Advanced Fuel Cycle Cost Basis Report:

Module I

Consolidated Interim Storage

Nuclear Fuel Cycle and Supply Chain

Prepared for

U.S. Department of Energy

Systems Analysis and Integration

May 2021

INL/EXT-21-62600

Revision 1

REVISION LOG

Rev.	Date	Affected Pages	Revision Description
	2004	All	Version of AFC-CBR in which Module first appeared: 2004 as Module E2. In 2012 this module was renamed to Module I. The Module now deals mainly with off-reactor-site, centralized (or “consolidated”) interim spent fuel storage.
	2017	All	Latest version of module in which new technical data was used to establish unit cost ranges: 2012 New technical/cost data which has recently become available and will benefit next revision: The USDOE Used Fuel Disposition (UFD) Campaign continues to conduct engineering, cost, and schedule studies. Some of these were conducted in FYs 2015 through 2016. The results of these studies should be included. One such document is a cost sensitivity analysis conducted by Oak Ridge National Laboratory (ORNL 2016). Many utilities are constructing on-reactor-site interim spent fuel storage facilities using US Government funding resulting from lawsuit settlements. Cost information on these “on-site” facilities should be available.
	2021	All	Re-formatted module consistent with revised approach to release of the AFC-CBR and escalated cost estimates from year of technical basis to escalated year 2020. Cost estimates are in US dollars ($) of year 2020.

Page intentionally left blank

ACKNOWLEDGEMENT

This latest version of the Module I Consolidated Interim Storage is the result of the cumulative effort of many authors that have contributed to the Advanced Fuel Cycle Cost Basis Report (AFC-CBR). It is not possible to identify and acknowledge all those contributions to the AFC-CBR and this module. All the authors, including the four primary authors, fifteen contributing authors, the twelve contributors acknowledged, and the many other unacknowledged contributors in the 2017 version of the report may have contributed various amounts to the development and writing of this module prior to this current revision. Unfortunately, there is not a consolidated history that allows us to properly acknowledge those that built the foundation that was updated and revised in this latest revision.

This update reformats previous work to the current format for rerelease of the entire report as individual modules so there is no primary technical developer or lead author. J. Hansen (INL) and E. Hoffman (ANL) can be contacted with any questions regarding this document.

jason.hansen@inl.gov; ehoffman@anl.gov

Suggested Citation:

DOE-NE Systems Analysis & Integration Campaign, *Advanced Fuel Cycle Cost Basis Report: Module I Consolidated Interim Storage*. Idaho Falls: Idaho National Laboratory, 2021.

Page intentionally left blank

CONTENTS

FIGURES

TABLES

ACRONYMS

CEO	Chief Executive Officer
CSF	consolidated storage facility
EIS	Environmental Impact Statement
ISFSI	Independent Spent Fuel Storage Installation
LCC	Life-Cycle Costs
ORNL	Oak Ridge National Laboratory
PFS	Private Fuel Storage
RF	re-packaging facility
ROM LCC	Rough order of magnitude life cycle cost
TVF	test and validation facility
DOE	Department of Energy
USDOE	U.S. Department of Energy
UFD	Used Fuel Disposition
UNF	used nuclear fuel

Page intentionally left blank

Module I
Consolidated Interim Storage

I-MD. SHORT DESCRIPTION OF METHODOLOGY USED FOR ESTABLISHMENT OF MOST RECENT COST BASIS AND UNDERLYING RATIONALE

- **Constant $ base year 2020 for this FY21 update.**
- **Nature of this FY21 Module update from previous AFC-CBRs:** Escalation only.
- Estimating Methodology for latest (2012 AFC-CBR) technical update from which this FY21 update was escalated: In addition to earlier cost information on the Private Fuel Storage (PFS) Skull Valley Utah proposal, new FY 2012 information from Systems Architecture Studies conducted by USDOE-NE's UFD Campaign were added.

I-1. BASIC INFORMATION

In the 1990s the U.S. Department of Energy (DOE) completed a number of system analyses investigating consolidated interim storage as a part of the waste management solution. These analyses are "dated" and do not reflect the present situation regarding at-reactor used nuclear fuel (UNF) management, alternatives for away from reactor management of used nuclear fuel, and alternatives for the ultimate disposal of UNF. The Blue Ribbon Commission for America's Nuclear Future and the Nuclear Waste Technical Review Board have both pointed out the need for further analysis in light of the current situation, These analyses were re-started in FY2012 by the U.S. DOE-NE Used Fuel Disposition Campaign and are discussed below.

The first consolidated storage concept was conducted when the Skull Valley Band of Goshute Indians proposed and developed a detailed conceptual design of the nongovernmental adjunct, a privately owned and operated Independent Spent Fuel Storage Installation (ISFSI) to be located in Tooele County, Utah. Indeed, on February 21, 2006, the Nuclear Regulatory Commission issued a license to Private Fuel Storage, LLC (PFS) to build and operate its proposed temporary storage facility for spent nuclear fuel on the Skull Valley Goshute reservation in Skull Valley, Utah—the first nuclear facility to receive an NRC license in more than 20 years.

Preliminary cost estimates for the Skull Valley ISFSI have been developed by PFS based on the detailed conceptual design depicted in Figure I-1 and having the layout as illustrated in Figure I-2. The detailed information is contained in the Skull Valley Environmental Impact Statement (EIS) (NRC 2001), which is prepared and submitted to the Environmental Protection Agency but also constitutes the basis of the formal license application to the Nuclear Regulatory Commission. The concept of the facility consists of a remotely located open area on which casks are stored in an upright position, having a maximum facility capacity of 4,000 casks, which is equivalent to approximately 40,000 MTHM.

