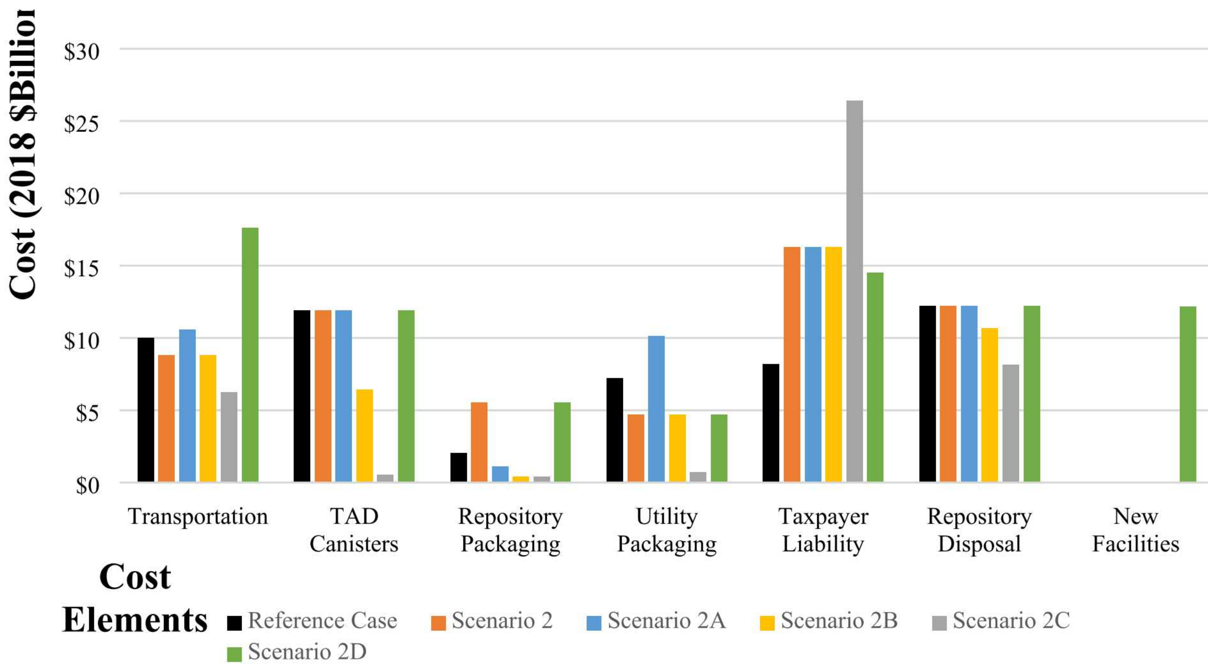

Figure 4-2. Potentially Discriminating Cost Elements for Scenario 2 and its Variants

Table 4-1. Costs of Scenario 2 and Variants (Billions of 2018$)

Cost Element	Reference Case Scenario 1	Scenario 2	Scenario 2A	Scenario 2B	Scenario 2C	Scenario 2D
Transportation	10.022	8.807	10.578	8.807	6.232	17.615
TAD Canisters	11.922	11.922	11.922	6.435	0.000	11.922
Repository Packaging	2.043	5.562	0.434	0.434	0.434	5.562
Utility Packaging	7.226	4.726	10.808	4.726	0.731	4.726
Taxpayer Liability	8.219	16.307	16.307	16.307	26.521	14.515
Repository Disposal	12.232	12.232	12.232	10.666	7.937	12.232
New Facilities	0.000	0.000	0.000	0.000	0.000	12.290
Common Costs	60.420	60.420	60.420	60.420	60.420	60.420
Total	**112.084**	**119.975**	**122.701**	**107.795**	**102.275**	**139.281**

For Scenario 2 and its variants, delaying the receipt of waste at Yucca Mountain until 2031 results in more DPCs (and correspondingly fewer TADs) being loaded and stored at the utility sites as compared to the Reference Case (Scenario 1). TADs are not loaded at the utility sites until 2025. The repository delay until 2031 also increases the time over which taxpayer liabilities (payments from the Judgment Fund) are incurred.

In Scenario 2 (Figure 3-1), the estimated total cost is about $8 billion greater than the Reference Case. Increased costs relative to the Reference Case are due to:

- Repository Packaging – There are more DPCs to repackage at the repository and there is more LLW to be disposed.
- Taxpayer Liability – More DPCs are loaded at the utilities and the ISFSI operating costs are incurred for 14 additional years.

Decreased costs relative to the Reference Case do not fully offset the cost increases. Decreased costs are due to:

- Transportation – More of the waste is transported in DPCs, which contain more waste than TADs; therefore, fewer overall shipments are required.
- Utility Packaging – There are fewer TADs loaded at the utility sites.

In Scenario 2A (Figure 3-2), CSNF loaded and stored in DPCs is repackaged into TADs at utility sites rather than at the repository, as it was in Scenario 2 and in the Reference Case. The estimated total cost for Scenario 2A is about $3 billion greater than for Scenario 2 and about $11 billion greater than the Reference Case. Increased costs relative to Scenario 2 are due to:

- Transportation – All the waste is transported from the utilities to the repository in TADs; which contain less waste than DPCs; therefore, more overall shipments are required.
- Utility Packaging – Repackaging of DPCs to TADs, and associated LLW disposal, occurs at the utility sites rather than at the repository.

These cost increases are not fully offset by the decreased costs due to:

- Repository Packaging – No DPCs are repackaged at the repository, but there is still bare fuel repackaging at the repository.

In Scenario 2B (Figure 3-3), CSNF loaded and stored in DPCs as of 2025 is not repackaged into TADs. Rather, the CSNF that is already in DPCs is disposed of in DPCs, and the fuel that is placed into TADs after 2025 is disposed of in TADs; only bare fuel is repackaged at the repository. The estimated total cost for Scenario 2B is about $12 billion less than for Scenario 2 and about $4 billion less than the Reference Case. This is one of two scenarios/variants with estimated costs lower than the Reference Case, primarily because CSNF already in DPCs is not repackaged into TADs. Decreased costs relative to Scenario 2 are due to:

- TAD Canisters – Fewer TAD canisters are required because fuel is disposed of in the DPCs.
- Repository Packaging – No DPCs are repackaged and there is no associated LLW disposal; only bare fuel is repackaged at the repository.
- Repository Disposal – Fewer disposal overpacks are required because there are fewer total waste packages (DPCs plus TADs). This cost decrease is much larger than the small increased cost to modify the DPCs for direct disposal (e.g., adding filler material to reduce the probability of in-package criticality).

In Scenario 2C (Figure 3-4), all CSNF is loaded into and disposed of in DPCs. The estimated total cost for Scenario 2C is about $6 billion less than for Scenario 2B, about $18 billion less than for Scenario 2 and about $10 billion less than the Reference Case. This scenario has the lowest estimated cost of all the scenarios. Decreased costs relative to Scenario 2B (and to Scenario 2 and to the Reference Case) are due to:

- Transportation – All waste (except bare fuel) is transported in DPCs, which have a higher capacity than TADs, thus requiring fewer overall shipments.
- TAD Canisters – No TAD canisters are required.
- Utility Packaging – There are no TADs loaded at the utility sites.
- Repository Disposal – Fewer disposal overpacks are required because there are fewer total waste packages. As in Scenario 2B, this cost decrease is much larger than the small increased cost to modify the DPCs for direct disposal.

There is a corresponding cost increase, but it is smaller than the cost decreases. The increased costs are due to:

- Taxpayer Liability – The maximum number of DPCs are loaded at the utilities; these costs come from the Judgment Fund. ISFSI operating costs, incurred for 14 additional years beyond the Reference Case, are the same as for Scenario 2 and 2B.

Scenario 2D (Figure 3-5) is the same as Scenario 2 except that a federal CIS facility becomes available in 2025. The estimated total cost for Scenario 2D is about $19 billion greater than for Scenario 2 and about $27 billion greater than the Reference Case. Increased costs relative to Scenario 2 are due to:

- Transportation – Costs increase significantly because each TAD or DPC must be shipped twice, once to the CIS site and then again to the repository.
- New Facilities – The costs associated with constructing and operating the CIS facility.

There is also a small cost decrease due to:

- Taxpayer Liability – The opening of the federal CIS facility in 2025 means that waste from some of the shutdown sites can be removed earlier than in Scenario 2; operating costs at shutdown sites are larger than at sites with operating reactors.

4.1.2. *Scenario 3 and Variant: Repository Opens in 2041*

As discussed in Section 3.2, Scenario 3 and its variant are based on the assumption that the repository opens in 2041, rather than 2031. Figure 4-3 and Table 4-2 show the relative contributions of each cost element for Scenario 3; the cost elements for the Reference Case are provided for comparison.

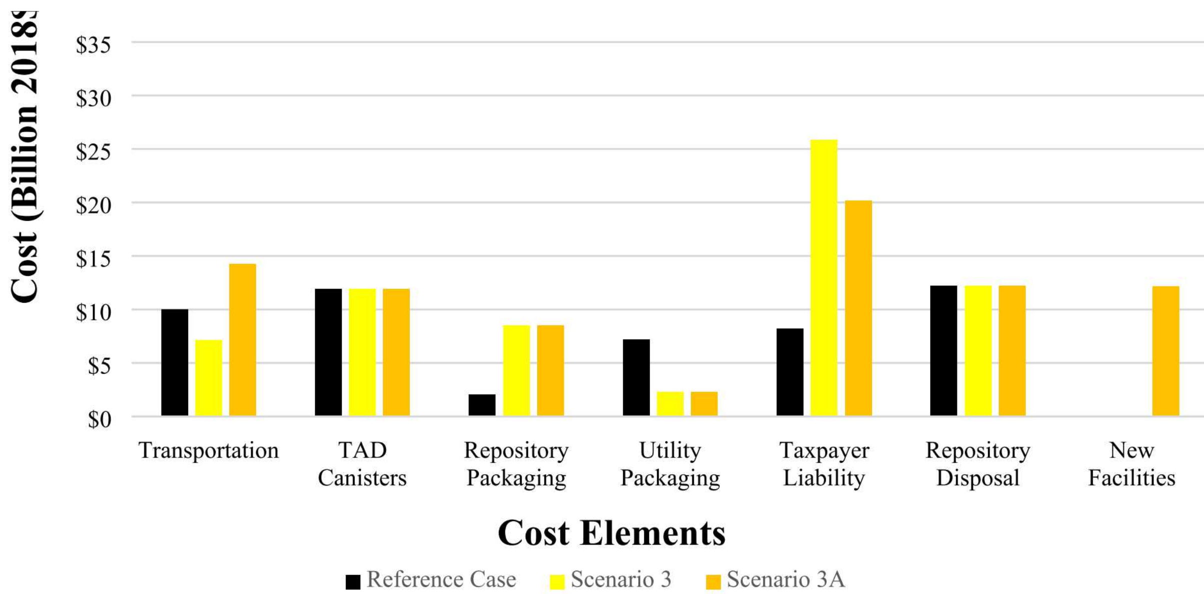

Figure 4-3. Potentially Discriminating Cost Elements for Scenario 3

Table 4-2. Scenario 3 Estimated Costs (Billions of 2018$)

Cost Element	Reference Case Scenario 1	Scenario 3	Scenario 3A
Transportation	10.022	7.121	14.241
TAD Canisters	11.922	11.922	11.922
Repository Packaging	2.043	8.547	8.547
Utility Packaging	7.226	2.292	2.292
Taxpayer Liability	8.219	25.869	20.190
Repository Disposal	12.232	12.232	12.232
New Facilities	0.000	0.000	12.142
Common Costs	60.420	60.420	60.420
Total	**112.084**	**128.403**	**141.986**

For Scenario 3, delaying the receipt of waste at Yucca Mountain until 2041 results in more DPCs (and correspondingly fewer TADs) being loaded and stored at the utility sites as compared to Scenario 2 and as compared to the Reference Case. TADs are not loaded at the utility sites until 2035. The repository delay until 2041 also increases the time over which taxpayer liabilities (payments from the Judgment Fund) are incurred.

In Scenario 3 (Figure 3-6), the estimated total cost is about $16 billion greater than the Reference Case and about $8 billion greater than Scenario 2. Increased costs relative to the Reference Case (and to Scenario 2) are due to:

- Repository Packaging – There are more DPCs to repackage at the repository and there is more LLW to be disposed.
- Taxpayer Liability – More DPCs are loaded at the utilities and the ISFSI operating costs are incurred for 24 additional years.

Decreased costs relative to the Reference Case do not fully offset the cost increases. Decreased costs are due to:

- Transportation – More of the waste is transported in DPCs, which have a higher capacity than TADs; therefore, fewer overall shipments are required.
- Utility Packaging – Fewer TADs are loaded at the utility sites.

Scenario 3A (Figure 3-7) is the same as Scenario 3 except that a federal CIS facility becomes available in 2025. The estimated total cost for Scenario 3A is about $14 billion greater than for Scenario 3 and about $30 billion greater than the Reference Case. Increased costs relative to Scenario 3 are due to:

- Transportation – Costs increase significantly because each TAD or DPC must be shipped twice, once to the CIS site and then again to the repository.
- New Facilities – The costs associated with constructing and operating the CIS facility.

There is also a cost decrease due to:

- Taxpayer Liability – The opening of the federal CIS facility in 2025 means that waste from some of the shutdown sites can be removed earlier than in Scenario 3; operating costs at shutdown sites are larger than at sites with operating reactors.

4.1.3. Scenario 4 and Variants: Repository Opens in 2117

As discussed in Section 3.3, in Scenario 4 and its variants it is assumed that a Yucca Mountain-like repository opens in 2117. It is assumed that the common costs for the new repository are the same as the common costs associated with Yucca Mountain in the other scenarios (Table 2-2). However, due to the 100-year delay, repository development and evaluation costs are assumed to be re-incurred and are categorized as part of the New Facilities cost element. Figure 4-4 and Table 4-3 show the relative contributions of each cost element for Scenario 4, along with the cost elements for the Reference Case for comparison.

For Scenario 4 and its variants, delaying the repository until 2117 results in all CSNF being loaded and stored in DPCs at the utility sites. The 100-year repository delay as compared to the Reference Case also significantly increases the taxpayer liabilities (payments from the Judgment Fund).

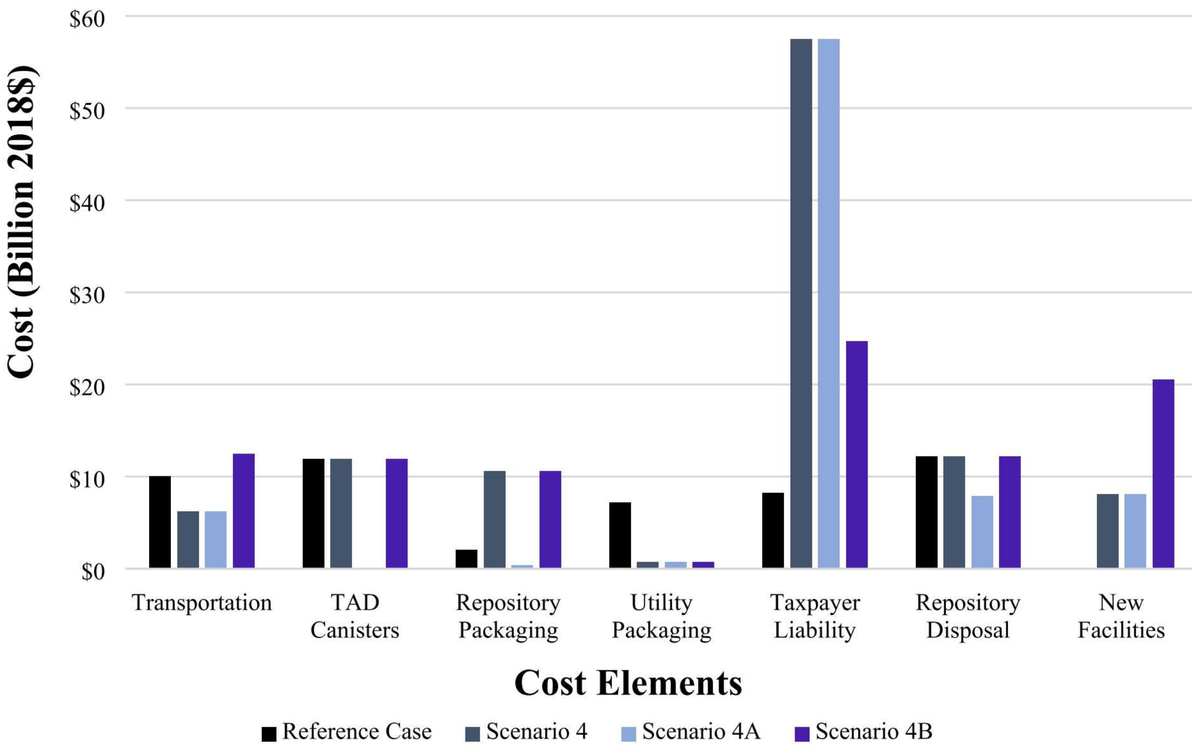

Figure 4-4. Potentially Discriminating Cost Elements for Scenario 4 and Variants

Table 4-3. Scenario 4 and Variant Estimated Costs (Billions of 2018$)

Cost Element	Reference Case Scenario 1	Scenario 4	Scenario 4A	Scenario 4B
Transportation	10.022	6.232	6.232	12.465
TAD Canisters	11.922	11.922	0.000	11.922
Repository Packaging	2.043	10.621	0.434	10.621
Utility Packaging	7.226	0.731	0.731	0.731
Taxpayer Liability	8.219	57.480	57.480	24.729
Repository Disposal	12.232	12.232	7.937	12.232
New Facilities	0.000	8.099	8.099	20.518
Common Costs	60.420	60.420	60.420	60.420
Total	**112.084**	**167.737**	**141.333**	**153.637**

In Scenario 4 (Figure 3-8), the DPCs are repackaged into TADs at the repository, similar to Scenario 2. The estimated total cost for Scenario 4 is about $56 billion greater than the Reference Case and about $48 billion greater than Scenario 2. Increased costs relative to the Reference Case (and to Scenario 2) are due to:

- Repository Packaging – All of the CSNF is in DPCs and needs to be repackaged into TADs at the repository. More LLW will also be generated as a result.
- Taxpayer Liability – All of the CSNF is loaded into DPCs at the utilities. In addition, the ISFSI operating costs are incurred for a much longer period of time, and as operating reactors shut down over time, more of the ISFSIs are at shutdown sites, which have higher operating costs.
- New Facilities – Costs to develop and evaluate the new repository.

Decreased costs relative to the Reference Case do not fully offset the cost increases. Decreased costs are due to:

- Transportation – All waste (except bare fuel) is transported in DPCs, which contain more waste than TADs; therefore, fewer overall shipments are required.
- Utility Packaging – There are no TADs loaded at the utility sites.

In Scenario 4A (Figure 3-9), the CSNF in the DPCs is not repackaged into TADs but is instead disposed of in the repository, similar to Scenario 2C. The estimated total cost for Scenario 4A is about $29 billion greater than the Reference Case, but about $26 billion less than Scenario 4. Decreased costs relative to Scenario 4 are due to:

- TAD Canisters – No TAD canisters are required.
- Repository Packaging – No DPCs are repackaged and there is no associated LLW disposal, only the small amount of bare fuel is repackaged at the repository.
- Repository Disposal – Fewer disposal overpacks needed because there are fewer total waste packages (the CSNF fits in fewer DPCs are compared to TADs), even though there is some cost associated with treating the DPCs prior to disposal.