Figure I-1. Artist rendition of Skull Valley Independent Spent Fuel Storage Facility.

I-2. FUNCTIONAL AND OPERATIONAL DESCRIPTION

The following description was extracted with slight modifications from the Skull Valley EIS (NRC 2001). The basic site plan for the proposed private fuel storage facility is illustrated in Figure I-2. A fence would mark the boundaries of the 330-hectare (820-acres) general area. Within the general area, a 40-hectare (99-acre) restricted-access area would contain the storage pads and some of the support facilities. The entire 330-hectare site would be enclosed by a typical four-strand barbed wire range fence. Fencing around the restricted-access area would consist of two 2.4-m (8-ft) chain link security fences topped with barbed wire. The inner fence would be separated from the outer chain link nuisance fence by a 6-m (20-ft) isolation area. A new 4-km (2.5-mile) access road would lie within an 82-hectare (202-acre) right-of-way. The road would be built east of the site and would connect the site to the existing public roads. No fence would be constructed to enclose the new access road. Buildings and storage areas would primarily be located within the restricted-access area, with the exception of the administration building, concrete batch plant, and operations and maintenance building, which would be located on the site outside the security fences.

The facility would contain 4,000 modular concrete storage pads that would be 20 × 9 × 1 m (67 × 30 × 3 ft). Each storage pad would be constructed flush with grade level and would hold up to eight storage casks in a 2 × 4 array. Areas between the storage pads would be surfaced with compacted crushed rock 20 cm (8 in.) thick and sloped toward the north to facilitate drainage.

In addition to the storage pads described above, there would be four buildings:

1. The Canister Transfer Building, a reinforced-concrete, high-bay structure approximately 60 m (200 ft) wide, 80 m (260 ft) long, and 27 m (90 ft) high. The Canister Transfer Building would facilitate the transfer of the spent nuclear fuel canister from its shipping cask into the storage cask and would be equipped with a 180-metric-ton (200-ton) overhead bridge crane for moving the shipping casks, a 135-metric-ton (150-ton) semi-gantry crane for canister transfer operations, and three canister transfer cells to provide a radiation-shielded work space for transferring the spent nuclear fuel canisters from the shipping casks to the storage casks. Shipping casks would be moved into the high bay portion of the building either on railcars or heavy/haul trailers, depending on the transportation option.
2. The Security and Health Physics Building, the entrance point for the 40-hectare (99-acre) restricted-access area, would be located adjacent to the Canister Transfer Building and consists of a

single-story, concrete masonry structure approximately 23 m (76 ft) wide, 37 m (120 ft) long, and 5.5 m (18 ft) high. This building would provide office and laboratory space for security and health physics staff and would house security, communication, and electrical equipment needed by personnel.

3. The Administration Building consists of a single-story, steel-frame building approximately 24 m (80 ft) wide, 46 m (150 ft) long, and 5 m (17 ft) high that would include office and records management space, an emergency response center, meeting rooms, and a cafeteria.
4. The Operations and Maintenance Building consists of a single-story, steel-frame building approximately 24 m (80 ft) wide, 61 m (200 ft) long, and 8 m (26 ft) high, which would house maintenance shops and storage areas for spare parts and equipment to service vehicles and equipment at the facility.

Paved parking areas would be constructed adjacent to the Administration Building, the Operations and Maintenance Building, and the Security and Health Physics Building.

The storage pad emplacement area has a soil-cement subgrade to support the cask storage pads.

An 82-hectare (202-acre) right-of-way between the site and public roads would contain an asphalt paved access road to the proposed facility and overhead power and telephone lines. The road would consist of two 4.5-m (15-ft) lanes.

Onsite drainage at the storage pad area would be conveyed by a surface flow system to a 3-hectare (8-acre) storm water collection and detention basin to be located at the northern boundary of the restricted-access area (Figure I-3).

Electrical power for lighting, the security system, equipment operation, and other general purposes would be obtained from a new transformer to be connected with new lines on standard poles to existing 12.5 kV commercial power systems. Backup power for the security system, emergency lighting, and the site public address system would be provided by a diesel generator located in the Security and Health Physics Building. The communication system would consist of telephones, a public address system, and short-wave radio equipment. All buildings would be heated by propane due to the remoteness of the facility. Four propane tanks are located at a minimum distance of 550 m (1,800 ft) from the Canister Transfer Building and the cask storage area, and each propane tank would hold up to 19 m^3 (5,000 gal). A potable water supply system would be provided for the facility, taking water from either a groundwater well on the site or from offsite sources. Aboveground storage tanks would provide adequate water for potable water for extinguishing fires and for the concrete batch plant. A fire suppression system in the Canister Transfer Building would be fed by fire pumps and both a primary and backup water tank, each with a capacity of 380 m^3 (100,000 gal).

Other infrastructure includes a rail siding to connect to the existing trunk lines. The proposed right-of-way for the rail line would be approximately 51 km (32 miles) long and 60 m (200 ft) wide.

Figure I-4 shows the functional flow for the facility. Spent nuclear fuel is received in shipping casks, transferred to storage casks, and stored on a pad. At some later time, the spent nuclear fuel is transferred back to a shipping cask and shipped out (via Module O) for reprocessing (Modules F1 and F2/D2) or disposal (Module L).