Scenario 4B (Figure 3-10) is the same as Scenario 4 except that a federal CIS facility becomes available in 2025. The estimated total cost for Scenario 4B is about $42 billion greater than the Reference Case but about $14 billion less than Scenario 4. Decreased costs relative to Scenario 4 are due to:

- Taxpayer Liability – The opening of the federal CIS facility in 2025 means that waste can be removed from the ISFSI sites nearly 100 years earlier than in Scenario 4; this significantly decreases taxpayer liability, in the form of payments from the Judgment Fund.

There are also increased costs relative to Scenario 4, but they do not fully offset the cost decreases. Increased costs are due to:

- Transportation – Costs increase significantly because each TAD or DPC must be shipped twice, once to the CIS site and then again to the repository.
- New Facilities – The costs associated with constructing and operating the CIS facility.

4.1.4. Selected Scenario Comparisons

The results shown in Figure 4-1 are repeated in Figure 4-5 through Figure 4-9, showing subsets of results as direct comparisons that support the major conclusions of the analysis.

4.1.4.1. Possible Impacts of Delay in Repository Opening

Figure 4-5 compares Scenarios 1, 2, 3, and 4, and shows that if all other factors are held constant, delay in the beginning of disposal operations results in a steady increase in overall program cost. Specifically, the adjusted Reference Case (Scenario 1) cost for disposal beginning in 2017 increases from $112.1 billion (2018$) to

- $120.0 billion (2018$) if disposal begins in 2031 (Scenario 2),
- $128.4 billion (2018$) if disposal begins in 2041 (Scenario 3), and
- $167.7 billion (2018$) if disposal is delayed to 2117 (Scenario 4).

These cost increases are primarily due to ongoing costs of continued storage of spent nuclear fuel at commercial sites and are paid by the U.S. taxpayer through the Judgment Fund.

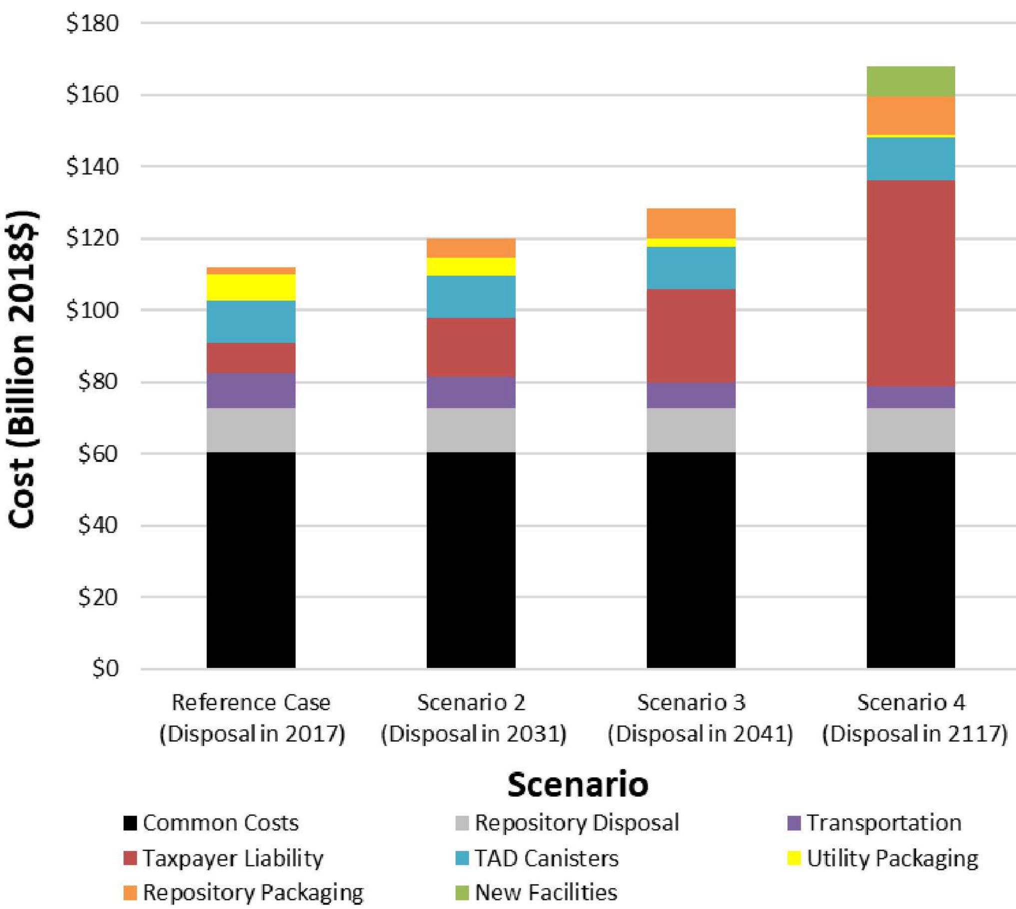

Figure 4-5. Comparison of Estimated Costs for Different Repository Opening Dates

4.1.4.2. Possible Impacts from Disposal of DPCs Without Repackaging

Figure 4-6 and Figure 4-7 show that total life-cycle costs can be reduced if some or all of the CSNF can be disposed of in DPCs without repackaging. Specifically, Figure 4-6 compares costs for disposal operations that begin in 2031 with no disposal (full repackaging) of DPCs (Scenario 2), disposal only of the DPCs that exist as of 2025 (Scenario 2B), and disposal of all CSNF in DPCs (Scenario 2C). Conclusions from Figure 4-6 are:

- Directly disposing of DPCs that exist as of 2025 has the potential to reduce costs for a repository that opens in 2031 by about $12 billion (2018$) as compared to full repackaging.
- Directly disposing of all CSNF in DPCs has the potential to reduce costs for a repository that opens in 2031 by about $18 billion (2018$) as compared to full repackaging.

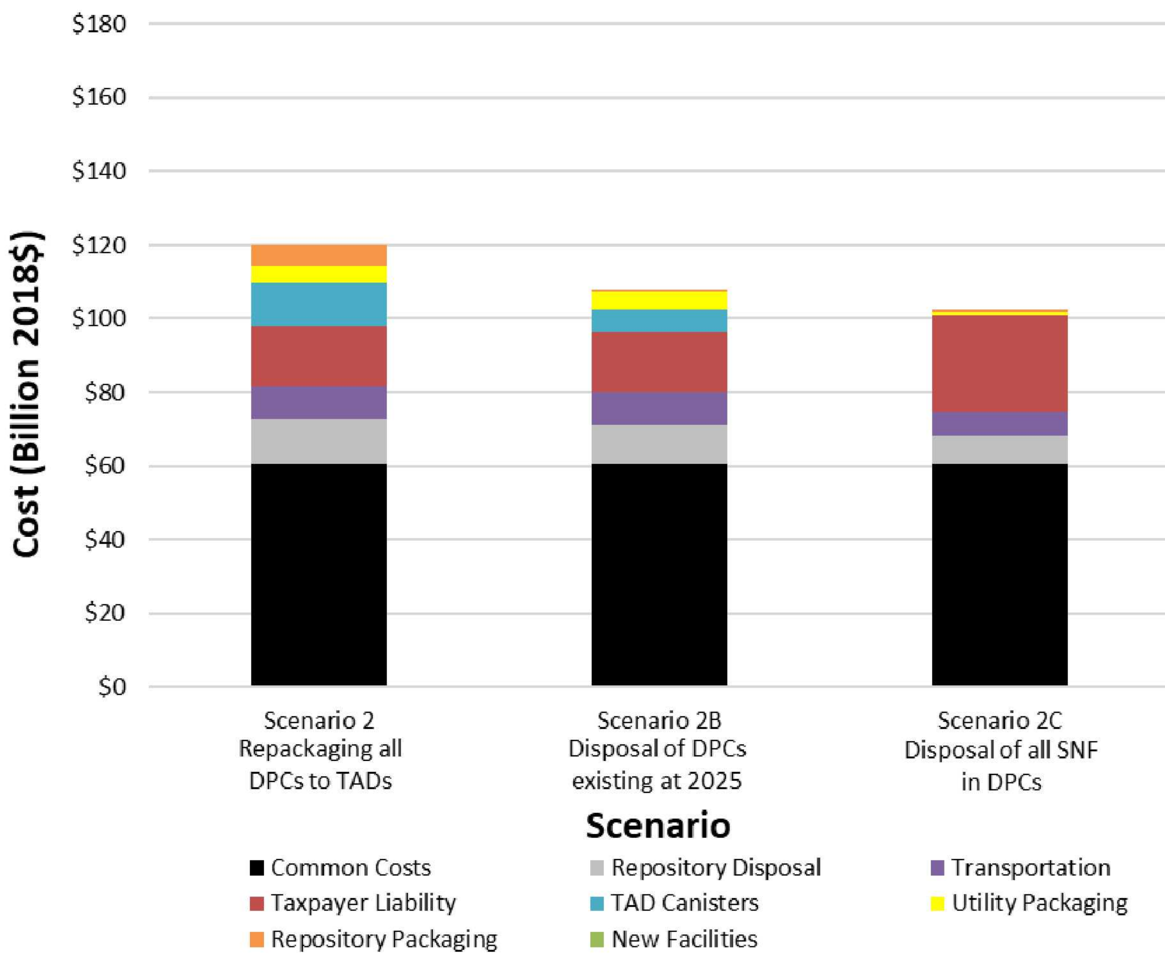

Figure 4-6. Comparison of Estimated Costs for Different DPC Disposal Options (Repository Opens in 2031)

Figure 4-7 shows a similar comparison for disposal operations that begin in 2117 for full repackaging of DPCs (Scenario 4) versus full disposal of DPCs (Scenario 4A).

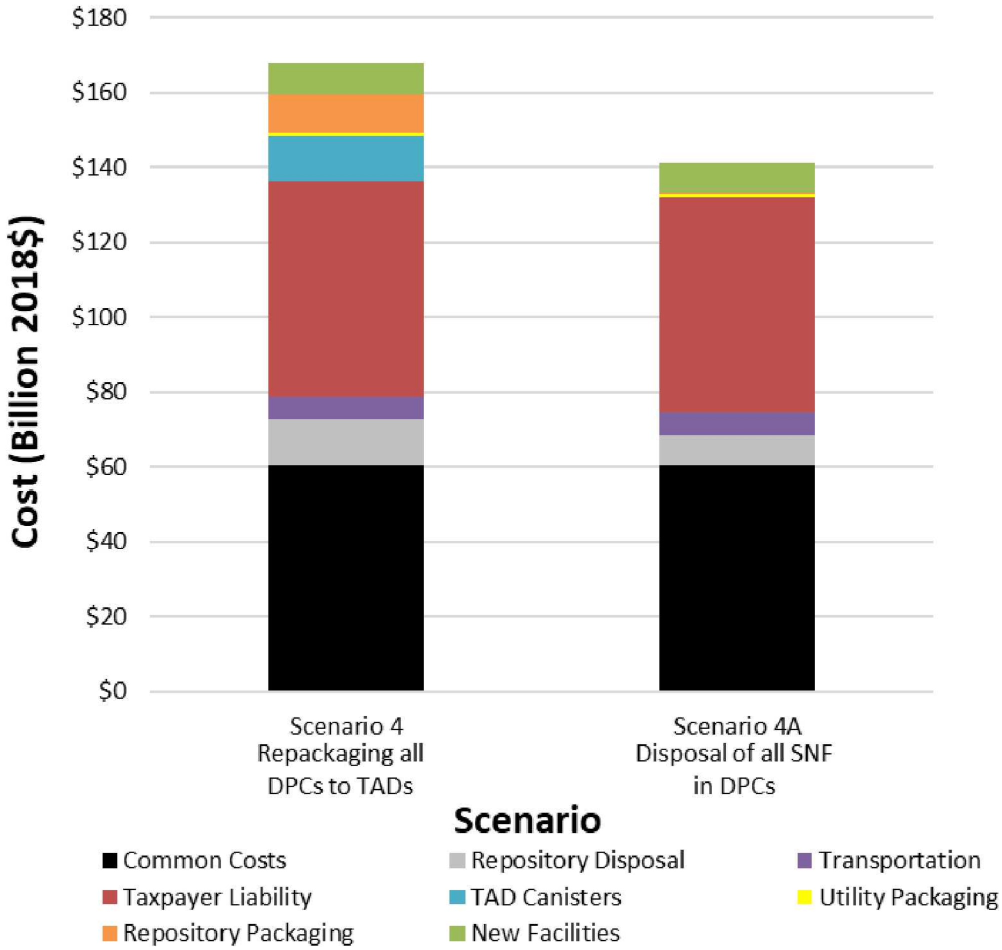

Figure 4-7. Comparison of Estimated Costs for Different DPC Disposal Options (Repository Opens in 2117)

4.1.4.3. Possible Impacts from Federal Consolidated Interim Storage

Figure 4-8 shows the potential cost impacts of a federal CIS facility that is available in 2025, assuming disposal operations at a repository begin in 2031 (Scenario 2D), 2041 (Scenario 3A), and 2117 (Scenario 4B). The primary conclusion drawn from this comparison is that the relative cost impact of implementing CIS depends on the date at which the repository begins disposal operations.

- If the repository is available relatively soon after the CIS facility begins operations (e.g., Scenarios 2D and 3A), the increased costs associated with construction, operation, and transportation for the CIS facility are greater than the savings associated with earlier termination of the Judgment Fund liabilities, resulting in an overall increase in scenario cost of as much as $20 billion (2018$).
- If disposal operations are delayed by 100 years (e.g., Scenario 4B), cost savings from a CIS facility, due primarily to early termination of the Judgment Fund liabilities, are estimated to be about $14 billion (2018$).

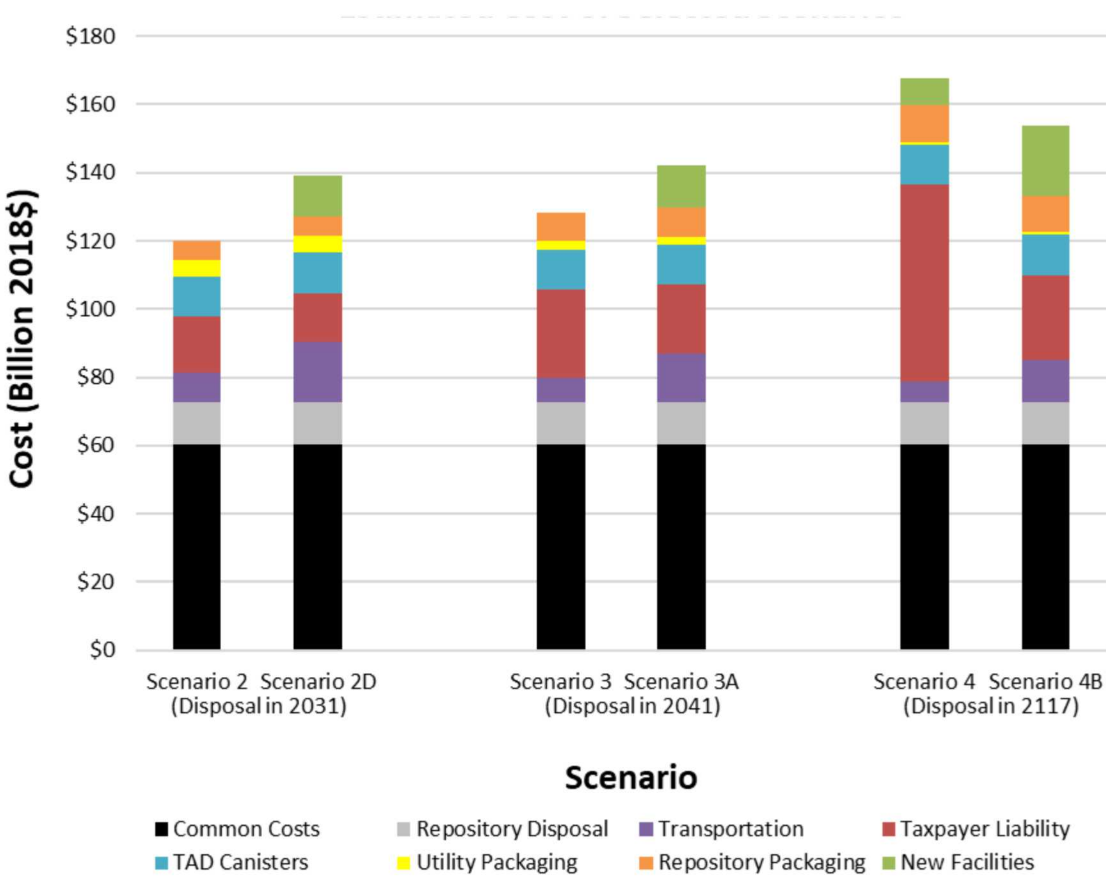

Figure 4-8. Comparison of Estimated Costs for Scenarios with CIS and Different Repository Opening Dates

4.1.4.4. Possible Impacts of Where Spent Nuclear Fuel is Repackaged

Figure 4-9 shows a comparison that addresses the relative impacts of assuming that repackaging of spent nuclear fuel occurs at the repository (Scenario 2) rather than at the commercial nuclear power plant sites (Scenario 2A). The primary conclusion drawn from Figure 4-9 is that, although there are significant changes in where in the system costs are incurred, the impact on the overall total life-cycle costs is less important than other factors considered in this analysis. Specifically:

- For a repository that begins disposal operations in 2031, repackaging spent nuclear fuel at the commercial nuclear power plant sites rather than at the repository results in an overall increase in total life-cycle cost of about $3 billion (2018$), primarily in increased transportation costs associated with the larger number of shipments required to move TADs rather than DPCs.

This cost comparison is shown only for a single date for the beginning of disposal operations (2031), but impacts can be inferred to be similar for other dates. Note that estimated costs of repackaging at either location do not include the cost of additional facility improvements that may be required to support operations.