I-3. PICTURES AND DIAGRAMS

Figures I-2, I-3, and I-4 describe the Skull Valley site plan and layout.

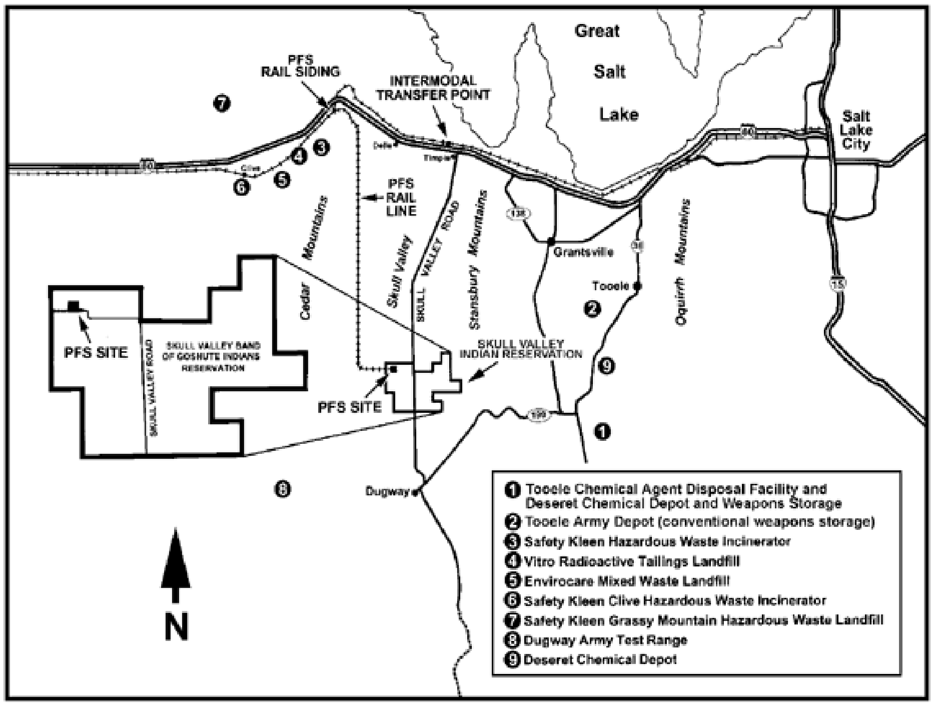
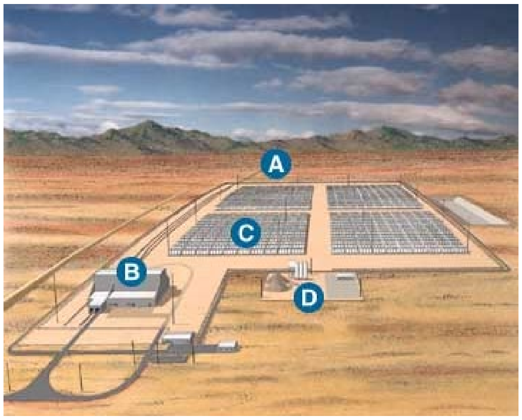


Figure I-2. Basic site plan for the proposed private fuel storage facility.



This illustration shows the rail line **(A)** that will enter the PFS facility from the west and run to the cask transfer building **(B)**. There, the shipping casks will be removed from the rail cars. Then the storage canisters will be removed from the shipping casks and placed into steel and concrete storage casks. The storage casks will then be placed on three-foot thick reinforced concrete pads **(C).** The concrete for the robust storage casks will be made on site at the batch plant **(D)**.

http://www.privatefuelstorage.com/project/facility.html

Figure I-3. Skull Valley facility layout and major components (NRC 2001).

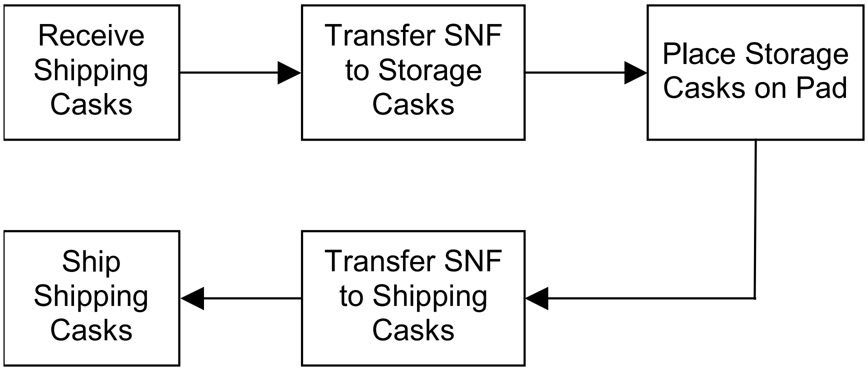


Figure I-4. Facility functional block diagram.

I-4. MODULE INTERFACES

The module will accept spent nuclear fuel casks transported (Module O) from wet (Module E1) or dry storage (Module E2) at nuclear power plants. On arrival, sealed canisters containing the spent fuel assemblies will be transferred to various storage cask systems and placed in storage. At unspecified future dates, fuel can be removed for ultimate disposition (Module L) or for reprocessing (Modules F1 or F2/D2). The FY-12 System Architecture Study begins to assess the Life-Cycle Costs (LCC) impact on storage for delays in final disposition.

I-5. SCALING CONSIDERATIONS

Within a site, facilities can be expanded via development of modular concepts. Multiple fuel handling and storage modules are expected to be required, in part due to the increasing number of dry storage systems currently in use at utilities. There are more than 30 dry storage containers in the current inventory and new concepts to continue to be developed as industry continues to develop larger containers.

I-6. COST BASES, ASUMPTIONS, AND DATA SOURCES

I-6.1 PFS COSTS

The reference cost basis in 2006 dollars for a private ISFSI is presented in Table I-1, generated from a top-down estimate based on the Skull Valley representative design for a monitored retrievable system. Combining the capital cost of $480M and Operations and Maintenance cost of $2,400M for a 40,000 MTHM facility operating over a 40-year lifetime, yields a Total Life-Cycle Cost of $2,880M ($72/kgHM) before financing. $72/kgHM is approximately 20% of the used fuel disposition cost inherent to the nuclear waste disposal fee of $0.001 per kW(e) collected by the government from the nuclear plant generators.

The Skull Valley annual operating expenses were estimated by a principal of PFS at $60M per year, as quoted during a recent (2006) interview in an industry trade publication. Division of the annual cost by the maximum number of casks envisioned to be stored at the facility yields a value of $15,000 per year as the amount required for operations on a per cask basis, which is the source of the entry in Table I-1.

Table I-1. Surface monitored retrievable storage (Skull Valley).

Private Fuel Storage (PFS) Goshute Reservation, Skull Valley, Utah	Value 2006 $	Units	Data Source or Person Making Assumption
Maximum number of casks onsite	4,000	casks	PFS/JD Parkyn, Chairman and Chief Executive Officer (CEO)
MTHM maximum onsite	40,000	MTHM	PFS/JD Parkyn, Chairman and CEO
Average kgHM per cask	10,000	kgHM/cask	PFS/JD Parkyn, Chairman and CEO
Facility capital investment per cask	120,000	$/cask	PFS/JD Parkyn, Chairman and CEO
Total PFS capital investment for land/facility development	480	$10^6$$	Calculated
Assumed number of years for facility to reach full storage capacity	10	years	ORNL/KA Williams
Facility fill rate	400	casks/year	Calculated
	4,000,000	kgHM/year	Calculated
Operations charge	15,000	$/cask/year	*Nuclear Fuel*, March 27, 2006, Operations: $60 M/y
Operations charge per year per kgHM	1.5	$/kgHM/year	Calculated
Typical storage time	20	years	ORNL/KA Williams
$/kgHM for operations	30	$/kgHM	Calculated
Fixed charge rate	10.00%	%	ORNL/KA Williams
Fixed charge rate to amortize capital over 10 yrs	16.27%	%	Calculated
Annual capital charge for facility	78.12	$10^6$$/year	Calculated
Capital investment per kgHM	19.53	$/kgHM	Calculated
Total levelized storage cost	49.53	$/kgHM	Calculated
Total life-cycle cost for PFS facility (without interest)	2.88	$10^9$$	Calculated
Total life-cycle cost with interest	3.78	$10^9$$	Calculated

I-6.2 SYSTEM ARCHITECTURE STUDY

In Fiscal Year 2012 system-level analyses of the overall interface between at-reactor, consolidated storage, and ultimate disposition along with the development of supporting logistic simulation tools were initiated by the Department of Energy. The objective of the Fiscal Year 2012 effort was two-fold: 1) develop methodologies, approaches, and tools (capability development), and 2) evaluate select UNF disposition scenarios (capability demonstration). The scenarios chosen for evaluation and the assumptions, inputs, and boundary conditions selected allowed for an initial set of analyses to gain insight regarding integrated system dynamics and an understanding of trends. This initial set of analyses also points to where additional system architecture analyses should focus.

An important waste management system interface consideration is the need for ultimate disposal of UNF fuel assemblies contained in waste packages sized to be compatible with the geologic medium of the final repository. Thermal analyses completed by the Used Fuel Disposition Campaign indicate that waste package sizes for the geologic media under consideration by the Used Fuel Disposition Campaign are significantly smaller than the canisters being used for on-site dry storage by the nuclear utilities. Therefore, at some point along the UNF disposition pathway there may be a need to re-package fuel assemblies already loaded into the types of dry storage canisters currently in use unless the feasibility of direct disposal of these large canisters can be demonstrated.

A high-level diagram of the alternative UNF disposition pathways is shown in Figure I-1 and involves UNF storage at a consolidated storage facility (CSF) and UNF packaging/re-packaging prior to ultimate disposal.