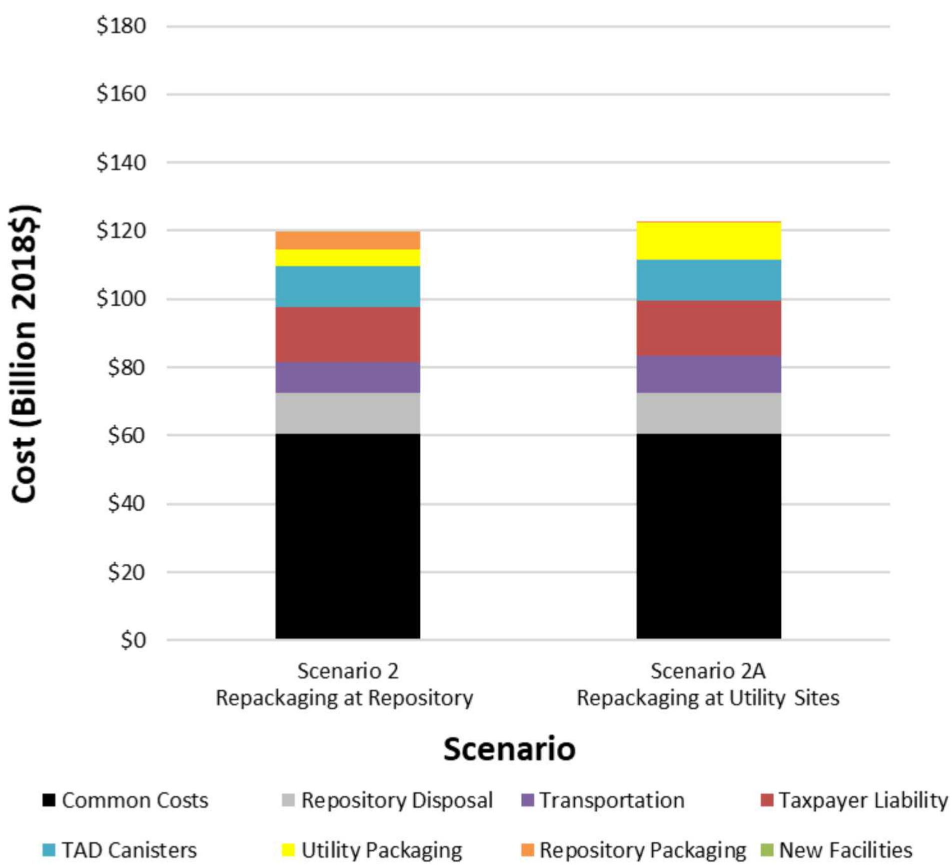

Figure 4-9. Comparison of Estimated Costs for Different DPC Repackaging Locations

4.2. Cost Uncertainty

Several parameters that serve as input to the potentially discriminating costs were recognized as being uncertain in the cost analyses described in Section 4.1. The uncertainties arise due to cost inputs that cannot be accurately estimated due to the effects of advancing technology, marketplace conditions, variations in approaches to SNF operations, etc. An approach to evaluate the effects of uncertainty and/or variability in those parameters on the total cost estimates is described in detail in Appendix D and summarized here.

Table D-1 identifies eleven parameters that are inputs to the seven potentially discriminating cost elements. Some of the parameters contribute to more than one cost element, and some cost elements have more than one input parameter. The effects of uncertainty in the eleven parameters was examined by assuming three different values for each parameter: a low estimate, a nominal estimate, and a high estimate, as shown in Table 4-4. The nominal estimate parameter values correspond to the values listed in Appendix C and used to calculate the cost estimates for the alternative scenarios in Section 4.1.

Table 4-4. Uncertain Parameters and Values (2018$)

Parameter	Low Estimate	Nominal Estimate	High Estimate
Cost of rail cask shipment	639,850	853,140	1,279,710
Cost for a single TAD canister	688,720	918,290	1,377,440
Cost of loading or unloading operation per canister (TAD or DPC)	337,500	450,000	675,000
Cost of storage overpack (TAD or DPC) (per overpack)	262,500	350,000	525,000
Cost of transferring a canister (TAD or DPC) from storage to a transportation overpack	75,000	100,000	150,000
Percentage of TADs staged at ISFSIs prior to transportation to repository or CIS facility	0%	50%	100%
LLW disposal cost per used DPC	87,600	175,200	350,400
Cost to modify DPCs to facilitate disposal (per DPC)	0	100,000	200,000
Annual operations cost per ISFSI-only site	2,500,000	5,000,000	10,000,000
Annual operations cost per ISFSI at operating reactor site	310,000	1,240,000	2,480,000
Cost of a federal CIS facility	8,357,013,000	11,142,684,000	16,714,026,000

In general, the low estimate value is 75% of the nominal estimate value, and the high estimate value is 50% more than the nominal estimate value, although this is not always the case. The -25% to +50% range was chosen to be within industry project management accepted practices for rough-order-of-magnitude (ROM) cost estimates. This approach typically applies ROM estimates to the early or conceptual project as a cost-ranging tool (PMI 2008). For the four parameters that use a different uncertainty range, these ranges were justified by cost estimates from a variety of sources, as noted in Appendix C (Parameters AO, AP, AV, and AY). All cost values are adjusted for inflation to constant 2018 dollars. These cost ranges are illustrative of the full spectrum of cost potentials for the purpose of scenario comparisons.

Figure 4-10 compares the low, nominal, and high cost estimates for each scenario. Scenarios 4 and 4A show the greatest difference between high estimate and low estimate values as compared to the other scenarios. This is due to the large increase in costs to taxpayers via payments from the Judgment Fund, which is driven by the large uncertainty (i.e., ratio of high estimate value to low estimate value) in annual operations costs at ISFSIs, both at ISFSI-only sites and at operating reactor sites (Table 4-4). Other than this case, uncertainty in underlying costs is not a discriminator among scenarios.

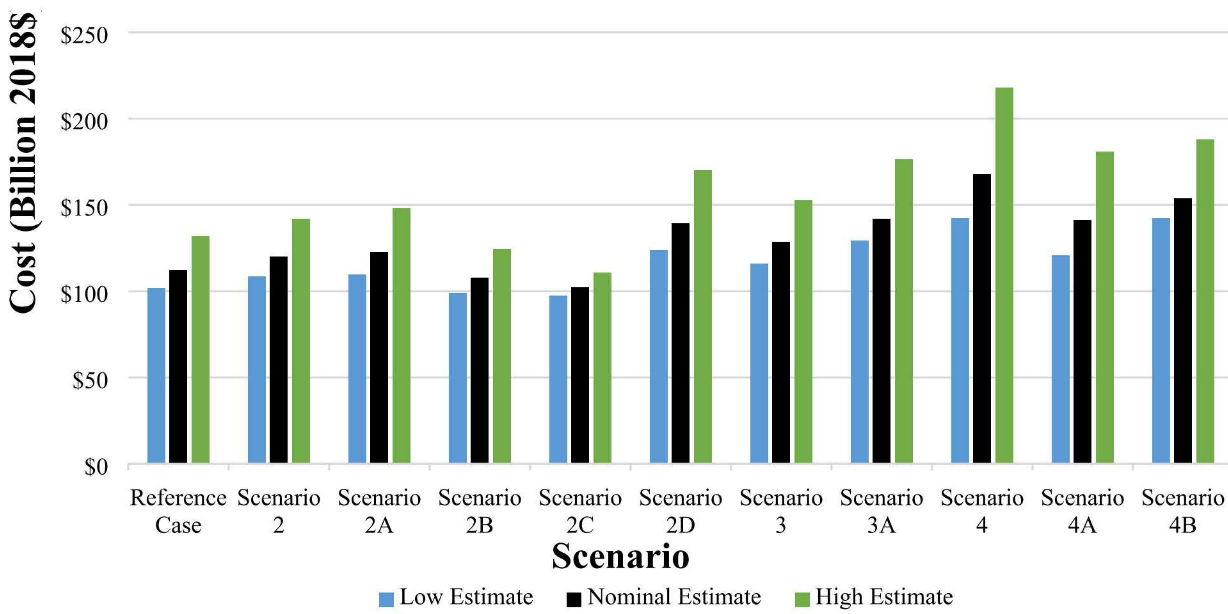

Figure 4-10. Estimated Costs with Uncertainty

4.3. Costs by Funding Source

As described in Section 2, possible funding sources for the various cost elements include: the Nuclear Waste Fund; Taxpayer Liability (Judgment Fund); and Other (not yet identified/allocated). A breakdown of the estimated costs for each scenario by funding source is shown in Figure 4-11, with details tabulated in Table 4-5.

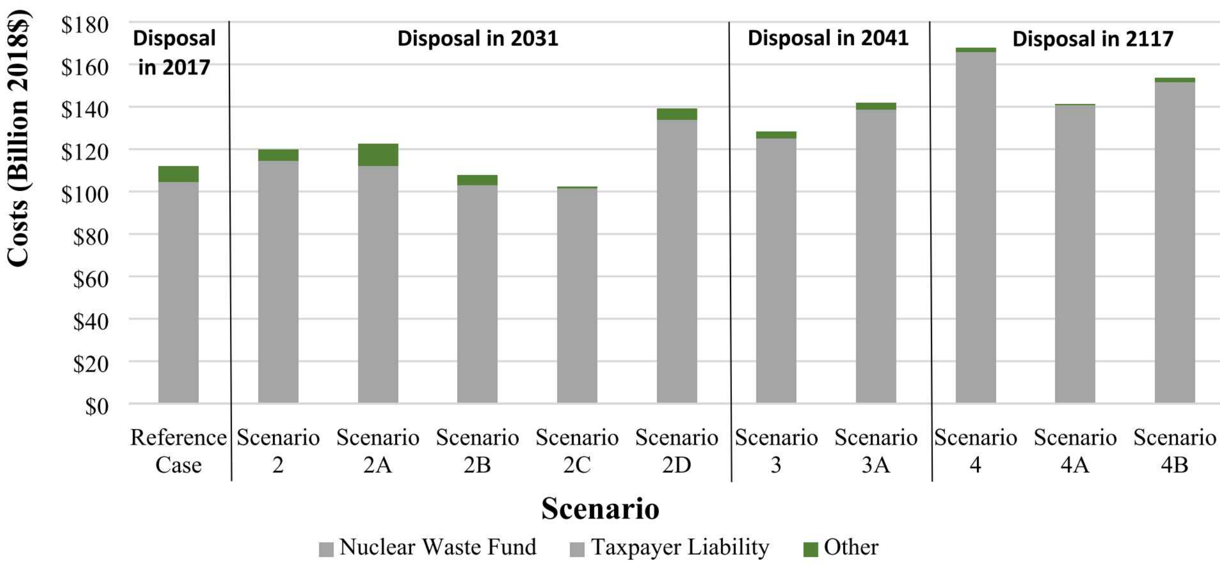

Figure 4-11. Estimated Costs by Funding Source

Table 4-5. Costs by Funding Source for Each Scenario (Billions of 2018$)

Scenario Description	Total Cost	Costs Paid by Nuclear Waste Fund	Costs Paid by Judgment Fund (Taxpayer Liability)	Costs Paid by Other Source	Comments on Funding Sources
Scenario 1: Disposal at Yucca Mountain in 2017 (Reference Case)					
Reference Case (Adjusted TSLCC) • Start loading TADs in 2011 • Repackage DPCs at repository • Judgment Fund (DPCs) to 2011 • Judgment Fund (ISFSIs) to 2027	$112.08	$96.43	$8.22	$7.44	Primary funding source is Nuclear Waste Fund.
Scenario 2: Disposal at Yucca Mountain in 2031					
Scenario 2 • Start loading TADs in 2025 • Repackage DPCs at repository • Judgment Fund (DPCs) to 2025 • Judgment Fund (ISFSIs) to 2041	$119.98	$98.26	$16.31	$5.41	**Comparison to Scenario 1** Nuclear Waste Fund cost increases slightly due to repackaging additional DPCs loaded through 2025. Judgment Fund cost increases due to loading more DPCs and operating ISFSIs longer.
Scenario 2A (Variant of Scenario 2) • Repackage DPCs at utility sites	$122.70	$95.59	$16.31	$10.81	**Comparison to Scenario 2** Nuclear Waste Fund cost decreases slightly and Other costs increase slightly due to repackaging of DPCs at utility sites rather than at the repository.
Scenario 2B (Variant of Scenario 2) • Directly dispose DPCs loaded ≤ 2025	$107.79	$86.76	$16.31	$4.73	**Comparison to Scenario 2** Nuclear Waste Fund cost drops significantly due to direct disposal of DPCs loaded to 2025 entailing: - Fewer TADs and disposal overpacks - Fewer repackaging operations
Scenario 2C (Variant of Scenario 2B) • Continue loading DPCs ≥ 2025 • Directly dispose DPCs loaded ≤ 2043 • Judgment Fund (DPCs) to 2043	$102.27	$75.02	$26.52	$0.73	**Comparison to Scenario 2B** Nuclear Waste Fund cost drops very significantly due to direct disposal of all CSNF in DPCs entailing: - No TADs and significantly fewer disposal overpacks - Fewer shipments - Minimal repackaging operations Judgment Fund cost increases significantly due to loading more DPCs.
Scenario 2D (Variant of Scenario 2) • CIS available in 2025 • Store DPCs and TADs at CIS • Judgment Fund (ISFSIs) to 2035	$139.28	$119.36	$14.52	$5.41	**Comparison to Scenario 2** Nuclear Waste Fund cost increases very significantly due to the cost of a federal CIS facility and additional transportation.
Scenario 3: Disposal at Yucca Mountain in 2041					

Scenario Description	Total Cost	Costs Paid by Nuclear Waste Fund	Costs Paid by Judgment Fund (Taxpayer Liability)	Costs Paid by Other Source	Comments on Funding Sources
Scenario 3 • Start loading TADs in 2035 • Repackage DPCs at repository • Judgment Fund (DPCs) to 2035 • Judgment Fund (ISFSIs) to 2051	$128.40	$99.22	$25.87	$3.31	**Comparison to Scenario 2** Nuclear Waste Fund cost increases slightly due to repackaging additional DPCs loaded through 2035. Judgment Fund cost increases due to loading more DPCs and operating ISFSIs longer.
Scenario 3A • CIS available in 2025 • Store DPCs and TADs at CIS • Judgment Fund (ISFSIs) to 2035	$141.99	$118.49	$20.19	$3.31	**Comparison to Scenario 3** Nuclear Waste Fund cost increases very significantly due to the cost of a federal CIS facility and additional transportation. Judgment Fund cost decreases due to earlier removal of waste from ISFSIs.
Scenario 4: Disposal at Yucca Mountain in 2117 (Extended Storage)					
Scenario 4 • Continue loading DPCs ≥ 2025 • Repackage DPCs at repository • Judgment Fund (DPCs) to 2043 • Judgment Fund (ISFSIs) to 2127	$167.74	$108.25	$57.48	$2.01	**Comparison to Scenario 2** Nuclear Waste Fund cost increases due to repackaging the full inventory. Judgment Fund cost increases significantly due to loading more DPCs and operating ISFSIs longer.
Scenario 4A (Variant of Scenario 4) • Directly dispose DPCs loaded ≤ 2043	$141.33	$83.12	$57.48	$0.73	**Comparison to Scenario 4** Nuclear Waste Fund cost drops very significantly due to direct disposal of all CSNF in DPCs entailing: - No TADs and significantly fewer disposal overpacks - Fewer shipments - Minimal repackaging operations Other costs decrease due to no LLW disposal.
Scenario 4B • CIS available in 2025 • Store DPCs and TADs at CIS • Judgment Fund (ISFSIs) to 2035	$153.64	$126.90	$24.73	$2.01	**Comparison to Scenario 4** Nuclear Waste Fund cost increases significantly due to the cost of a federal CIS facility and additional transportation. Judgment Fund cost decreases significantly due to much earlier removal of waste from ISFSIs.

Payments from the Nuclear Waste Fund include the costs for the following: repository activities captured under the common costs (see Table 2-2), transportation operations and infrastructure, fabrication of TAD canisters, repackaging spent fuel into TADs at the repository, disposal overpacks for both DPCs and TADs, waste emplacement modification of DPCs prior to disposal (e.g., add filler material to reduce the probability of criticality), and new facilities, such as a CIS facility or a new repository.

Taxpayer Liability includes the monies already paid to utilities (as of 2017) and the projected future costs to the utilities for maintaining ISFSIs, as paid through the Judgment Fund.

The Other category includes cost for the following activities: transferring DPCs from their storage overpacks at utilities to transport casks in preparation for transport to a repository or a CIS site, loading fuel into TADs, removing spent fuel from DPCs before repackaging the fuel into TADs at utility sites, and disposing of used DPC shells as LLW. These activities are in the Other category because it is not clear if they would be paid for by the Nuclear Waste Fund, or whether they would be reimbursed from the Judgment Fund.

As shown in Figure 4-11, the primary funding source for all scenarios is the Nuclear Waste Fund. Nuclear Waste Fund costs are lowest in scenarios that include direct disposal of DPCs (Scenarios 2C and 4A) because fewer TAD canisters are required and significantly less repackaging is necessary. The larger capacity of DPCs relative to TADs also means there are fewer shipments of spent fuel, and fewer disposal overpacks needed. Nuclear Waste Fund costs are highest in scenarios where there are new facilities, such as costs associated with CIS (Scenarios 2D, 3A, and 4B).

Taxpayer Liability, in the form of payments from the Judgment Fund, increases in scenarios where there is a delay in opening a repository and the utilities are required to maintain ISFSIs for a long time (Scenarios 4 and 4A).

Further analysis of costs by funding source is provided in Appendix E.

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5. CONCLUSIONS

This report provides a technical analysis of possible approaches to optimize the management of CSNF from nuclear power plants and support the DOE in decision making and policy development.

A set of alternative scenarios was developed to encompass a representative range of possible combinations of alternative spent fuel management approaches. Some of the alternative scenarios also include "one-off" sub-scenarios or variants. The alternative scenarios were evaluated in terms of the timing, options, and costs for waste packaging, storage, transportation, and disposal at the proposed Yucca Mountain repository or an equivalent repository. The costs of the alternative scenarios were baselined against a Reference Case scenario derived from transportation and disposal activities and cost elements described in the TSLCC (DOE 2008).

Analyses were performed to provide simple and credible estimates of relative costs to the nuclear utilities via the Nuclear Waste Fund and to the U.S. taxpayers via the Judgment Fund for moving forward with each scenario; these are presented in Section 4. A summary of estimated costs, by cost element, for each scenario is provided in Table 5-1. Figure 5-1 shows the change in cost elements as compared to the Reference Case for each scenario.

Based on the comparative cost analyses in Section 4, and the summary cost comparisons shown in Table 5-1, and Figure 5-1, the following conclusions are made:

- The adjusted Reference Case (Scenario 1), with disposal at Yucca Mountain in 2017, results in an estimated civilian (commercial) share of the total life-cycle cost of $112.1 billion (2018$).
- Scenarios that delay the beginning of disposal operations, with all other elements of the system unchanged, increase estimates of total life-cycle cost, to:
  - $120.0 billion (2018$) if disposal begins in 2031,
  - $128.4 billion (2018$) if disposal begins in 2041, and
  - $167.7 billion (2018$) if disposal is delayed to 2117.

  Doing nothing and delaying disposal for 100 years is the most expensive option, costing the taxpayers nearly $50 billion (2018$) in additional payments from the Judgment Fund. This increase includes about $15 billion (2018$) for loading more DPCs and about $35 billion (2018$) for continued operation of ISFSIs at shutdown sites as compared to the Reference Case.
- Scenarios that allow direct disposal of DPCs without repackaging to TADs reduce estimated life-cycle costs. For a repository that opens in 2031:
  - Directly disposing of DPCs existing up to 2025, and loading TADs thereafter, has the potential to reduce costs by approximately $12 billion (2018$).
  - Directly disposing of all CSNF in DPCs has the potential to reduce costs by approximately $18 billion (2018$).
- The relative cost impact of implementing a federal CIS facility depends on the date at which the repository begins disposal operations. If a repository is available relatively soon after the CIS facility begins operations, costs for construction and operation of the CIS

facility and for transportation are greater than the savings associated with the earlier termination of Judgment Fund liabilities. If disposal operations are delayed for a longer period, the earlier termination of Judgment Fund liabilities from a CIS facility can lead to overall cost savings.