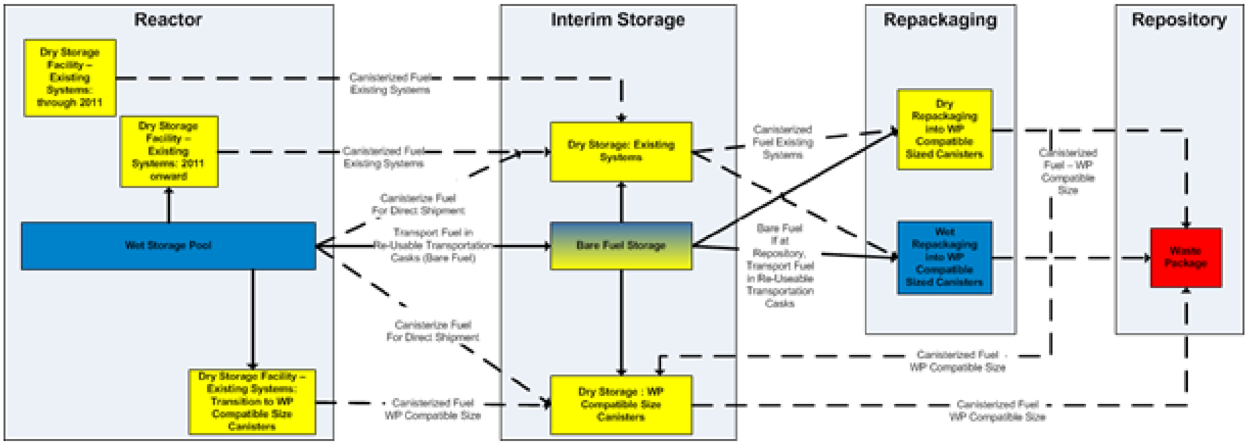


Figure I-5. Alternative Used Nuclear Fuel Disposition Pathways (Nutt, et al. 2012).

While the reactors will continue to transfer UNF to dry storage, there will always be UNF in the used fuel pools, at least until a reactor is shut down and decommissioned. Another important aspect is how the UNF residing in the used fuel pools is managed when acceptance of the fuel from the reactor sites begins. UNF residing in the pools can be transported off-site in re-useable transportation casks, placed in dual-purpose canisters suitable for both storage and transportation, or placed in a standard canister once one is designed and licensed. This choice impacts the design of both a CSF (canistered fuel storage only or canistered and bare fuel storage) and the quantity of UNF that would ultimately have to be re-packaged.

These considerations resulted in the identification of nine potential disposition pathways that consider how UNF would be transported from the reactors, where UNF packaging/re-packaging would be performed (repository or CSF), and when UNF packaging/re-packaging would be performed (at CSF receipt or prior to shipment from the CSF to a repository). These nine disposition pathways were evaluated considering complexity and flexibility, resulting in a down-select of the disposition pathways that would be considered in FY12 to four, representing the possible combinations of two features: what would be accepted from reactors by the waste management system (fuel packaged into existing size canisters only, or bare fuel as well as canisterized fuel), and where/when the canisterized fuel would be packaged/re-packaged for disposal (at a CSF when the fuel is about to be sent to the repository, or at the repository when fuel is received there). The packaging/re-packaging of bare fuel/canisters into disposal size canisters at reactors or into either existing size or disposal size canisters at CSF receipt were not evaluated in this phase of the analysis. The cases considered are summarized in Table I21 (see Section 3.1 for details regarding each case).

Table I-2. TSL Case Matrix.

	Case 1	Case 2	Case 3	Case 4
Transport From Reactors	Existing Size Canisters	Existing Size Canisters / Bare Fuel	Existing Size Canisters	Existing Size Canisters / Bare Fuel
CSF	Existing-Size Canisters	Existing Size Canisters / Bare Fuel	Existing-Size Canisters	Existing Size Canisters / Bare Fuel
Package/ Re-Package at ==>	Repository	Repository	CSF	CSF
Transport from CSF to MGR	Existing-Size Canisters	Existing Size Canisters / Bare Fuel	Waste Package Size Canisters	Waste Package Size Canisters

A range of input parameters was then determined for evaluating each disposition pathway. Parameters selected include start of CSF operations (2020, 2035), start of repository operations (2040, 2055), UNF acceptance rates (1500, 3000, and 6000 MTHM/yr), and waste package size (4/9, 12/24, 21/44 PWR/BWR assemblies). The combination of disposition pathways and input parameters results in 36 individual scenarios that were evaluated.

I-6.3 SYSTEM ARCHITECTURE COST STUDY

Rough order of magnitude life cycle cost (ROM LCC) estimates of the entire nuclear waste management system varied depending on the scenario. Table I-3 provides the LCC summary from this study for the 36 scenarios. Table I-3 includes the ROM LLC for CSF operations, an associated test and validation facility (TVF) as recommended by the BRC and in which extended fuel storage research and development activities will be conducted and the packaging/re-packaging facility (RF) costs. The table is color shaded to group similar processing rates.

Table I-3. Away from Reactor Back End Fuel Cycle Management Life-Cycle Costs.

Scenario	Acceptance Rate	CSF Start	Repository Start	Disposal Canister Size	CSF Total Life Cycle FY 2012 ($B)	TVF Total Life Cycle FY 2012 ($B)	RF Total Life Cycle FY 2012 ($B)	Away From Reactor UNF Management Life Cycle (CSF + TVF + RF) FY 2012 ($B)
Canisters Only - Re-Package at Repository (Case 1)	1,500	2020	2040	4	$7.5	$4.4	$12.0	$23.9
	3,000	2020	2040	4	$11.3	$3.4	$14.4	$29.0
	3,000	2020	2040	12	$11.3	$3.4	$8.4	$23.1
	3,000	2020	2040	21	$11.3	$3.4	$6.6	$21.3
	6,000	2020	2040	4	$17.5	$2.9	$19.6	$40.1
	1,500	2020	2055	4	$11.9	$4.7	$12.0	$28.7
	3,000	2020	2055	4	$20.4	$3.7	$14.4	$38.4
	6,000	2020	2055	4	$25.7	$3.3	$20.3	$49.2
	3,000	2035	2055	4	$12.9	$3.4	$13.6	$29.9
Canisters and Bare Fuel - Re-Package at Repository (Case 2)	1,500	2020	2040	4	$22.5	$4.4	$12.5	$39.4
	3,000	2020	2040	4	$40.2	$3.4	$14.4	$58.0
	3,000	2020	2040	12	$40.2	$3.4	$8.5	$52.1
	3,000	2020	2040	21	$40.2	$3.4	$7.2	$50.7
	6,000	2020	2040	4	$67.2	$2.9	$20.3	$90.4
	1,500	2020	2055	4	$31.8	$4.7	$12.5	$49.0
	3,000	2020	2055	4	$58.4	$3.7	$14.4	$76.5
	6,000	2020	2055	4	$78.7	$3.2	$19.3	$101.3
	3,000	2035	2055	4	$30.5	$3.4	$14.1	$48.0
Canisters Only - Re-Package at CSF (Case 3)	1,500	2020	2040	4	$10.3	$4.4	$13.6	$28.4
	3,000	2020	2040	4	$15.2	$3.4	$15.8	$34.4
	3,000	2020	2040	12	$15.2	$3.4	$8.7	$27.3
	3,000	2020	2040	21	$15.2	$3.4	$6.7	$25.3
	6,000	2020	2040	4	$18.0	$2.9	$24.6	$45.6
	1,500	2020	2055	4	$15.8	$4.7	$13.6	$34.1
	3,000	2020	2055	4	$22.9	$3.7	$15.8	$42.4
	6,000	2020	2055	4	$25.7	$3.3	$24.6	$53.6
	3,000	2035	2055	4	$25.9	$3.4	$15.8	$45.1
Canisters and Bare Fuel - Re-Package at CSF (Case 4)	1,500	2020	2040	4	$28.7	$4.4	$13.0	$46.1
	3,000	2020	2040	4	$50.1	$3.4	$15.8	$69.2
	3,000	2020	2040	12	$50.1	$3.4	$8.7	$62.1
	3,000	2020	2040	21	$50.1	$3.4	$6.7	$60.2
	6,000	2020	2040	4	$67.1	$2.9	$21.2	$91.2
	1,500	2020	2055	4	$40.3	$4.7	$13.0	$57.9
	3,000	2020	2055	4	$64.4	$3.7	$15.8	$83.9
	6,000	2020	2055	4	$78.6	$3.2	$21.2	$103.0
	3,000	2035	2055	4	$37.5	$3.4	$15.6	$56.4

🟦 1500 MTHM/yr 🟧 3000 MTHM/yr 🟩 6000 MTHM/yr

I-7. DATA LIMITATIONS

The PFS cost estimate is based on direct conversations with the chairman and chief executive officer, accompanied by recent information available from trade publications.

The technology readiness is considered to be commercially viable. While no facilities of this type currently exist, the technology is not substantially different from the interim dry storage facilities presently operating at multiple reactor sites throughout the country. The data quality is categorized as a top-down scoping assessment with a common basis/approach.

The PFS concept is limited in that it only addressed a single dry storage canister design; it did not recognize the need for an extended storage test and validation facility and did not recognize the need to repackage the fuel to meet disposal constraints for decay heat at the time of waste emplacement. The UFD

System Architecture Study explores a number of these limitations with the added program elements increasing cost. The System Architecture Study also indicates higher cost for higher processing rates and continued delays in establishing final disposition. Bare fuel processing and storage, which includes unloading and handling uncontainerized fuel assemblies, also increases cost significantly.

The UFD System Architecture Study is based on a multi-module concept based upon current commercial practices. Cost estimates were developed for individual modules and operating concepts and expanded to cover a broad range of possible fuel cycle back end management scenarios. The individual module concepts are based on pre-conceptual designs and the cost estimates are considered to be rough order-of-magnitude quality. More detailed UFD Campaign studies are currently underway and should reflect a pre-conceptual, bottom-up cost estimating approach.

I-8. COST SUMMARIES

Table I-4 presents the UFD System Architecture Study ROM LCC results as unit costs per kg of initial heavy metal. Due to the inclusion of a broad range of considerations this study, as of 2012, serves as the most comprehensive cost study to date for consolidated storage and related costs.

Table I-4. Away from Reactor Back End Fuel Cycle Management Unit Costs.