- Decisions about where spent nuclear fuel is repackaged for disposal (i.e., at the commercial nuclear power plants or at the repository) result in significant changes in where in the system costs are incurred, but the impact on overall total life-cycle costs is less important than other factors considered in the analysis.
- Cost estimates are relatively insensitive to uncertainty in component costs. Uncertainty in costs to the taxpayer from Judgment Fund liabilities cause the costs associated with lengthy delays before disposal and prolonged ISFSI operations to increase more than those in other scenarios. Otherwise, uncertainty in costs is not a discriminator among the scenarios.
- The primary funding source for all scenarios is the Nuclear Waste Fund. Taxpayer liability, in the form of payments from the Judgment Fund, increases in scenarios where there is a delay opening a repository.

This report provides analyses of alternatives and options related to spent nuclear fuel management based on technical and programmatic considerations that can be quantified in cost estimates. However, they do not include explicit evaluations of more difficult to quantify factors such as regulatory and legal considerations, political sensitivities, or public opinion towards nuclear waste and/or potential storage or disposal sites, although these considerations are likely to factor into decision making. No inferences should be drawn from this report regarding future actions by DOE. To the extent this report conflicts with provisions of the Standard Contract, those provisions prevail.

Table 5-1. Summary of Estimated Costs for All Scenarios (Billions of 2018$)

Cost Element	Reference Case Scenario 1	Scenario 2	Scenario 2A	Scenario 2B	Scenario 2C	Scenario 2D	Scenario 3	Scenario 3A	Scenario 4	Scenario 4A	Scenario 4B
Transportation	10.022	8.807	10.578	8.807	6.232	17.615	7.121	14.241	6.232	6.232	12.465
TAD Canisters	11.922	11.922	11.922	6.435	0.000	11.922	11.922	11.922	11.922	0.000	11.922
Repository Packaging	2.043	5.562	0.434	0.434	0.434	5.562	8.547	8.547	10.621	0.434	10.621
Utility Packaging	7.226	4.726	10.808	4.726	0.731	4.726	2.292	2.292	0.731	0.731	0.731
Taxpayer Liability (Judgment Fund)	8.219	16.307	16.307	16.307	26.521	14.515	25.869	20.190	57.480	57.480	24.729
Repository Disposal	12.232	12.232	12.232	10.666	7.937	12.232	12.232	12.232	12.232	7.937	12.232
New Facilities	0.000	0.000	0.000	0.000	0.000	12.290	0.000	12.142	8.099	8.099	20.518
Common Costs	60.420	60.420	60.420	60.420	60.420	60.420	60.420	60.420	60.420	60.420	60.420
Total	**112.084**	**119.975**	**122.701**	**107.795**	**102.275**	**139.281**	**128.403**	**141.986**	**167.737**	**141.333**	**153.637**

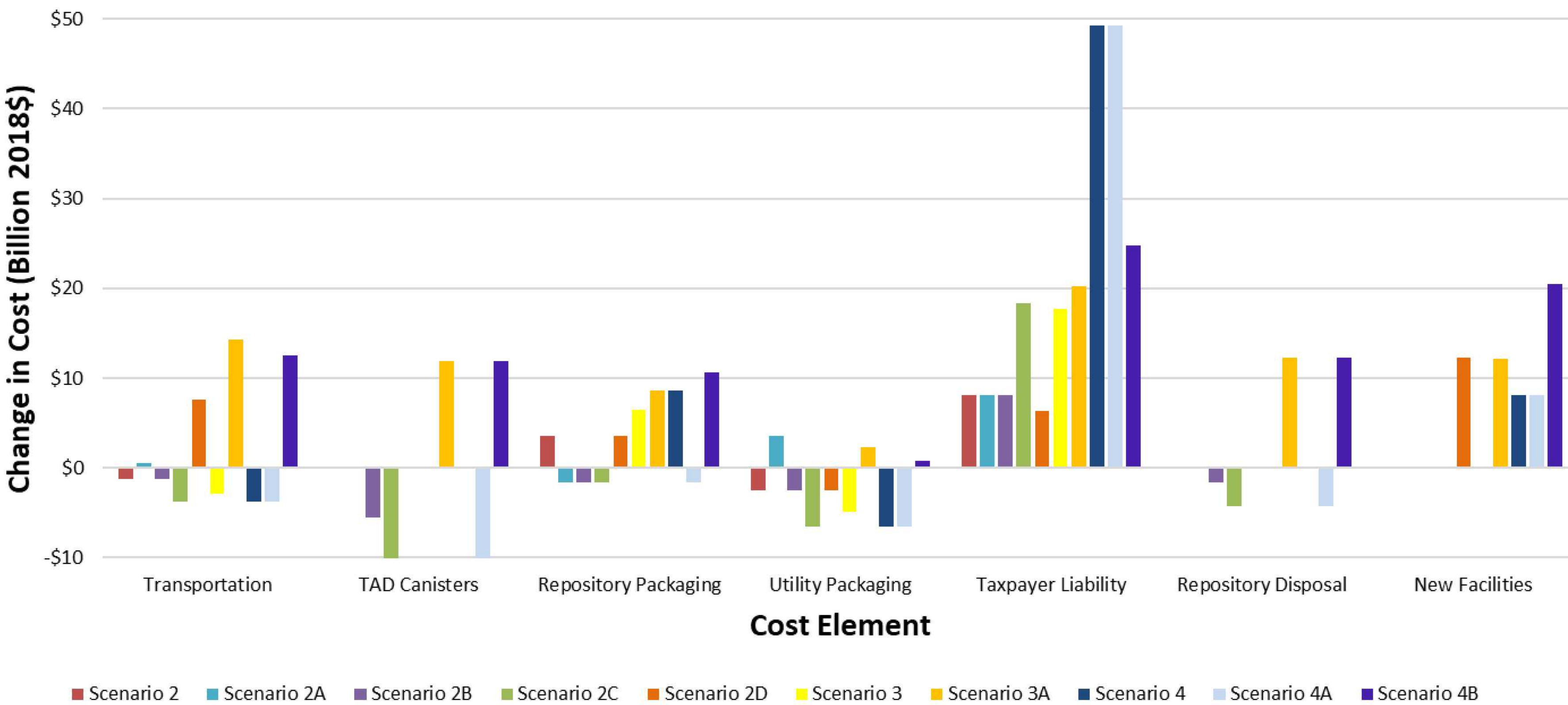

Figure 5-1. Change in Estimated Costs Compared to the Reference Case for Each Scenario by Cost Element

6. REFERENCES

10 CFR Part 72. Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste.

10 CFR Part 961. Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste.

31 CFR Part 256. Obtaining Payments from the Judgment Fund and Under Private Relief Bills.

ATI-TR-13047. *Storage and Transport Cask Data for Used Commercial Nuclear Fuel, 2013.* U.S. Edition, August 9, 2013

BLS (U.S. Bureau of Labor Statistics) 2018. Bureau of Labor Statistics Inflation Calculator. Available at: https://data.bls.gov/data/inflation_calculator.htm (accessed 12/07/18).

Bonano, E.J.; E.A. Kalina; and P.N. Swift, 2018. "The Need for Integrating the Back End of the Nuclear Fuel Cycle in the United States of America." MRS Advances, 3(19), 991-1003. doi:10.1557/adv.2018.231.

DOE (U.S. Department of Energy) 2007. *Draft Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*. DOE/EIS-0250FS1D. Washington, DC: U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

DOE 2008. *Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program, Fiscal Year 2007*. DOE/RW-0591. Washington, DC: U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

DOE 2008b. *Yucca Mountain Repository License Application*. DOE/RW-0573. Washington, DC: U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

DOE 2009. *Yucca Mountain Repository License Application*. DOE/RW-0573. Update 1, February 2009. https://www.nrc.gov/waste/hlw-disposal/yucca-lic-app.html

DOE 2017. *Fiscal Year 2017 Agency Financial Report.* DOE/CF-0138. Washington, DC: U.S. Department of Energy.

EPRI (Electric Power Research Institute) 2012. *Impacts Associated with Transfer of Spent Nuclear Fuel from Spent Fuel Storage Pools to Dry Storage After Five Years of Cooling*, Revision 1 (1025206).

Entergy 2007. *Entergy Nuclear Operations, Inc. Spent Fuel Management Plan.* Submitted in accordance with 10 CFR 50.54(bb), Docket 50-293, June 7, 2007.

Energy Northwest v. United States. United States Court of Federal Claims, No 0410C, Energy Northwest v the United States, February 26, 2010.

GAO (U.S. Government Accountability Office) 2014. *Spent Nuclear Fuel Management: Outreach Needed to Help Gain Public Acceptance for Federal Activities That Address Liability*. GAO-15-141. Washington, DC: U.S. Government Accountability Office.

Jarrell, J.; R. Joseph; R. Howard; R. Hale; G. Petersen; B. Wilkerson; J. Fortner; E. Kalinina 2015. *Initial Standardized Canister System Evaluation.* FCRD-NFST-2004-000084, Rev. 01.

Lytle, J.E. 1995. "Disposal of DOE-owned high-level waste and spent nuclear fuel." Interoffice memorandum to D.A. Dreyfus, U.S. Department of Energy, Office of Civilian Radioactive Waste Management from J.E. Lytle, U.S. Department of Energy, Office of Environmental Management.

NAS (National Research Council / National Academy of Sciences) 1957. *The Disposal of Radioactive Waste on Land, Report of the Committee on Waste Disposal of the Division of Earth Sciences.* National Academy of Sciences – National Research Council Publication 519. Washington DC).

NAS 2001. *Disposition of High-Level Waste and Spent Nuclear Fuel: The Continuing Societal and Technical Challenges*. Washington, DC: National Academy Press.

NEI (Nuclear Energy Institute) 2018a. *U.S. Nuclear Operating Plant Basic Information*. Available at https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/US-Nuclear-Operating-Plant-Basic-Information (accessed 02/16/18).

NEI 2018b. *U.S. Nuclear Plant License Information*. Available at https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/US-Nuclear-Plant-License-Information (accessed 02/19/18).

NEI 2018c. *U.S. Nuclear License Renewal Filings*. Available at https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/US-Nuclear-License-Renewal-Filings (accessed 02/19/18).

NEI 2018d. *Decommissioning Status for Shut Down US Nuclear Power Reactors*. Available at https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/Decommissioning-Status-for-Shut-Down-US-Nuclear-Po (accessed 02/16/18).

NRC (U.S. Nuclear Regulatory Commission) 2014a. *Generic Environmental Impact Statement for Continued Storage of Spent Nuclear Fuel, Final Report.* NUREG-2157, Volume 1.

NRC 2014b. *Continued Storage of Spent Nuclear Fuel*. Federal Register, Vol. 79, No. 182, September 19, 2014, pp. 56238-56263.

NRC 2015. *Safety Evaluation Report Related to Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada*. NUREG-1949. Five volumes. https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1949/

NRC 2017. "Dry Cask Storage." Available at https://www.nrc.gov/waste/spent-fuel-storage/dry-cask-storage.html (accessed 12/05/17).

NRC 2019. "Typical Dry Cask Storage System." Available at https://www.nrc.gov/waste/spent-fuel-storage/diagram-typical-dry-cask-system.html (accessed 01/10/19).

NWTRB (U.S. Nuclear Waste Technical Review Board) 2011. *Experience Gained from Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries, A Report to Congress and the Secretary of Energy*. Arlington, VA: U.S. Nuclear Waste Technical Review Board.

Nuclear Waste Policy Act of 1982. 42 U.S.C. 10101 et seq. Public Law 97-425; 96 Stat. 2201.

Nuclear Waste Policy Amendments Act of 1987. Public Law 100-203; 101 Stat. 1330.

OIG (U.S. Office of Inspector General) 2018. *Department of Energy Nuclear Waste Fund's Fiscal Year 2017 Financial Statement Audit*. Audit Report DOE-OIG-18-34, May 2018. U.S. Department of Energy.

PMI (Project Management Institute) 2008. *A Guide to the Project Management Body of Knowledge*. Fourth Edition. ANSI/PMI 99-001-2008.

Rechard, R.P.; L.L. Price; and E.A. Kalinina 2015. *Integrating Management of Spent Nuclear Fuel from Generation to Disposal*. SAND2015-5503. Sandia National Laboratories, Albuquerque, NM.

Shropshire, D.E.; K.A. Williams; J.D. Smith; B.W. Dixon; M. Dunzik-Gougar; R.D. Adams; D. Gombert; J.T. Carter; E. Schneider; and D. Hebditch 2009. *Advanced Fuel Cycle Cost Basis*. INL/EXT-07-12107 Rev. 2. Idaho Falls, ID: Idaho National Laboratory.

Sproat, E.F. 2008. "Yucca Mountain Repository License Application (LA) for Construction Authorization" Letter to Michael F. Weber, U.S. Nuclear Regulatory Commission Office of Nuclear Material Safety and Safeguards, from Edward F. Sproat, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, June 3, 2008.

StoreFuel 2008. Store Fuel and Decommissioning Report, December 2008.

StoreFuel 2011. Store Fuel and Decommissioning Report, May 2011.

StoreFuel 2017. Store Fuel and Decommissioning Report, August 2017.

StoreFuel 2018. Store Fuel and Decommissioning Report, January 9, 2018.

StoreFuel 2019. Store Fuel and Decommissioning Report, January 8, 2019.

Vinson, D. and K. Metzger 2017. *Commercial Spent Nuclear Fuel and High-Level Radioactive Waste Inventory Report*. FCRD-NFST-2013-000263, Rev. 5. Washington, DC: U.S. Department of Energy.

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APPENDIX A – TSLCC COSTS

The *Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program* (DOE 2008) (the "TSLCC") provides a cost estimate for the prospective repository life cycle (design, engineering, licensing, construction, surface and subsurface operations, and decommissioning) and transportation activities based on the system described in the *Draft Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE 2007). The TSLCC cost estimate (DOE 2008, Section 1) includes the project-specific TAD-canister-based system design used for the License Application that was subsequently submitted by the DOE to the NRC for authorization to construct a repository at Yucca Mountain. The TSLCC estimate includes historical (sunk) costs starting from 1983 and projected costs through an assumed closure date of 2133 (DOE 2008, Section 1).

Although the project was not fully funded by Congress and was eventually suspended by DOE, the TSLCC cost estimate is based on the following schedule milestones from the then-current baseline schedule (DOE 2008, Sections 1.3 and 2.2):

- Submittal of the License Application for construction to the NRC in 2008
- Repository Construction Authorization by the NRC in 2011
- Utilities stop loading CSNF into DPCs and start loading it into TADs in 2011
- Submittal of the License Application to receive and possess to the NRC in 2013
- Initial waste receipt and start of repository surface and subsurface operations in 2017
- End of 57-year period of waste emplacement in 2073
- End of 50-year period of monitoring with drift ventilation in 2123 (drip shields are emplaced from 2113 to 2123)
- End of 10-year period of closure operations in 2133.

The TSLCC cost estimate is based on the following assumptions about repository operations (DOE 2008, Section 1.3 and Table A-2):

- As stated in the Yucca Mountain Repository License Application (DOE 2009, Section 1.2.1.1 and 1.2.1.1.2), approximately 10% of the commercial SNF accepted for disposal at Yucca Mountain could arrive as uncanistered "bare" fuel in transportation casks or in DPCs and would be packaged in TAD canisters for disposal at the repository. The remaining 90% of the commercial SNF would be transported and disposed of in TAD canisters sealed at the utility sites. Upon receipt at the repository site, DOE would remove the TAD canisters from transportation casks/overpacks and place them in waste package overpacks suitable for disposal underground. The TADs, with capacities of 21 PWR or 44 BWR assemblies, would be provided to the utilities by the DOE.

- 122,100 MTHM of civilian (commercial) and defense wastes as the inventory projected for disposal as of 2007. This includes:
  - o 109,300 MTHM of CSNF in 12,983 TAD-based waste packages (7,978 with PWR assemblies and 5,005 with BWR assemblies), based on actual and projected CSNF discharges (projections assume discharges from 47 reactors with license extensions as of January 1, 2007 and no new reactors), and
  - o 12,800 MTHM of DOE-managed SNF and HLW in 4,465 waste packages.

The TSLCC cost estimate is based on the following assumptions about transportation (DOE 2008, Section 3 and Table A-2):

- The preferred mode of transportation to the repository is "mostly rail" using dedicated rolling stock (100 cask cars, 37 buffer cars, and 18 escort cars). Waste pickup uses the "Oldest Fuel First" acceptance priority in the Standard Contract for CSNF acceptance. Nominal acceptance rates for CSNF are 3,000 MTHM/year.
- The fleet of transportation casks and overpacks required includes 12,983 TAD canisters, 42 CSNF overpacks, 31 CSNF medium/small casks, 30 CSNF truck casks, and 30 DOE rail casks.
- A total of 20,858 shipments – 16,619 by rail (10,989 TADs, 920 DPCs and 4,710 DOE) and 4,239 by truck (some commercial waste and some defense waste). A shipment consists of one loaded canister (TAD or DPC) in a cask/overpack transported on a single rail car or flatbed trailer.

The "TSLCC Total" cost estimate of $96.18 billion (in 2007$), which includes transportation and disposal of commercial and defense wastes, is summarized in Table A-1. A description of cost elements that comprise the TSLCC total cost is provided in Table A-2.

Also shown in Table A-1 are the following cost adjustments to facilitate comparison with alternative scenarios:

- TSLCC Civilian Share (in 2007$) – The civilian (commercial) cost share allocation, totals $77.38 billion (in 2007$), as described in DOE (2008, Section 5). The total civilian allocation, representing costs for the disposal of commercial SNF and HLW and which is to be paid from the Nuclear Waste Fund, is 80.4%. The remainder, 19.6%, is the total government allocation, representing costs for the disposal of DOE-managed waste and which is to be paid by annual appropriations. The total commercial allocation is a cost-weighted average of the commercial allocation for repository costs (78.2%), transportation costs (87.7%), and balance of program costs (80.4%) (DOE 2008, Table 5-2).
- TSLCC Civilian Share (in 2018$) – The escalation of the commercial cost share allocation to constant 2018 dollars, based on an average annual inflation rate of 2% from 2007 to 2018 (BLS 2018)[4]. All line item costs are escalated by the same percentage.

[4] The average annual inflation rate from 2007 to 2018, calculated from annual inflation rates from the Bureau of Labor Statistics (BLS 2018), is approximately 2%.

Key components of the commercial share, which are lower than the full cost estimate include:

- Inventory is 109,300 MTHM of CSNF. Disposal is for 12,983 TAD-based waste packages. This includes 10,989 TADs loaded at utilities and shipped to repository and 1,994 TADs loaded at repository. For the TADs loaded at the repository 1,410 come from 920 DPCs shipped from the utility sites (~1.53 TADs/DPC) and 584 come from spent fuel in other types of containers (e.g., casks of uncanistered "bare" fuel) shipped from the utility sites.
- Transportation includes 11,909 shipments – The commercial allocation for transportation costs is assumed to be based on the rail shipments (10,989 TADs and 920 DPCs). A shipment consists of one loaded canister (TAD or DPC) in a cask/overpack transported on a single rail car.