Scenario	Acceptance Rate	CSF Start	Repository Start	Disposal Canister Size	CSF Total Life Cycle FY 2012 ($/kg)	TVF Total Life Cycle FY 2012 ($/kg)	RF Total Life Cycle FY 2012 ($/kg)	Away from Reactor UNF Management Life Cycle FY 2012 ($/kg)
Canisters Only - Re-Package at Repository (Case 1)	1,500	2020	2040	4	$53.6	$31.5	$85.6	$170.7
	3,000	2020	2040	4	$80.5	$24.5	$102.5	$207.5
	3,000	2020	2040	12	$80.5	$24.5	$59.8	$164.7
	3,000	2020	2040	21	$80.5	$24.5	$47.0	$151.9
	6,000	2020	2040	4	$125.3	$21.0	$140.2	$286.5
	1,500	2020	2055	4	$85.4	$33.8	$85.6	$204.7
	3,000	2020	2055	4	$145.4	$26.7	$102.5	$274.6
	6,000	2020	2055	4	$183.4	$23.2	$144.9	$351.5
	3,000	2035	2055	4	$92.2	$24.5	$96.9	$213.6
Canisters and Bare Fuel - Re-Package at Repository (Case 2)	1,500	2020	2040	4	$160.7	$31.5	$89.2	$281.4
	3,000	2020	2040	4	$286.9	$24.5	$102.7	$414.0
	3,000	2020	2040	12	$286.9	$24.5	$61.0	$372.3
	3,000	2020	2040	21	$286.9	$24.5	$51.1	$362.4
	6,000	2020	2040	4	$480.3	$21.0	$144.7	$646.0
	1,500	2020	2055	4	$227.2	$33.7	$89.2	$350.0
	3,000	2020	2055	4	$417.3	$26.7	$102.7	$546.7
	6,000	2020	2055	4	$562.5	$23.2	$138.1	$723.8
	3,000	2035	2055	4	$217.9	$24.5	$100.5	$342.8
Canisters Only - Re-Package at CSF (Case 3)	1,500	2020	2040	4	$73.9	$31.6	$97.2	$202.7
	3,000	2020	2040	4	$108.3	$24.5	$112.9	$245.7
	3,000	2020	2040	12	$108.3	$24.5	$62.1	$195.0
	3,000	2020	2040	21	$108.3	$24.5	$48.2	$181.0
	6,000	2020	2040	4	$128.7	$21.0	$175.9	$325.6
	1,500	2020	2055	4	$112.9	$33.8	$97.2	$243.9
	3,000	2020	2055	4	$163.5	$26.8	$112.9	$303.1
	6,000	2020	2055	4	$183.7	$23.3	$175.9	$382.8
	3,000	2035	2055	4	$184.9	$24.5	$112.7	$322.2
Canisters and Bare Fuel - Re-Package at CSF (Case 4)	1,500	2020	2040	4	$205.1	$31.3	$92.8	$329.3
	3,000	2020	2040	4	$357.7	$24.2	$112.6	$494.5
	3,000	2020	2040	12	$357.7	$24.2	$61.8	$443.8
	3,000	2020	2040	21	$357.7	$24.2	$47.9	$429.8
	6,000	2020	2040	4	$479.2	$20.7	$151.3	$651.2
	1,500	2020	2055	4	$287.7	$33.3	$92.9	$413.9
	3,000	2020	2055	4	$460.2	$26.3	$112.6	$599.1
	6,000	2020	2055	4	$561.4	$22.8	$151.3	$735.4
	3,000	2035	2055	4	$267.6	$24.2	$111.3	$403.1

🟦 1500 MTHM/yr 🟧 3000 MTHM/yr 🟩 6000 MTHM/yr

The overall range in this table is over a factor of 5 when all program elements are included. Care must be taken when applying these data to follow-on cost studies in selecting the appropriate case therefore aligning the critical values for fuel receipt type, processing rate, start of consolidated storage and final disposition, and the program elements to be included. When the final disposition is a repository then the waste disposal package size is also a key variable. The What-It-Takes Table, I-5 only includes the low, high and nominal cost for Cases 3 and 4. Module L1 on Geological Disposal does not include repackaging at the repository, so Cases 1 and 2 are not included. The nominal values selected where those that define a conservative scenario of costs at the moderate 3,000 MTHM/year throughput.

Table I-5. Cost summary table for Consolidated Interim Storage Total Life Cycle Costs.

What-It-Takes Table (2012 $)				
Scenario	Low Cost	Mode Cost	Mean Cost	High Cost
Case 3 - Canisters only – repackage at CSF	$74 /kgHM	$164/kgHM		$185/kgHM
Case 4 - Canisters and Bare Fuel – repackage at CSF	$205 /kgHM	$460/kgHM		$561/kgHM
Case 4 Escalated to 2015$ >	$215/kgHM	$485/kgHM	$430	$590/kgHM
Case 4 Escalated to 2017$ >	$223/kgHM	$501/kgHM	$456/kgHM	$644/kgHM
Case 3 Escalated to 2020$	$84/kgHM	$186/kgHM	$160/kgHM	$210/kgHM
Case 4 Escalated to 2020$	$232/kgHM	$521/kgHM	$463/kgHM	$636/kgHM
Escalation factor from 2012 to 2020 of 13.4%. Mean is calculated from range.				

Figure I-6 diagrams the interim storage cost ranges defined by Case 4, storage of canisters and bare fuel with repackaging the CSF. While the most conservative from the cost stand-point, it includes management of both containerized and bare fuel bundles and will manage receipt of SNF from either storage pools or dry storage at the reactor sites. The FY 2017 values were obtained by escalating the 2012 values by 9 percent. (Note that 13.4% escalation was used to calculate the FY21 AFC-CBR values from the 2012 AFC-CBR values.)