Table A-1. Summary of TSLCC Costs ($Billions)

COST ELEMENT		TSLCC [a] TOTAL (2007$)	TSLCC [b] CIVILIAN SHARE (2007$)	TSLCC [c] CIVILIAN SHARE (2018$)
REPOSITORY COSTS	**Development and Evaluation (1983-2002)**	**8.330**	**6.514**	**8.099**
	Engineering, Procurement, and Construction (2003-2053)	**18.130**	**14.178**	**17.628**
	Licensing	2.340	1.830	2.275
	Initial TAD and Waste Package (WP) Procurement	0.240	0.188	0.233
	Surface and Subsurface Construction	15.550	12.160	15.120
	Repository Emplacement Operations (2017-2073)	**26.730**	**20.903**	**25.990**
	Waste Package (WP) Fabrication	12.580	9.838	12.232
	Surface and Subsurface Operations	9.580	7.492	9.315
	Performance Confirmation	1.680	1.314	1.633
	Regulatory, Infrastructure, and Management	2.890	2.260	2.810
	Monitoring (2074-2123)	**10.150**	**7.937**	**9.869**
	Drip Shield (DS) Fabrication and Emplacement	7.630	5.967	7.419
	Monitoring Activities	2.520	1.971	2.450
	Closure (2124-2133)	**1.390**	**1.087**	**1.352**
	REPOSITORY COSTS TOTAL	**64.730**	**50.619**	**62.938**
TRANSPORTATION COSTS	**Development and Evaluation (1983-2002)**	**0.640**	**0.490**	**0.610**
	Nevada Rail Infrastructure (2003-2017)	**2.690**	**2.062**	**2.563**
	National Transportation Project (2003-2073)	**16.920**	**15.207**	**18.908**
	TAD Canisters	9.589	9.589	11.922
	Operations	3.120	2.391	2.973
	Rail and Truck Casks and Overpacks	1.281	0.982	1.221
	Rolling Stock	0.280	0.215	0.267
	System Support and Maintenance	2.650	2.031	2.525
	TRANSPORTATION COSTS TOTAL	**20.250**	**17.759**	**22.081**
BALANCE OF PROGRAM COSTS	**Development and Evaluation (1983-2002)**	**2.300**	**1.849**	**2.299**
	Program Management (2003-2133)	**8.900**	**7.156**	**8.897**
	BALANCE OF PROGRAM COSTS TOTAL	**11.200**	**9.005**	**11.196**
TOTAL COSTS		***96.180***	***77.383***	***96.216***

Notes:

a Source is DOE 2008 (Tables 2-1 through 2-6 for Repository Costs; Tables 3-4, 3-6, and 3-7 for Transportation Costs; and Table 4-1 for Balance of Program Costs).

b Based on cost share allocations in DOE 2008, Table 5-2.

c Based on average annual inflation rate of 2% from 2007 to 2018 (BLS 2018).

Column totals may not add due to rounding

Table A-2. TSLCC Cost Elements

Cost Element	Description	Source
Repository Development and Evaluation	The historical costs, from 1983 to 2002, of evaluating multiple candidate sites in the 1980s, repository conceptual design and site characterization activities in the 1990s, through the approval by Congress of the Yucca Mountain Repository Site Recommendation in 2002.	(DOE 2008, Section 2.3.1)
Repository Engineering, Procurement, and Construction	The costs, from 2003 to 2053, of all activities necessary to design, license, and construct the geologic repository at Yucca Mountain. Licensing activities (license application preparation and interactions with the NRC), surface facility construction (infrastructure, waste handling buildings, and balance of plant), and subsurface construction (emplacement drifts) are the major contributors to cost. This cost element also includes the initial procurement of 35 TADs and disposal overpacks.	(DOE 2008, Section 2.3.2)
Repository Emplacement Operations	The costs, from 2017 to 2073, of surface (e.g., waste receipt and unloading, placement of waste canisters in disposal overpacks, and aging activities) and subsurface (e.g., waste emplacement) operations. Fabrication of 12,983 waste package overpacks is a line item in this cost element. Performance confirmation, site management and infrastructure, and safeguards and security activities are also included in this cost element.	(DOE 2008, Section 2.3.3)
Repository Monitoring	The costs, from 2074 to 2123, of gathering and analyzing data on repository performance as well as performing maintenance activities on the facilities. Fabrication and emplacement of drip shields is a significant cost contributor to this cost element.	(DOE 2008, Section 2.3.4)
Repository Closure	The costs, from 2124 to 2133, of decontaminating and decommissioning of surface facilities, backfilling shafts and ramps, permanently sealing the repository, and constructing monuments.	(DOE 2008, Section 2.3.5)
Transportation	The costs of historical development and evaluation (from 1983 to 2002), the Nevada Rail Infrastructure Project (from 2003 to 2017), and the National Transportation Project (from 2003 to 2073). The National Transportation Project includes acquisition of rail and truck cask systems, design and acquisition of rolling stock; national institutional activities, systems operations, physical security systems, and project management. The cost of TAD canisters is a significant cost contributor to the National Transportation Project.	(DOE 2008, Section 3.3)
Balance of Program	The costs include quality assurance, waste management, program management, and other miscellaneous costs.	(DOE 2008, Section 4.1)

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APPENDIX B – ALTERNATIVE SCENARIOS

The Reference Case (Scenario 1), described in Section 2, provides cost estimates for what might have been had the Yucca Mountain project proceeded as planned, with initial waste receipt and start of emplacement operations in 2017. The future alternative scenarios, described in Section 3, comprise a range of possible combinations of the timing, options, and costs for waste packaging, storage, transportation, and disposal. The alternative scenarios are constructed around three representative dates for the first receipt of spent fuel at the repository: 2031, which corresponds to an early date for the opening of Yucca Mountain should licensing activities resume immediately (Scenario 2); 2041, which represents an additional ten-year delay in restarting Yucca Mountain (Scenario 3); and 2117, which represents a 100-year delay in the repository program (Scenario 4).

Variants to the alternative scenarios examine the relative cost impacts of various decisions regarding repackaging of spent fuel from DPCs into TAD canisters and/or modifying repository operations (and licensing requirements) to allow for direct disposal of DPCs without repackaging. Cost impacts of having a federal CIS facility available in 2025 (thereby reducing Judgment Fund liabilities) are also considered.

Table 3-1 summarizes the alternative scenarios and their variants. Table B-1 provides supporting details of the alternative scenarios, with a focus on the timing (dates and durations) and canister counts (DPCs and TADs) of specific activities. In some cases, the information derives from input parameters and calculations documented in Appendix C.

Table B-1. Details of Scenarios and Variants

	Scenario	Quantity of CSNF (MTHM)	TAD Loading Start Date	Final DPC Disposition	Taxpayer Liability for DPCs End Date	Taxpayer Liability for ISFSIs End Date	Number of DPCs Loaded by Utilities	Number of TADs Loaded by Utilities	ISFSIs at Operating Reactor Sites	ISFSIs at Shutdown Reactor Sites	Number of Rail Shipments	DPCs Repackaged to TADs	DPC Shells for LLW Disposal	Disposal of Repackaged "Bare" Fuel	Total TADs for Disposal	Total DPCs for Disposal
Disposal at Yucca Mountain in 2017 (Reference Case)																
1	**YM Baseline (Adjusted TSLCC)** • Start loading TADs in 2011 • Repackage DPCs at repository	109,300	2011	Repackaged at repository	2011	2027	1,224	10,524	67	7	11,748	1,224 DPCs to 1,875 TADs at repository	1,224 at repository	584 TADs	12,983	0
Disposal at Yucca Mountain in 2031																
2	**YM Delayed to 2031** • Start loading TADs in 2025 • Repackage DPCs at repository	109,300	2025	Repackaged at repository	2025	2041	3,900	6,423	46	28	10,323	3,900 DPCs to 5,976 TADs at repository	3,900 at repository	584 TADs	12,983	0
2A	**Variant of Scenario 2** • Repackage DPCs at utility sites	109,300	2025	Repackaged at utility sites	2025	2041	3,900	6,423	46	28	12,399	3,900 DPCs to 5,976 TADs at utility sites	3,900 at utility sites	584 TADs	12,983	0
2B	**Variant of Scenario 2** • Directly dispose DPCs loaded ≤ 2025	109,300	2025	Disposed at repository	2025	2041	3,900	6,423	46	28	10,323	0	0	584 TADs	7,007	3,900
2C	**Variant of Scenario 2B** • Continue loading DPCs ≥ 2025 • Larger DPCs ≥ 2025 • Directly dispose DPCs loaded ≤ 2043	109,300	N/A	Disposed at repository	2043	2041	7,305	0	46	28	7,305	0	0	344 DPCs	0	7,649
2D	**Variant of Scenario 2** • CIS available in 2025 • Store DPCs and TADs at CIS	109,300	2025	Repackaged at repository	2025	2035	3,900	6,423	55	19	20,646 (10,323 to CIS; 10,323 to repository)	3,900 DPCs to 5,976 TADs at repository	3,900 at repository	584 TADs	12,983	0
Disposal at Yucca Mountain (YM) in 2041																
3	**YM Delayed to 2041** • Larger DPCs ≥ 2025 • Start loading TADs in 2035 • Repackage DPCs at repository	109,300	2035	Repackaged at repository	2035	2051	5,812	2,534	31	43	8,346	5,812 DPCs to 9,865 TADs at repository	5,812 at repository	584 TADs	12.983	0
3A	**Variant of Scenario 3** • CIS available in 2025 • Store DPCs and TADs at CIS	109,300	2035	Repackaged at repository	2035	2035	5,812	2,534	55	19	16,692 (8,346 to CIS; 8,346 to repository)	5,812 DPCs to 9,865 TADs at repository	5,812 at repository	584 TADs	12.983	0
Disposal at Yucca Mountain (YM) in 2117 (Extended Storage)																
4	**YM-Like Repository in 2117** • Continue loading DPCs ≥ 2025 • Larger DPCs ≥ 2025 • Repackage DPCs at repository	109,300	N/A	Repackaged at repository	2043	2127	7,305	0	0	74	7,305	7,305 DPCs to 12,399 TADs at repository	7,305 at repository	584 TADs	12.983	0
4A	**Variant of Scenario 4** • Directly dispose DPCs loaded ≤ 2043	109,300	N/A	Disposed at repository	2043	2127	7,305	0	0	74	7,305	0	0	344 DPCs	0	7,649
4B	**Variant of Scenario 4** • CIS available in 2025 • Store DPCs and TADs at CIS	109,300	N/A	Repackaged at repository	2043	2035	7,305	0	55	19	14,610 (7,305 to CIS; 7,305 to repository)	7,305 DPCs to 12,399 TADs at repository	7,305 at repository	584 TADs	12.983	0

APPENDIX C – INPUT PARAMETERS AND COST CALCULATIONS

Table C-1 provides values, descriptions, and sources for input parameters used in the Reference Case scenario. Table C-1 also provides formulas that show how the individual cost components are calculated from the input parameters. This same information is also used for cost calculations for the alternative scenarios. Differences in parameters between scenarios are noted, where applicable.

Table C-1. Input Parameters for Cost Estimates

Row No.	Parameter	Value for Scenario 1 (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
	SNF Inventory and Repository Parameters				
A	SNF Inventory (MTHM)	109,300	The TSLCC SNF inventory, which is used as the baseline for this cost evaluation.	DOE 2008, Table A-2	N/A
B	Total number of assemblies	387,758	Calculated based on the total number of TADs and their capacity (21 PWR or 44 BWR). The TSLCC assumed there were 7,978 PWR TADs and 5,005 BWR TADs.	DOE 2008, Table A-2	B = 7,978 * 21 + 5,005 * 44
C	Average MTHM per assembly	0.28	Calculated based on total SNF inventory and total number of assemblies.	N/A	C = A / B
	Facility, siting, licensing and construction, operations, and balance costs				
D	Cost of a federal CIS facility	$0	The CIS cost includes cost of design, construction, staging pads, overpacks, storage modules, maintenance, operations, and security. Transportation costs (to and from the CIS site) are not included. The CIS scenarios include CIS facility operations starting in 2025, the operational cost assumes a CIS facility lifetime with ISFSIs (i.e., 40-year initial license). For Scenarios including CIS, the 40-year cost is $11,142,684,000.	Jarrell et al. 2015, Figure 36	N/A
E	Transportation (Excluding cost of TADs)	$10,159,182,945	A description of these costs is provided in Table A-2. The cost of TADs is not included in these costs. The total transportation cost in the TSLCC is $20.25 billion (2008$). The fraction for commercial SNF from the TSLCC is 0.877.	DOE 2008, Section 3.3.1 and Table 5-2.	E = 20,250,000,000 * 0.877 – 9,588,594,650

Row No.	Parameter	Value for Scenario 1 (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
	DPC Parameters				
F	Number of DPCs filled per year	191	Calculated based on the number of DPCs filled from 2011 to 2017	N/A	F = (H – G) / (2017 – 2011)
G	Number of loaded DPCs in 2011	1,224	Number of DPCs (does not include metal casks)	StoreFuel 2011.	N/A
H	Total number of DPCs loaded as of 2017	2,371	Number of DPCs (does not include metal casks)	StoreFuel 2017.	N/A
I	Capacity of PWR DPC (assemblies)	32	Average number of PWR assemblies for currently loaded DPCs. For scenarios in which DPCs are loaded after 2025, the average PWR DPC capacity is assumed to be 34.5 (average of 32 and 37).	N/A	N/A
J	Capacity of BWR DPC (assemblies)	68	Average number of BWR assemblies for currently loaded DPCs. For scenarios in which DPCs are loaded after 2025, the average BWR DPC capacity is assumed to be 78.5 (average of 68 and 89).	N/A	N/A
K	Capacity per DPC, MTHM	12.90	Calculated based on TAD capacity (MTHM/TAD) and number of TADs per DPC. For scenarios in which DPCs are loaded after 2025, the capacity per DPC, in terms of MTHM, is 14.29	N/A	K = P * S
L	Last year of loading DPCs	2011	The projected date for the start of loading TADs and the end of loading DPCs.	DOE 2007, Section D.2.2.4	N/A
M	Number of DPCs as of last year DPCs are loaded	1,224	Calculated based on number of DPCs in 2011, number of DPCs filled per year, and last year of loading DPCs based on scenario description.	N/A	M = G + (L – 2011) *FG Note that the entire inventory of 109,300 MTHM will be in DPCs by 2043. Therefore, for scenarios that extend beyond this date (e.g., 2117), the last year of loading DPCs is fixed to 2043.

Row No.	Parameter	Value for Scenario 1 (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
	TAD Parameters				
N	Capacity of PWR TAD	21	PWR TAD capacity based on TSLCC	N/A	N/A
O	Capacity of BWR TAD	44	BWR TAD capacity based on TSLCC	N/A	N/A
P	Capacity of a TAD, MTHM	8.42	Calculated based on SNF inventory and total number of TADs (12,983)	N/A	P = A / 12,983
Q	Fraction of PWR TADs	0.61	Calculated based on PWR and BWR TAD counts (7,978 PWR TADs)	DOE 2008, Table A-2	Q = 7978 / (7,978 + 5,005)
R	Fraction of BWR TADs	0.39	Calculated based on PWR and BWR TAD counts (5,005 BWR TADs)	DOE 2008, Table A-2	R = 5005 / (7,978 + 5,005)
S	Number of TADs per DPC	1.532	Calculated based on DPC capacity to TAD capacity averaged for PWR and BWRs canister fractions.	N/A	S = (I / N) * Q + (J/ O) * R
T	Total number of TADs	12,983	Total Number of TADs in TSLCC.	DOE 2008, Table A-2	T = 12,983 for scenarios that do not involve disposal of SNF in DPCs T = (A – K * M) / P for scenarios that involve disposal of SNF in DPCs T = 0 for scenarios that do not involve disposal of SNF in TADs.
U	TAD Canister cost	$918,294	Cost of TAD including materials and fabrication.	DOE 2008, Table 3-7	N/A
V	Total Cost of TADs	$11,922,212,241	Calculated based on total number of TADs and TAD canister cost.	N/A	V = T * U
W	Number of TADs transported to repository	10,524	Calculated based on the difference between the total number of TADs and those loaded at the repository.	N/A	W = T - Z
X	Number of TADs needed to dispose of SNF currently stored in bare fuel casks	584	Calculated by subtracting the number of TADs transported to Yucca Mountain and the number of TADs to be loaded from the DPCs transported to Yucca Mountain from the total number of DPCs expected to be disposed of.	DOE 2008, Table A-2	X=7978 + 5005 – 10989 - (920 * S)

Row No.	Parameter	**Value for Scenario 1** (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
Y	Number of DPCs needed to dispose of SNF currently stored in bare fuel casks	0	Calculated based on the number of TADs needed to dispose of SNF currently stored in bare fuel casks divided by the TAD/DPC capacity ratio averaged for PWR and BWR canisters. Used in Scenarios 2C and 4A.	DOE 2008, Table A-2	Y=X / S for scenarios 2C and 4A Y = 0 for all other scenarios
Z	Number of TADs loaded at repository	2,459	Calculated based on the SNF delivered to the repository in DPCs and number of TADs per DPC. Based on the TSLCC bases (i.e., 920 DPCs), assumed capacity per DPC (32 PWR OR 68 BWR), 4.5% of the TADs are calculated to be loaded at the repository with SNF delivered in bare fuel casks, which totals 584 TADs.	DOE 2008, Table A-2	X = 584 + M * S for scenarios that involve disposal of SNF in TADs Z = 0 for Scenarios 2C and 4A
	Packaging / Repackaging Costs				
AA	Cost of loading or unloading operations per canister (TAD or DPC).	$450,000	This cost element takes into account the operations associated with preparing a canister for loading into the pool, transfer of assemblies into the canister, removal from the pool, draining, drying, backfilling, welding, and transfer to ISFSI. This cost element is independent of canister capacity because most of the time-consuming operations are not associated with assembly movements. The unloading operations cost per canister, which includes retrieval from storage, cutting lid, cooling, flooding, and unloading of assemblies, is assumed to be similar to loading operations cost. The value used is a rounded average from the provided sources.	*Energy Northwest v. United States,* 2010 Entergy 2007 EPRI 2012	N/A.
AB	Cost of storage overpack (for TAD or DPC)	$350,000	The cost element is used regardless of canister type or capacity. The value used is a rounded average from the provided sources.	*Energy Northwest v. United States,* 2010 Entergy 2007 EPRI 2012	N/A