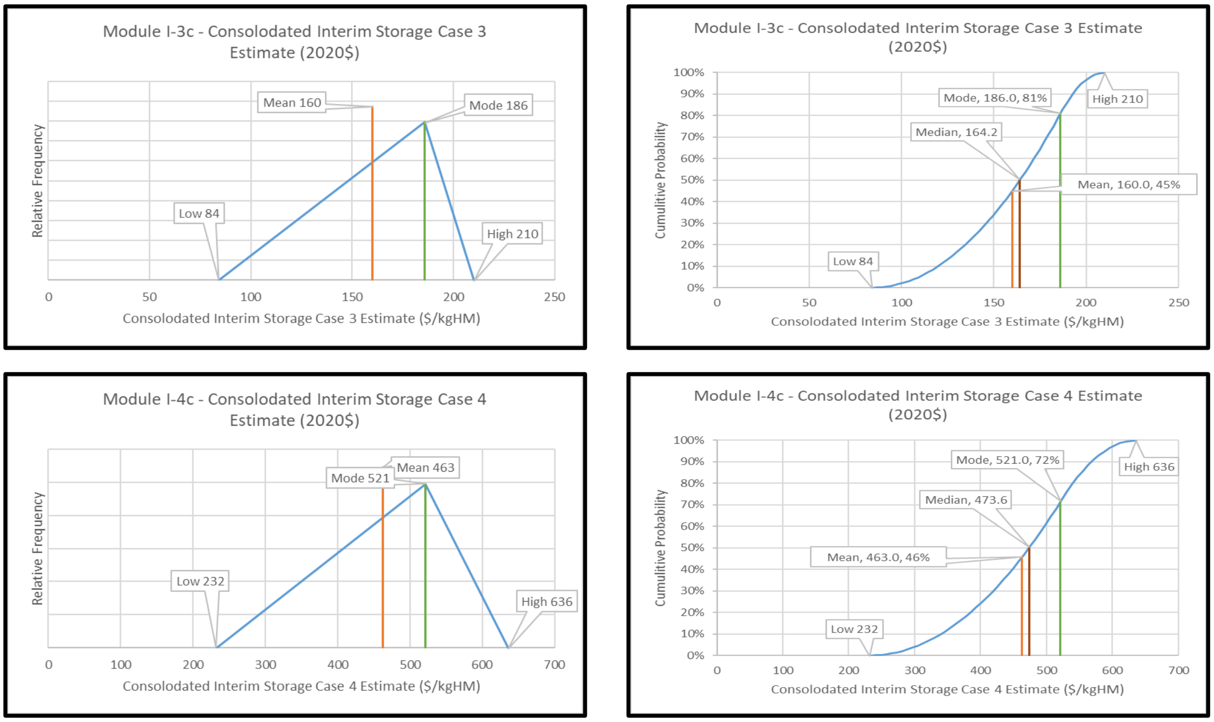


Figure I-6. Consolidated Interim Storage estimated cost frequency distribution.

I-9. SENSITIVITY AND UNCERTAINTY ANALYSES

Table I-3 and I-4 present the average of the high and low range included in the reference document. Inclusion in this additional uncertainty in application of these data in future studies is at the discretion of the cost analyst.

Cumberland, R; Williams, K.A.; Jarrell, J.J.; and Joseph, R.A.; Cost Sensitivity Analysis for Consolidated Interim Storage of Spent Fuel: Evaluating the Effects of Economic Environment Parameters; ORNL/SR-2016/681. FCRD-NFST-2016-000721, Rev.1; December 30, 2016; [energy.gov/sites/prod/files/2017/03/f34/cost%20sensitivity] unlimited distribution.

I-10. REFERENCES

NRC, 2001, *Final Environmental Impact Statement for the Construction and Operation of an Independent Spent Fuel Storage Installation on the Reservation of the Skull Valley Band of Goshute Indians and the Related Transportation Facility in Tooele County, Utah,* NUREG-1714, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Washington, DC, December 2001.

Nutt, M, Morris, E., Puig, F., Carter, J., Rodwell, P., Delley, A., Howard, R., and Giuliano, D., "Used Fuel Management System Architecture Evaluation, Fiscal Year 2012", FCRD-NFST-2013-000020 Rev. 0, October 31, 2012.

I-11. BIBLIOGRAPHY

Alvarez, R., J. Beyea, K. Janberg, J. Kang, E. Lyman, A. Macfarlane, G. Thompson, F. N. von Hippel, 2003, "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States, Science & Global Security, Vol. 11, No. 1, 2003, pp. 1–51, http://www.princeton.edu/sgs/publications/sgs/pdf/11_1Alvarez.pdf, Web page accessed September 2, 2009.

Bunn, M., et al., 2001, *Interim Storage of Spent Nuclear Fuel: A Safe, Flexible, and Cost-Effective Near-Term Approach to Spent Fuel Management*, Harvard University Project on Managing the Atom and the University of Tokyo Project on Sociotechnics of Nuclear Energy, June 2001.

Bunn, M., 2003, *The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel*, Cambridge, Mass, Project on Managing the Atom, Harvard University, DE-FG26-99FT4028, December 2003, pp. 19, 55–57.

Fairlie, I., 2000, "Dry Storage of Spent Nuclear Fuel: The Safer Alternative to Reprocessing," Report to Greenpeace International in Response to COGEMA Dossiers to the La Hague Public Inquiry, May 2000, http://www.scholar.google.com/scholar?hl=en&lr=&q=cache:ZVJt2rZ0S, Web page accessed September 2, 2009.

GAO, 2003, "Spent Nuclear Fuel: Options Exist to Further Enhance Security," U.S. General Accounting Office, GAO-03-426, July 2003, http://www.gao.gov/new.items/d03426.pdf, Web page September 2, 2009.

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

OECD Nuclear Energy Agency and International Atomic Energy Agency, 1994, "The Economics of the Nuclear Fuel Cycle," 1994, pp. 11, 27, 37–38, 50, 77–80, http://www.nea.fr/html/ndd/reports/efc/, Web page accessed September 9, 2009.

DOE, 2008, United States of America National Report, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, DOE/EM-0654, U.S. Department of Energy Office of Environmental Management, Washington, October 2008.