Row No.	Parameter	Value for Scenario 1 (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
AC	Cost of transferring a canister (TAD or DPC) from storage to a transportation overpack.	$100,000	Takes into account removal of a canister from a storage overpack and loading it into a transportation cask, loading of the cask onto a railcar, and preparation for transportation.	Entergy 2007	N/A
AD	Percentage of TADs staged at ISFSIs prior to transportation to repository or CIS	50%	This value is the assumed fraction of TADs that are staged at an ISFSI requiring an overpack prior to transportation.	N/A	N/A
AE	Cost of loading TADs at utility sites	$7,103,459,556	Calculated based on the number of TADs transported to the repository, the cost of loading TADs at utility sites, cost of staging a fraction of the TADs at utility sites, and cost of removal of staged TADs from utility ISFSIs for transportation.	N/A	AE = W * AD * (AA + AB + AC) + W * (1 – AD) * AA
AF	Repository packaging/repackaging cost beyond what is currently assumed in the TSLCC	$346,087,371	Calculated based on the number of unloaded DPCs and loaded TADs at the repository beyond what is currently assumed in the TSLCC (920 DPCs and 1994 TADs) taking into account unloading and loading costs and DPC capacity.	N/A	AF = (Z – 1994) * AA + ((Z – 1994) / S) * AA
AG	Utility DPC repackaging cost	$0	Calculated based on the number of DPCs as of the last year DPCs are loaded and repackaging cost.	N/A	AG = M * AA
	Transportation Cost				
AH	Total rail shipments to the repository	11,748	Calculated based on the total number of DPCs and TADs loaded at utility sites	N/A	AH = M + W
AI	Cost per rail cask shipment	$853,139	Calculated based on the TSLCC transportation cost and total number of assumed rail shipments (920 DPCs + 10989 TADs).	N/A	AI = E / (10,989 + 920)
AJ	Cost per MTHM for DPC shipments	$66,140	Calculated based on the cost per rail shipment and the average MTHM inventory in a DPC.	N/A	AJ = AI / K
AK	Cost per MTHM for TAD shipments	$101,339	Calculated based on the cost per rail shipment and the average MTHM inventory in a TAD.	N/A	AK = AI / P

Row No.	Parameter	**Value for Scenario 1** (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
AL	Total transportation cost	$10,144,776,755	Calculated based on the cost per rail shipment per MTHM for TADs and DPCs, and the number of shipments to the repository and CIS (for this scenario the number of shipments is doubled), and cost of removal of DPCs from ISFSI sites for transportation (this cost is not applicable to removal of DPCs and TADs from a CIS site).	N/A	AL = AJ * K * M + AK * P * W + M * AC
	Judgment Fund (Taxpayer) Liability				
AM	Number of ISFSI-only sites	7	Number of ISFSIs at shutdown reactor sites subject to payments from the Judgment Fund. Sites that are operated by the DOE and Private Fuel Storage are not included in this total. It is assumed that by 2060 all ISFSIs will be at shutdown reactor sites. The specific number for the various scenarios is determined based on a rate of 1.5 reactor shutdowns/year (67/(2060-2017)), continuing until 10 years after the repository becomes available or 10 years after the CIS opens.	NRC website (ML18102B087)	AM = 7 + (AQ – 2027) * 1.5
AN	Number of ISFSIs at reactor sites	67	Number of ISFSIs at operating reactor sites. It is assumed that by 2060 all ISFSIs will be at shutdown reactor sires. It is also assumed that the three sites in the cited source that have not yet declared their intentions will operate an ISFSI under a general license. The specific number for the various scenarios is determined based on a rate of 1.5 reactor shutdowns/year (67/(2060-2017)), continuing until 10 years after the repository becomes available or 10 years after the CIS opens.	NRC website (ML18102B087)	AN = 74 - AM

Row No.	Parameter	**Value for Scenario 1** (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
AO	Annual operations cost for ISFSI-only sites	$5,000,000	This cost takes into account administrative and relatively minimal aging management costs. Costs associated with significant remediation or replacement (e.g., replacement of overpacks or repackaging the SNF) are not anticipated. Given the varying estimates in the various source documents, a mid-range value of $5 million/year is assumed. Jarrell et al. 2015, Table C-1 provides a value of $10 million; the source of information is vendor elicitation. GAO 2014 provides a range of $2.5 to $6.5 million.	Jarrell et al. 2015, Table C-1 GAO 2014	N/A
AP	Annual operations cost for ISFSI at reactor site	$1,240,000	This cost takes into account administrative and relatively minimal aging management costs. The range varies widely between $212,000 and $2 million based on several sources. The value chosen is an average taken from EPRI 2012 with 2% inflation per year.	EPRI 2012	N/A
AQ	Average last year of ISFSI Operations	2027	This date assumes that the Judgment Fund would provide for ISFSIs operations 10 years after repository or CIS availability.	N/A	AQ = Date of Repository or CIS Availability + 10 years
AR	Total Judgment Fund liability as of 2017	$7,038,000,000	The amount paid as of September 30, 2017, under settlements and as a result of final judgments.	DOE 2017, page 78.	N/A
AS	Judgment Fund liability beyond 2017	$1,180,800,000	This liability is calculated based on two parameters. The first is based on the loading of additional DPCs, which is determined by extrapolating the judgment fund obligation at the end of 2017 taking into account the total number of DPCs loaded at that time, and the annual DPC loading rate. The second is based on the annual maintenance cost of the ISFSIs.	N/A	AS = AM * AO * (AQ – 2017) + AN * AP * (AQ – 2017) + (((L – 2017) * F) / H) * AR Note that L cannot be less than 2017.
AT	Total Judgment Fund liability	$8,218,800,00	This is the sum of the Judgment Fund already obligated and future liability.	N/A	AT = AR + AS

Row No.	Parameter	Value for Scenario 1 (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
	LLW Disposal Cost				
AU	LLW volume for a DPC (m^3)	12.00	This is estimated based on the size of a typical DPC (diameter 68 in., length 190 in.)	ATI-TR-13047 2013.	N/A
AV	LLW disposal cost (per m^3)	$14,600	The estimated cost for LLW near surface disposal ranges between $1,250 and $2,500/m3 in 2006. The estimated cost for debris characterization, packaging and treatment, which may be assumed for the DPC disposal, is $9,000/m3.	Shropshire et al. 2009, Table J-7 for disposal, and Section G3-8 for characterization, packaging and treatment.	N/A
AW	Total LLW Disposal Cost	$214,444,800	Calculated based on the total volume of repackaged DPCs and the disposal cost per ft^3.	N/A	AW = M* AM * AV Note that AW is 0 for scenarios that involve disposal of SNF in DPCs.
	Inflation Rate				
AX	Annual inflation rate	2.00%	Assumed.	N/A	N/A
	DPC costs				
AY	DPC modification cost to facilitate disposal (per DPC)	$100,000	Assumed based on potential use of fillers for existing DPCs and/or modification of future DPCs. The range of values include $0 if direct disposal of DPCs could be facilitated via analysis, $100,000 if simple fillers are used through ports/siphon tubes (or future DPCs are modified to include corrosion resistant neutron absorbers), and $200,000 as an upper limit.	N/A	N/A
AZ	DPC modification cost to facilitate disposal (all DPCs)	$0	Calculated based on the cost per DPC and the total number of disposed DPCs.	N/A	AZ = 0 for scenarios that do not involve disposal of SNF in DPCs. AZ = M * AY for scenarios that involve disposal of SNF in DPCs.

Row No.	Parameter	Value for Scenario 1 (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
BA	Emplacement cost reduction (WP only)	$0	This cost delta takes into account the reduced number of disposal overpacks needed for DPC direct disposal scenarios. Note that there is no reduction in drip shield cost because the drift length needs, and associated drip shields, are a function of thermal load not number of waste packages. The Reference Case cost of disposal overpacks is $12.232 billion (see Row BH).	DOE 2008, Table 2-4 and Table 5-2	BA = 0 for scenarios that do not involve disposal of SNF in DPCs. BA = -BH * (1 – ((M + T) / 12983) for scenarios that involve disposal of SNF in DPCs.
BB	Total DPC direct disposal cost delta	$0	Calculated based on the sum of DPC modification to facilitate disposal and emplacement cost reduction.	N/A	BB = AZ + BA
BC	Years the CIS is operational	0	The CIS is assumed to operate until repository operations cease, which is 57 years after the repository opens.	DOE 2008, Section 2.2	BC = Date of Repository Availability + 57 - 2025
BD	Annual cost of operating a CIS after the first 40 years of operation	$5,000,000	The operational cost is included in the cost of a CIS facility (row D) for the first 40 years of operation. Annual operating costs after that are assumed to be similar to annual costs for an ISFSI-only site (row AO)	N/A	N/A
BE	Total cost of operating a CIS after the first 40 years of operation	0	Calculated based on the annual operating cost after the first 40 years.	N/A	BE = (BC – 40) * BD

Row No.	Parameter	Value for Scenario 1 (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
Common Costs					
BF	Repository Development and Evaluation	$8,099,414,847	A description of these costs is provided in Table A-2. The value used herein is obtained by multiplying the value of the parameter in Table 2-2 of the TSLCC ($8,330,000,000) by the percent of cost allocated to disposal of civilian waste (78.2%) and then adjusting for inflation.	DOE 2008, Table 2-2 and Table 5-2	N/A
BG	Repository Engineering, Procurement, and Construction of a Repository	$17,628,138,197	A description of these costs is provided in Table A-2. The value used herein is obtained by multiplying the value of the parameter in Table 2-3 of the TSLCC ($18,130,000,000) by the percent of cost allocated to disposal of civilian waste (78.2%) and then adjusting for inflation.	DOE 2008, Table 2-3 and Table 5-2	N/A
BH	Disposal Overpacks	$12,231,769,361	This represents the cost of fabricating waste package overpacks. The value used herein is obtained by multiplying the value of the parameter in Table 2-4 of the TSLCC ($12,580,000,000) by the percent of cost allocated to disposal of civilian waste (78.2%) and then adjusting for inflation.	DOE 2008, Table 2-4 and Table 5-2	N/A
BI	Repository Emplacement Operations	$13,758,309,735	A description of these costs is provided in Table A-2. Note that the cost of disposal overpacks has been subtracted from the value. The value used herein is obtained by multiplying the value of the parameter in Table 2-4 of the TSLCC ($14,150,000,000) by the percent of cost allocated to disposal of civilian waste (78.2%) and then adjusting for inflation.	DOE 2008, Table 2-4 and Table 5-2	N/A

Row No.	Parameter	Value for Scenario 1 (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
BJ	Repository Monitoring	$9,869,034,898	A description of these costs is provided in Table A-2. The value used herein is obtained by multiplying the value of the parameter in Table 2-5 of the TSLCC ($10,150,000,000) by the percent of cost allocated to disposal of civilian waste (78.2%) and then adjusting for inflation.	DOE 2008, Table 2-5 and Table 5-2	N/A
BK	Repository Closure	$1,351,523.006	A description of these costs is provided in Table A-2. The value used herein is obtained by multiplying the value of the parameter in Table 2-6 of the TSLCC ($1,390,000,000) by the percent of cost allocated to disposal of civilian waste (78.2%) and then adjusting for inflation.	DOE 2008, Table 2-6 and Table 5-2	N/A
BL	Balance of Program Costs	$11,196,336,972	Cost of QA, Waste Management, Program Management, Benefits, etc. Cost of 35 TADs Canisters are included in this estimate. The value used herein is obtained by multiplying the value of the parameter in Table 4-1 of the TSLCC ($11,200,000,000) by the percent of cost allocated to disposal of civilian waste (78.2%) and then adjusting for inflation.	DOE 2008, Table 4-1 and Table 5-2	N/A
Totals					
BM	Total Cost	$112,084,307,741	Calculated based on the sum of the costs and deltas above and the common costs for all the scenarios (i.e., repository related costs).	N/A	BM= D + BF + BG + BH + BI + BJ + BK + BL + V + AE + AF + AG + AL + AT + AW + BB + BE For the long-term scenarios (i.e., 2117), an additional repository development cost, BA, is also added.

Row No.	Parameter	Value for Scenario 1 (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
Cost Elements					
BN	Cost Element: Transportation (Operations and Infrastructure)	$10,022,377,755	Cost of rail shipments to the repository and/or to a CIS site.	N/A	BN = AH * AI BN = 2 * AH * AI for the scenario with CIS
BO	Cost Element: TAD Canisters	$11,922,212,214	Cost of manufacturing TAD canisters	N/A	BO = V
BP	Cost Element: Repository Packaging	$2,043,167,085	Cost of repackaging SNF from DPCs to TADs at the repository and disposing of the resulting LLW.	N/A	BP = Z * AA + (Z/S) * AA + AF + AW for scenarios in which spent fuel is repackaged at the repository BP = Z * AA + (Z/S) * AA + AF for scenarios in which spent fuel is repackaged at the utilities.
BQ	Cost Element: Utility Packaging	$7,225,859,556	Cost of loading SNF from a pool into a TAD, cost of unloading SNF already stored in a DPC and loading it into a TAD, Cost of storage overpacks for TADs, and cost of transferring a TAD or a DPC from a storage cask to a transportation cask	N/A	BQ = M * AC + AE + AG For scenarios in which spent fuel is repackaged at the repository BQ = M * AC + AE + AG + AW For scenarios in which spent fuel is repackaged at the utilities
BR	Cost Element: Taxpayer Liability	$8,218,800,000	Payments from the Judgment Fund to utilities	N/A	BR = AT
BS	Cost Element: Repository Disposal	$12,231,769,361	Cost of modifying DPCs to facilitate disposal and cost of disposal overpacks (waste packages).	N/A	BS = BH + BB
BT	Cost Element: New Facilities	$0	Cost of a CIS facility (Scenario 2D) and cost of developing and evaluating a new repository (Scenario 4 and 4A). The cost of a CIS facility includes costs associated with the additional transfers of canisters from storage overpacks to transportation overpacks.	N/A	BT = D + W * AC + M * AC + BE (Scenarios 2D and 3A) BT = BF (Scenarios 4 and 4A) BT = D + W * AC + M * AC+ BE + BF (Scenario 4B)

Row No.	Parameter	**Value for Scenario 1** (All costs are in 2018$). Shaded values are the same for all scenarios.	Basis	Source	Formula
BU	Cost Element: Common Costs	$60,420,122,741	Costs that are common to all scenarios. Based on costs from the TSLCC, minus the costs associated with repackaging waste at the repository, which is scenario-specific. In the formula to the right, the "S" and "X" values are those from the Reference Case, regardless of the scenario.	N/A	BU = BF + BG + BI + BJ + BK + BL – (Z * AA + (Z/S) * AA)
Spending Categories					
BV	Spending Category: Taxpayer Liability	$8,218,800,000	Payments from the Judgment Fund to utilities	N/A	BV = AT
BW	Spending Category: Nuclear Waste Fund	$96,425,203,384	Activities funded by the Nuclear Waste fund	N/A	BW = BN + BO + BP – AW + BS + BT + BU
BX	Spending Category: Other	$7,440,304,356	Activities for which it is not clear whether they would be paid for by the Nuclear Waste Fund or the Judgment Fund.	N/A	BX = BQ + AW

APPENDIX D – EFFECTS OF UNCERTAINTY IN COST ANALYSES

The effects of uncertainty and/or variability in component costs on the total cost estimates were examined by varying parameters that serve as inputs to the seven potentially discriminating cost elements. Table D-1 shows the relationship between the seven potentially discriminating cost elements and the eleven parameters that contribute to those costs. Note that some of the parameters (e.g., cost of loading or unloading operation per canister, TAD or DPC) are included in more than one cost element, and some cost elements (e.g., utility packaging) are associated with several parameters.

Table D-1. Relationship Between Potentially Discriminating Cost Elements and Uncertain Parameters

Cost Element	Uncertain Parameter
Transportation cost	• Cost of rail cask shipment
TAD Canisters	• TAD canister cost for a single canister
Utility Packaging	• Cost of loading (TAD) or unloading (DPC) operations per canister • Cost of storage overpack (for TAD or DPC) • Cost of transferring a canister (TAD or DPC) from storage to a transportation overpack • Percentage of TADs staged at ISFSIs prior to transportation to repository or CIS site
Repository Packaging	• Cost of loading (TAD) or unloading (DPC) operations per canister • LLW disposal cost per used DPC
Repository Disposal	• Cost to modify DPCs to facilitate disposal
Taxpayer Liability	• Cost of loading operations per canister (DPC) • Annual operations cost per ISFSI-only site • Annual operations cost per ISFSI at operating reactor site
New Facilities	• Cost of a CIS facility

The effects of uncertainty in these eleven parameters was examined by assuming three different values for each parameter: a low estimate (LE), a nominal estimate (NE), and a high estimate (HE). These values are given in Table 4-4. The nominal estimate parameter values correspond to the values listed in Appendix C and used to calculate the cost estimates for the alternative scenarios in Section 4.1.

Figure D-1 through Figure D-10 show the results of this examination for the eight alternative scenarios and variants. In each figure, the cost of each cost element for the low estimate (LE) case, the nominal estimate (NE) case, and the high estimate (HE) case is shown for the given scenario and compared to the Reference Case costs.

As these figures demonstrate, costs associated with Transportation are approximately double between the LE and HE cases. This is because the cost of a rail cask shipment doubles between the LE and HE cases. Likewise, the costs associated with TAD canisters approximately doubles between the LE and HE cases for a given scenario because the HE cost to fabricate a TAD canister is approximately double that of the LE cost. The same is true for costs associated with Repository Packaging because the HE cost of loading or unloading operations per canister and the cost of LLW disposal is double their respective LE cost.

The costs associated with Utility Packaging approximately quadruple between the LE and the HE cases. This is because there are three uncertain costs associated with the Utility Packaging cost element (see Table D-1), all of which double between their LE and HE values. The costs associated with the Taxpayer Liability cost element increase by about 50% between the LE and HE cases, even though the variables associated with Taxpayer Liability (see Table D-1) vary by a factor of four, because the Taxpayer Liability cost element includes funds paid to utilities as of 2017, which is a fixed value.

The costs associated with Repository Disposal often are the same between the HE, LE, and NE cases because the uncertain parameter associated with that cost element, cost to modify DPCs to facilitate disposal, is used only when CSNF is disposed of in DPCs (Scenarios 2B, 2C, and 4A).

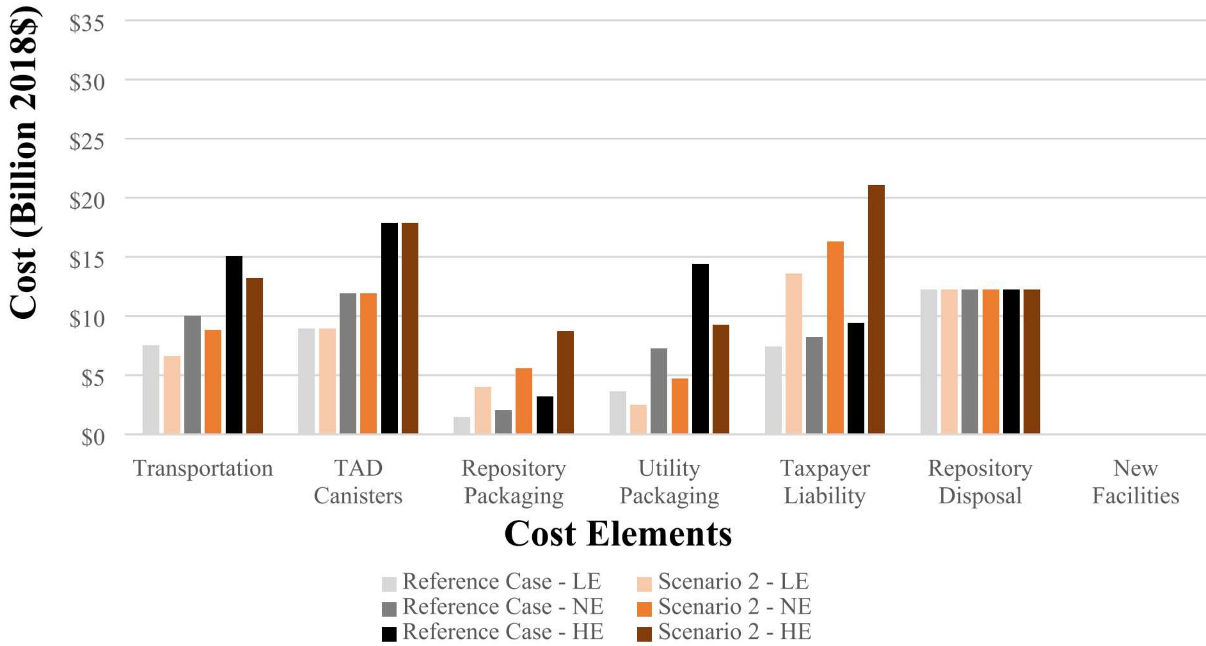

Figure D-1. Costs of the Low Estimate (LE), Nominal Estimate (NE), and the High Estimate (HE) for Reference Case and Scenario 2

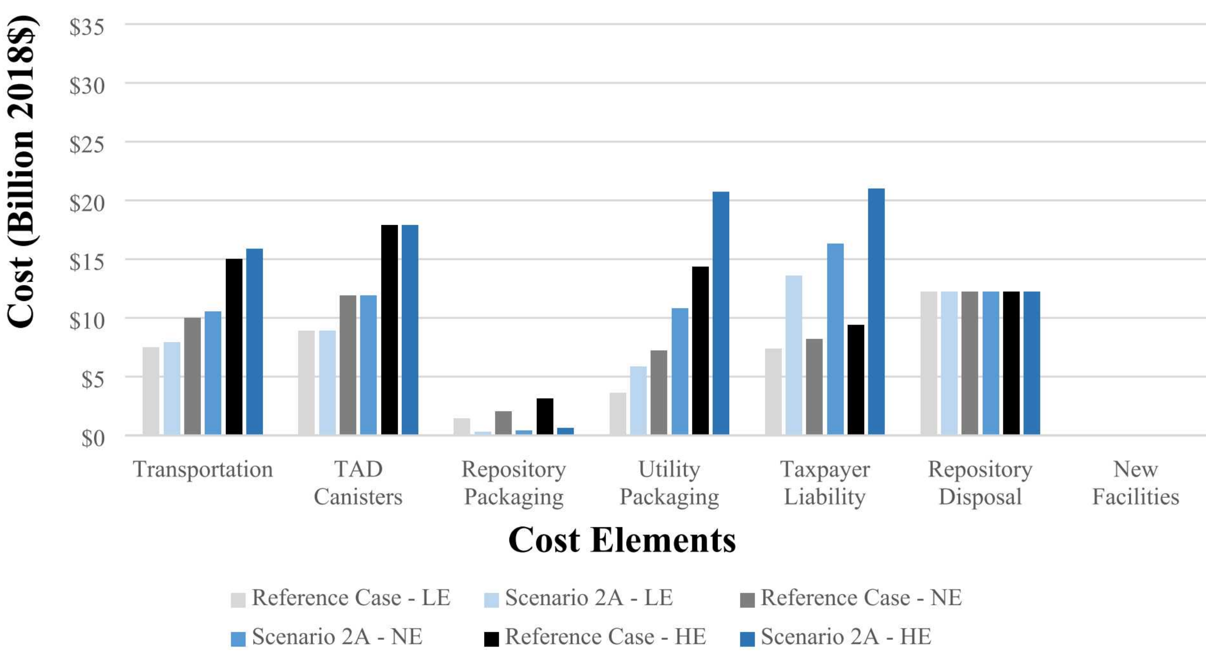

Figure D-2. Costs of the Low Estimate (LE), Nominal Estimate (NE), and the High Estimate (HE) for Scenario 1 (Reference Case) and Scenario 2A

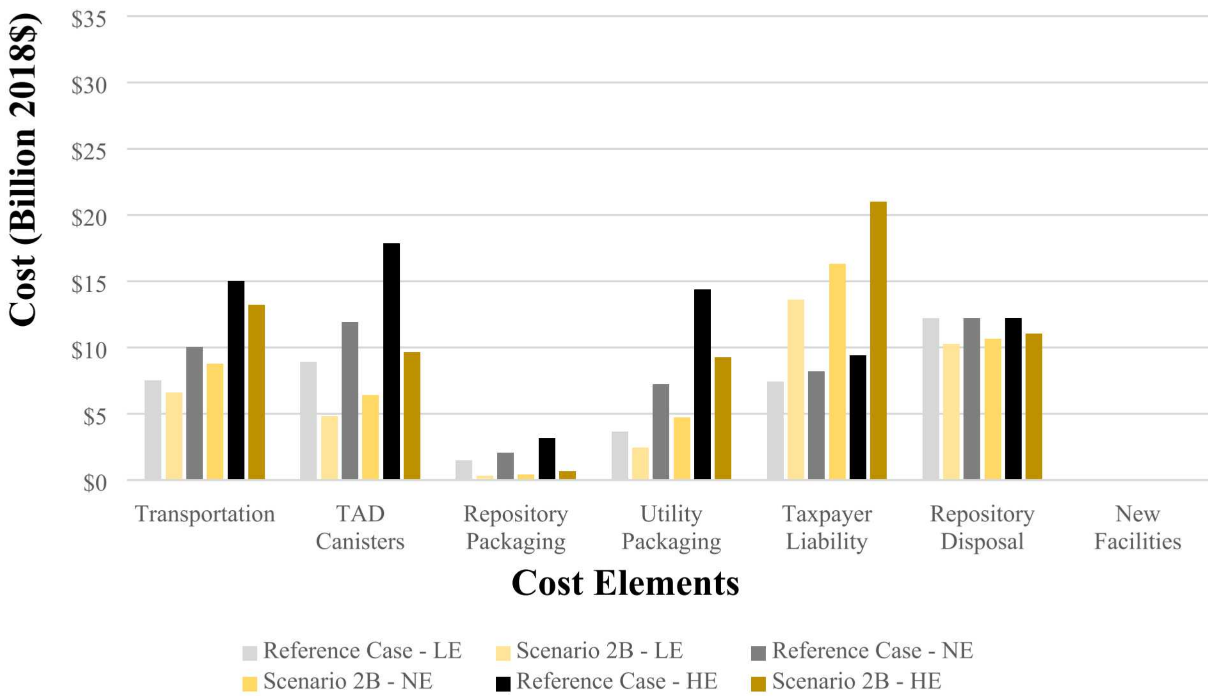

Figure D-3. Costs of the Low Estimate (LE), Nominal Estimate (NE), and the High Estimate (HE) for Scenario 1 (Reference Case) and Scenario 2B

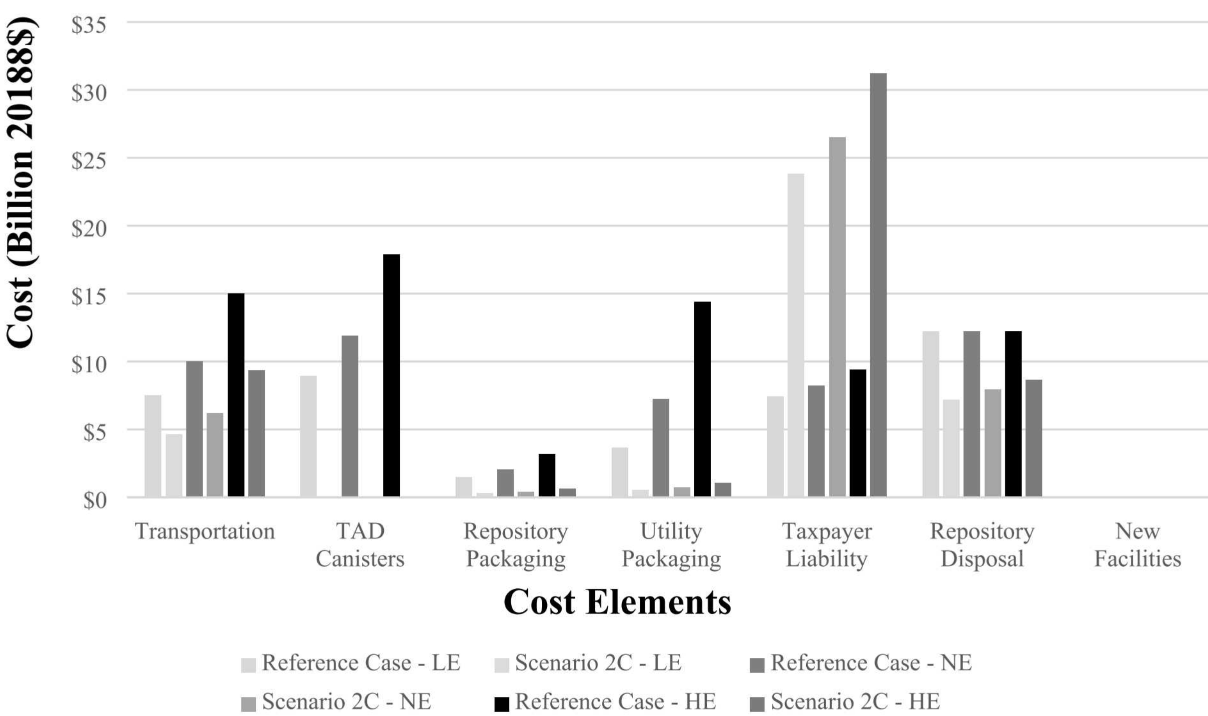

Figure D-4. Costs of the Low Estimate (LE), Nominal Estimate (NE), and the High Estimate (HE) for Scenario 1 (Reference Case) and Scenario 2C

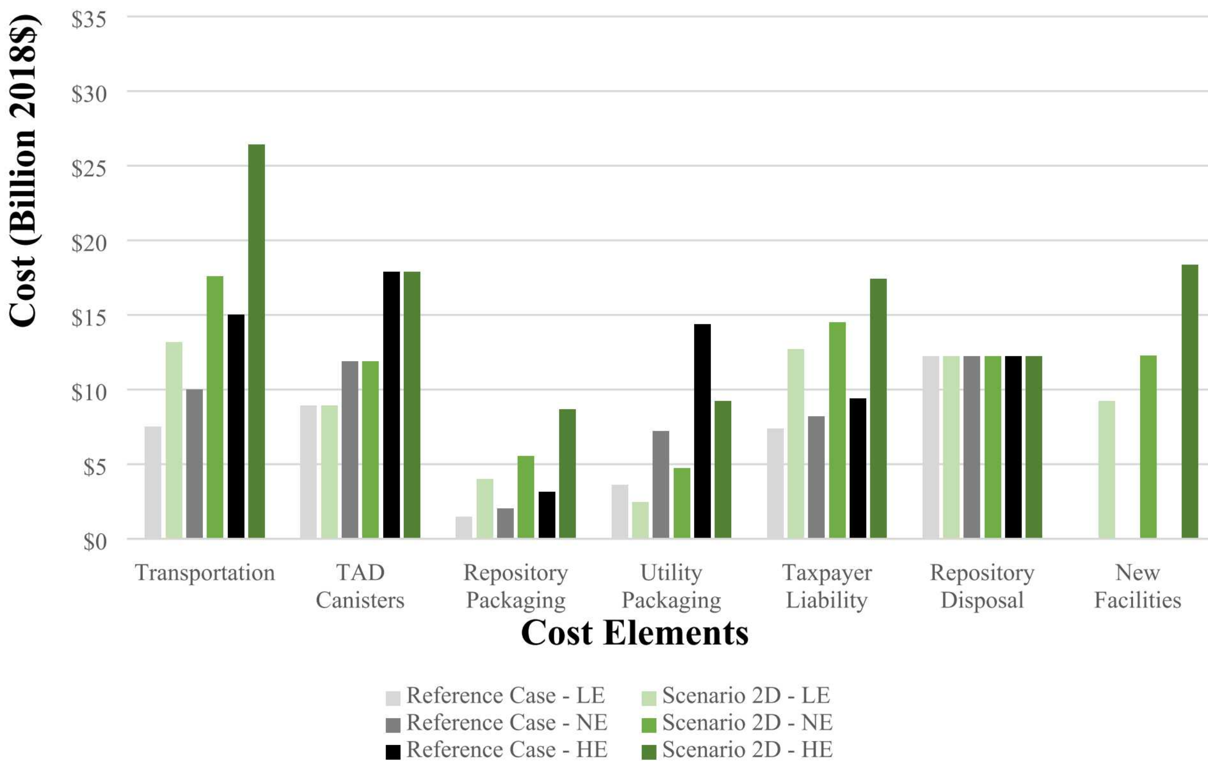

Figure D-5. Costs of the Low Estimate (LE), Nominal Estimate (NE), and the High Estimate (HE) for Scenario 1 (Reference Case) and Scenario 2D

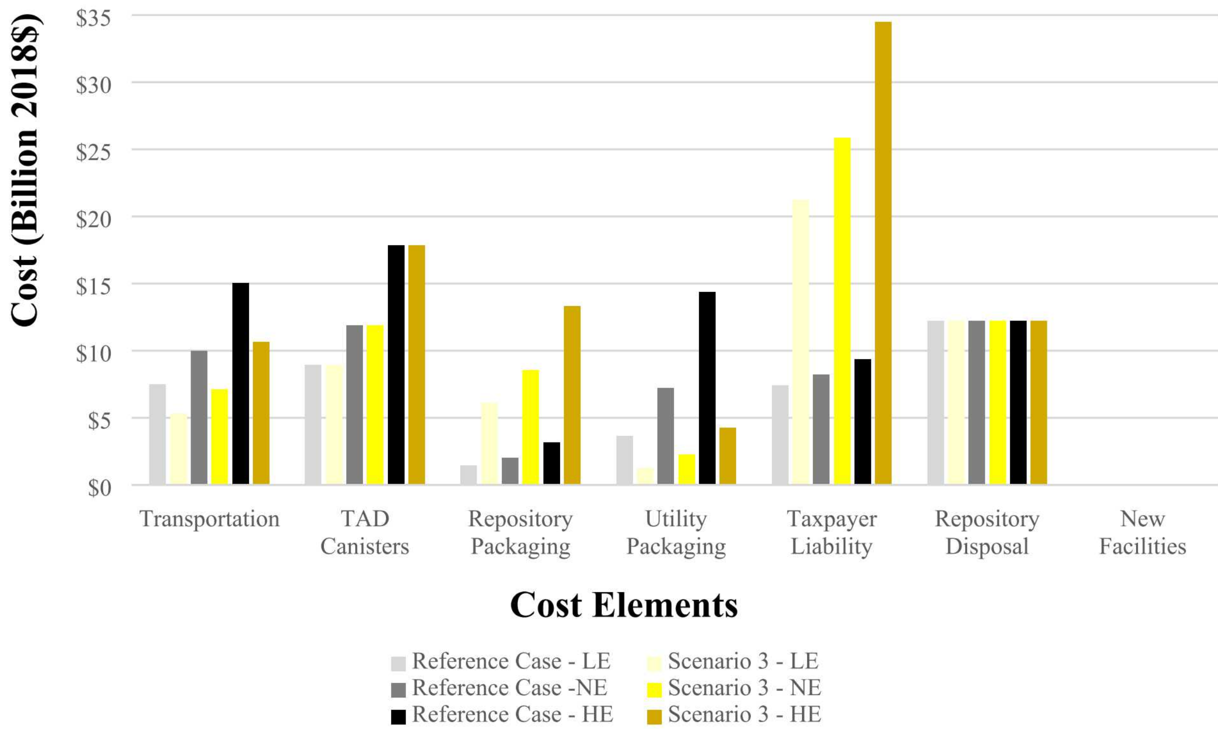

Figure D-6. Costs of the Low Estimate (LE), Nominal Estimate (NE), and the High Estimate (HE) for Scenario 1 (Reference Case) and Scenario 3

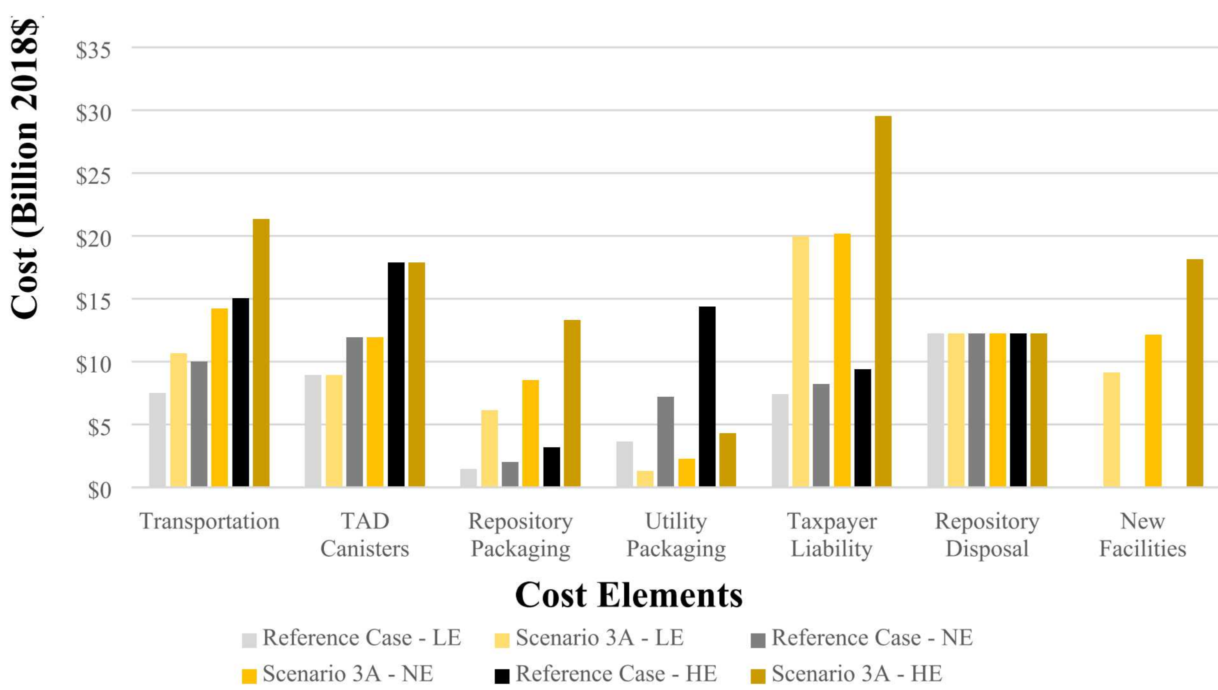

Figure D-7. Costs of the Low Estimate (LE), Nominal Estimate (NE), and the High Estimate (HE) for Scenario 1 (Reference Case) and Scenario 3A

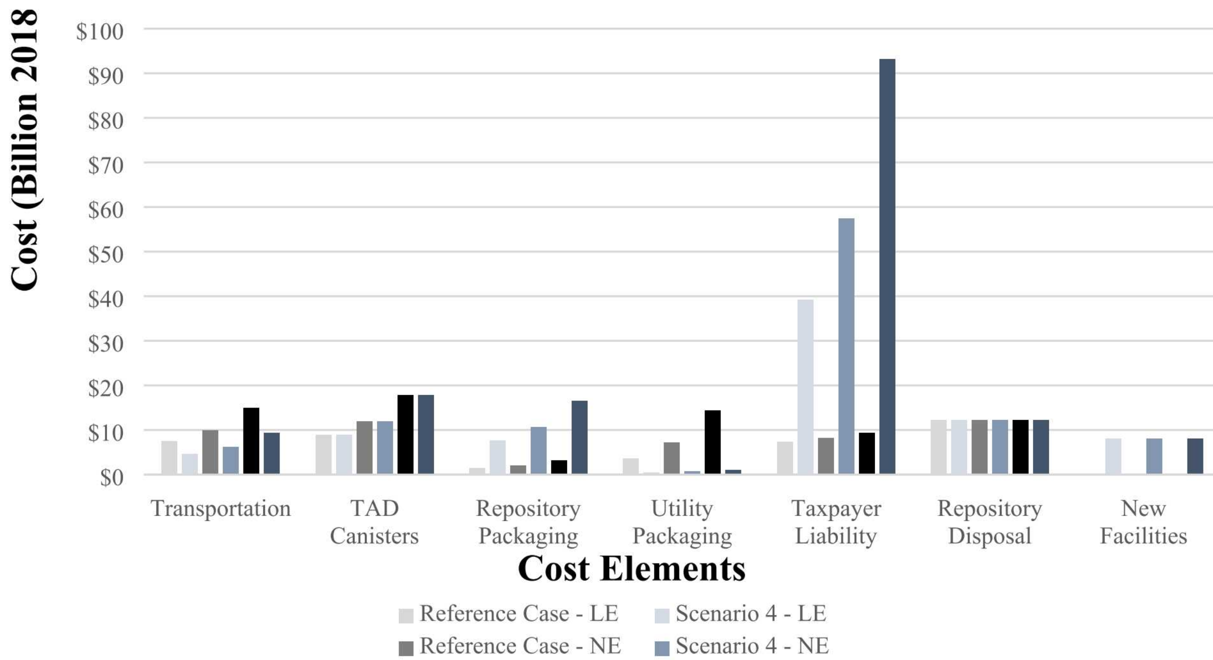

Figure D-8. Costs of the Low Estimate (LE), Nominal Estimate (NE), and the High Estimate (HE) for Scenario 1 (Reference Case) and Scenario 4

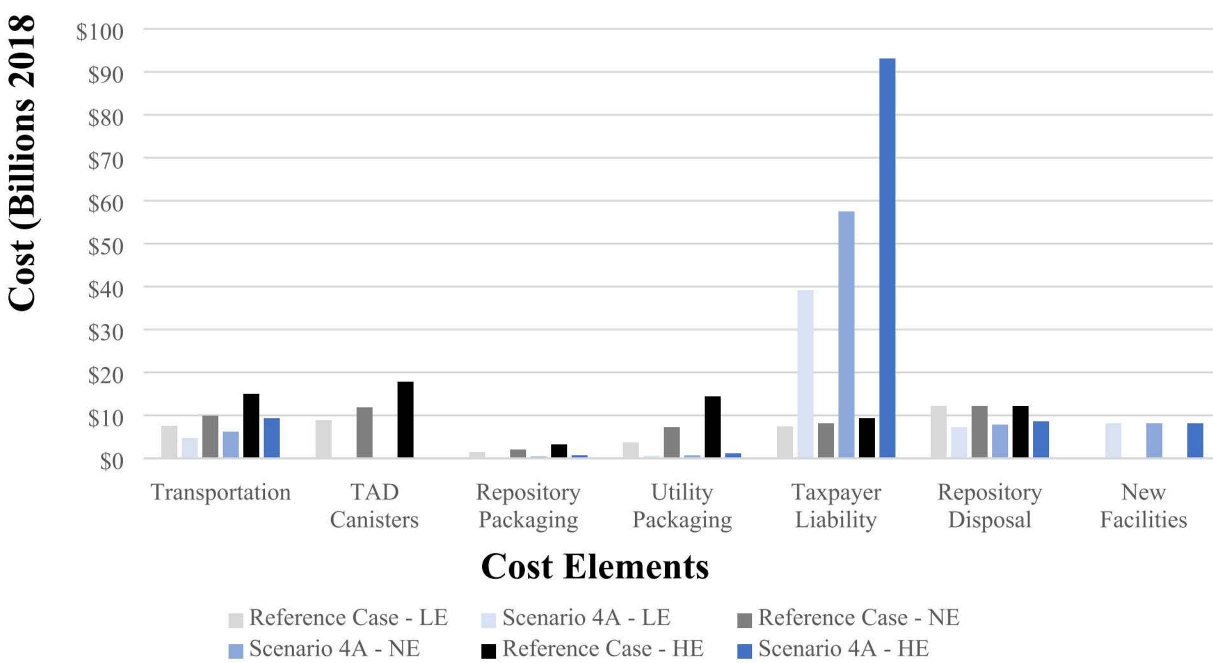

Figure D-9. Costs of the Low Estimate (LE), Nominal Estimate (NE), and the High Estimate (HE) for Scenario 1 (Reference Case) and Scenario 4A

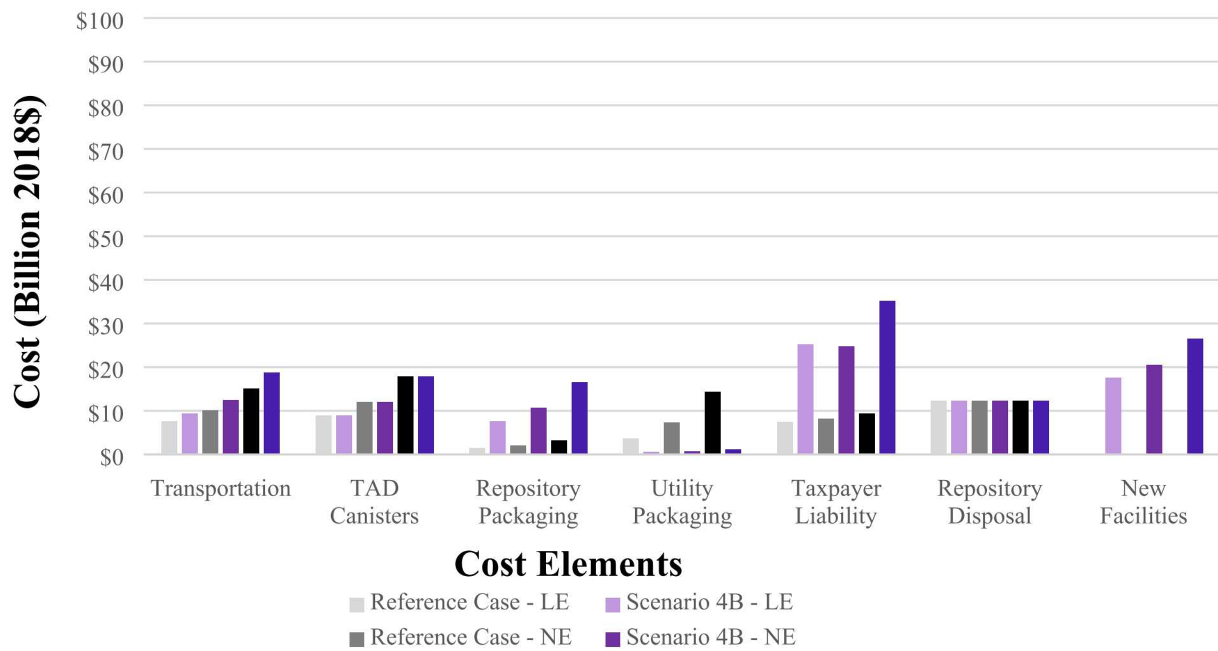

Figure D-10. Costs of the Low Estimate (LE), Nominal Estimate (NE), and the High Estimate (HE) for Scenario 1 (Reference Case) and Scenario 4B

APPENDIX E – ANALYSIS OF COSTS BY FUNDING SOURCE

Possible funding sources for the various cost elements include the Nuclear Waste Fund; Taxpayer Liability (Judgment Fund); and Other (not yet identified/allocated).

Payments from the Nuclear Waste Fund include the costs for the following activities: repository activities captured under the common costs (see Table 2-2), transportation operations and infrastructure, fabrication of TAD canisters, repackaging spent fuel into TADs at the repository, disposal overpacks for both DPCs and TADs, waste emplacement, modification of DPCs prior to disposal (e.g., add filler material to reduce the probability of criticality), and new facilities, such as a CIS facility or a new repository.

Taxpayer Liability includes the monies already paid to utilities (as of 2017) and the projected future costs to the utilities for maintaining ISFSIs, as paid through the Judgment Fund.

The Other category includes cost for the following activities: transferring DPCs from their storage overpacks at utilities to transport casks in preparation for transport to a repository or a CIS site, loading fuel into TADs, removing spent fuel from DPCs before repackaging the fuel into TADs at utility sites, and disposing of used DPC shells as LLW. These activities are in the Other category because it is not clear if they would be paid for by the Nuclear Waste Fund, or whether utilities would be reimbursed from the Judgment Fund for their expenses related to these activities.

A breakdown of the estimated costs for each scenario by funding source is shown in Table E-1. As shown in Table E-1, the primary funding source for all scenarios is the Nuclear Waste Fund. In Scenario 2, the costs paid by the Nuclear Waste Fund increase by just under $2 billion because of the increased number of DPCs containing fuel that has to be repackaged into TADs at the repository. This increase is somewhat offset by lower transportation costs, but not completely. Taxpayer liability, in the form of payouts from the Judgment Fund, increases by $8 billion because of the 14-year delay, compared to the Reference Case, in providing TADs to the utilities and the need for utilities to store spent fuel at their sites for a longer period of time. The primary Other cost in Scenario 2 is the cost of loading TADs at utility sites; this cost decreases by about $2 billion because there are fewer TADs compared to the Reference Case. Additional Other costs include disposal of used DPC shells as LLW, which increases slightly because there are more shells to be disposed of, and the transfer of DPCs from their storage casks to transportation casks, which also increases slightly because there are more DPCs to be transferred.

In Scenario 2A, the costs paid by the Nuclear Waste Fund decrease by less than $1 billion because repackaging fuel from DPCs to TADs occurs at utility sites, not at the repository. Only bare fuel is repackaged into TADs at the repository. Transportation costs increase somewhat because the fuel is transported to the repository in TADs. The savings from not repackaging at the repository are greater than the added expense of more shipments (compared to the Reference Case), so the overall effect is a slight reduction in the costs paid by the Nuclear Waste Fund. Costs to taxpayers for Scenario 2A are the same as for Scenario 2, and greater than those in the Reference Case for the same reasons. The costs of repackaging spent fuel from DPCs to TADs at utility sites and of disposing of the used DPC shells as LLW is shifted from the Nuclear Waste Fund to the Other category, so costs associated with the Other category increase by about $3 billion.

Table E-1. Estimated Costs and Funding Sources (Billions of 2018$)

Scenario Description	Total Cost	Costs Paid by Nuclear Waste Fund	Costs Paid by Judgment Fund (Taxpayer Liability)	Costs Paid by Other Source
Scenario 1: Disposal at Yucca Mountain in 2017				
Reference Case (Adjusted TSLCC) • Start loading TADs in 2011 • Repackage DPCs at repository • Judgment Fund (DPCs) to 2011 • Judgment Fund (ISFSIs) to 2027	$112.08	$96.43	$8.22	$7.44
Scenario 2: Disposal at Yucca Mountain in 2031				
Scenario 2 • Start loading TADs in 2025 • Repackage DPCs at repository • Judgment Fund (DPCs) to 2025 • Judgment Fund (ISFSIs) to 2041	$119.98	$98.26	$16.31	$5.41
Scenario 2A (Variant of Scenario 2) • Repackage DPCs at utility sites	$122.70	$95.59	$16.31	$10.81
Scenario 2B (Variant of Scenario 2) • Directly dispose DPCs DPCs loaded ≤ 2025	$107.79	$86.76	$16.31	$4.73
Scenario 2C (Variant of Scenario 2B) • Continue loading DPCs ≥ 2025 • Directly dispose of DPCs DPCs loaded ≤ 2043 • Judgment Fund (DPCs) to 2043	$102.27	$75.02	$26.52	$0.73
Scenario 2D (Variant of Scenario 2) • CIS available in 2025 • Store DPCs and TADs at CIS • Judgment Fund (ISFSIs) to 2035	$139.28	$119.36	$14.52	$5.41
Scenario 3: Disposal at Yucca Mountain in 2041				
Scenario 3 • Start loading TADs in 2035 • Repackage DPCs at repository • Judgment Fund (DPCs) to 2035 • Judgment Fund (ISFSIs) to 2051	$128.40	$99.22	$25.87	$3.31
Scenario 3A (Variant of Scenario 3) • CIS available in 2025 • Store DPCs and TADs at CIS • Judgment Fund (ISFSIs) to 2045	$141.99	$118.49	$20.19	$3.31
Scenario 4: Disposal at Yucca Mountain in 2117				
Scenario 4 • Continue loading DPCs ≥ 2025 • Extended storage • Repackage DPCs at repository • Judgment Fund (DPCs) to 2043 • Judgment Fund (ISFSIs) to 2127	$167.74	$108.25	$57.48	$2.01
Scenario 4A (Variant of Scenario 4) • Directly dispose of DPCs DPCs loaded ≤ 2043	$141.33	$83.12	$57.48	$0.73
Scenario 4B (Variant of Scenario 4) • CIS available in 2025 • Store DPCs at CIS • Judgment Fund (ISFSIs) to 2035	$153.64	$126.90	$24.73	$2.01

In Scenario 2B, Nuclear Waste Fund costs decrease by almost $10 billion compared to the Reference Case because there are fewer shipments of spent fuel, fewer TAD canisters are manufactured, only bare fuel is repackaged, and fewer disposal overpacks are manufactured. This leads to a decrease in Nuclear Waste Fund spending of almost $10 billion. Costs to taxpayers for Scenario 2B are the same as for Scenario 2, and greater than those in the Reference Case for the same reasons. Other costs in Scenario 2B are less than those in the Reference Case because less spent fuel is loaded into TADs, compared to the Reference Case.

In Scenario 2C, Nuclear Waste Fund costs drop by over $21 billion primarily because no TAD canisters are manufactured; bare fuel is disposed of in already-existing DPCs. Other cost reductions occur because most fuel is shipped in DPCs, no fuel is repackaged from a DPC to a TAD, and fewer disposal overpacks are required. Costs to taxpayers increase by about $18 billion because it is assumed that DPCs are loaded until 2043, 18 years longer than in the previous scenarios, and that Judgment Fund payouts continue until 2043. Other payments decrease significantly because TADs are not loaded at utilities and there are no LLW disposal costs. Costs for transferring DPCs to transport casks increase compared to the Reference Case because there are more DPCs, but this cost is more than offset by the savings from not loading TADs at utilities.

In Scenario 2D, Nuclear Waste fund costs increase by almost $23 billion primarily because of the additional costs associated with constructing and operating a federal CIS facility and with transporting the waste twice. In this scenario, more fuel is repackaged from DPCs into TADs, compared to the Reference Case, and this represents a secondary increase in cost from the Nuclear Waste Fund. Costs to taxpayers increase by about $6 billion, which is less of an increase than in the other scenarios, because the DOE is able to take title to the waste at the CIS facility earlier than in the other scenarios. Other costs decrease by about $2 billion primarily because there are fewer TADs to be loaded with spent fuel at utility sites compared to the Reference Case. Increased costs associated with transferring DPCs to transportation casks at utilities and LLW disposal are offset by the savings from loading fewer TADs with spent fuel at utility sites.

In Scenario 3, Nuclear Waste Fund costs increase by almost $3 billion because DPCs continue to be loaded until 2035 (DPCs are loaded until 2011 in the Reference Case and until 2025 in all Scenario 2 cases), thus requiring more repackaging of fuel from DPCs into TADs at the repository. The increase in cost associated with more repackaging is somewhat offset by decreased transportation costs because more fuel is transported in DPCs. Costs to taxpayers increase by over $17 billion because of the further delay in opening the repository (2041 vs. 2031 in Scenario 2 and its variants vs. 2017 in Reference Case). Other costs decrease by about $4 billion because fewer TADs are loaded with spent fuel at utility sites. Increased costs associated with transferring more DPCs to transportation casks and with having more LLW to dispose of are offset by the savings from loading fewer TADs with spent fuel at utility sites.

In Scenario 3A, Nuclear Waste Fund costs increase by just over $22 billion, primarily because of the additional costs associated with constructing and operating a federal CIS facility and with transporting the waste twice. As in Scenario 2D, more fuel is repackaged from DPCs into TADs compared to the Reference Case, and this represents a secondary increase in cost from the Nuclear Waste Fund. Costs to taxpayers increase by about $12 billion, which is less than the $17 billion increase in Scenario 3, but more than the $6 billion increase in Scenario 2D because

Judgment Fund payments end 10 years later in Scenario 3A than in Scenario 2D. Other costs decrease by about $4 billion primarily because there are fewer TADs to be loaded with spent fuel at utility sites compared to the Reference Case. Increased costs associated with transferring DPCs to transportation casks at utilities and LLW disposal are offset by the savings from loading fewer TADs with spent fuel at utility sites.

In Scenario 4, Nuclear Waste Fund costs increase by about $12 billion because utilities never stop using DPCs to store fuel, all of which is then repackaged into TADs at the repository, and because a new repository has to be sited, characterized, licensed, etc. Some of this increase is offset by the lower cost of transporting fuel in DPCs rather than in TADs. Costs to taxpayers increase by almost $50 billion because of the significant delay in opening the repository. Other costs decrease by about $5 billion because utilities do not load fuel into TADs, which more than offsets cost increases due to transferring DPCs to transportation casks at utilities and LLW disposal.

In Scenario 4A, Nuclear Waste Fund costs decrease by more than $12 billion because it is not necessary to design and build TAD canisters, transportation costs are lower because the fuel is transported in DPCs rather than in TADs, fewer overpacks are needed, and less fuel has to be repackaged than in the Reference Case. These savings offset the additional $8 billion cost of siting, characterizing, and licensing a new repository. Costs to taxpayers increase by almost $50 billion because of the significant delay in opening the repository. Other costs decrease by about $7 billion because utilities do not load fuel into TADs and there is no LLW to dispose of. These savings offset cost increases associated with transferring DPCs to transportation casks at utilities.

In Scenario 4B, Nuclear Waste Fund costs increase by just over $30 billion, primarily because of the additional costs associated with constructing and operating a federal CIS facility, but also because a new repository has to be sited, characterized, licensed, etc., because all CSNF is repackaged from DPCs to TADs, and because waste is transported twice. Costs to taxpayers increase by almost $17 billion, which is more than the $12 billion in Scenario 3A, because utilities continue to load spent fuel into DPCs (rather than into TADs) until the utilities shut down rather than loading spent fuel into TADs starting in 2035, which is the case in Scenario 3A. Other costs decrease by about $5 billion because utilities do not load fuel into TADs; this is somewhat offset by the costs of disposing of used DPC shells as LLW and the costs of transferring more DPCs from their storage casks to transport casks at utilities.

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