

Nuclear Industry Input to the Development of Concepts for the Consolidated Storage of Used Nuclear Fuel - 13411

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ABSTRACT

EnergySolutions and its team partners, NAC International, Exelon Nuclear Partners, Talisman International, TerranearPMC, Booz Allen Hamilton and Sargent & Lundy, have carried out a study to develop concepts for a Consolidated Storage Facility (CSF) for the USA's stocks of commercial Used Nuclear Fuel (UNF), and the packaging and transport provisions required to move the UNF to the CSF. The UNF is currently stored at all 65 operating nuclear reactor sites in the US, and at 10 shutdown sites. The study was funded by the US Department of Energy and followed the recommendations of the Blue Ribbon Commission on America's Nuclear Future (BRC), one of which was that the US should make prompt efforts to develop one or more consolidated storage facilities for commercial UNF. The study showed that viable schemes can be devised to move all UNF and store it at a CSF, but that a range of schemes is required to accommodate the present widely varying UNF storage arrangements. Although most UNF that is currently stored at operating reactor sites is in water-filled pools, a significant amount is now dry stored in concrete casks. At the shutdown sites, the UNF is dry stored at all but two of the ten sites. Various types of UNF dry storage configurations are used at the operating sites and shutdown sites that include vertical storage casks that are also licensed for transportation, vertical casks that are licensed for storage only, and horizontally orientated storage modules. The shutdown sites have limited to non-existent UNF handling infrastructure and several no longer have railroad connections, complicating UNF handling and transport off the site. However four methods were identified that will satisfactorily retrieve the UNF canisters within the storage casks and transport them to the CSF. The study showed that all of the issues associated with the transportation and storage of UNF from all sites in the US can be accommodated by adopting a staged approach to the construction of the CSF. Stage 1 requires only a cask storage pad and railroad interface to be constructed, and the CSF can then receive the UNF that is in transportable storage casks. Stage 2 adds a canister handling facility, a storage cask fabrication facility and an expanded storage pad, and enables the receipt of all canistered UNF from both operating and shutdown sites. Stage 3 provides a repackaging facility with a water-filled pool that provides flexibility for a range of repackaging scenarios. This includes receiving and repackaging "bare" UNF into suitable canisters that can be placed into interim storage at the CSF, and enables UNF that is being received, or already in storage onsite, to be repackaged into canisters that are suitable for disposal at a geologic repository. The study used the "Total System Model" (TSM) to analyze a range of CSF capacities and operating scenarios with differing parameters covering UNF pickup orders, one or more CSF sites, CSF start dates, CSF receipt rates and geologic repository start dates. The TSM was originally developed to model movement of UNF to the Yucca Mountain repository and was modified for this study to enable the CSF to become the "gateway" to a future geologic repository. The TSM analysis enabled costs to be estimated for each scenario and showed how these are influenced by each of the parameters. This information will provide essential underpinning for a future Conceptual Design preparation.

INTRODUCTION

When the Yucca Mountain used nuclear fuel (UNF) repository license application was withdrawn from consideration by the Nuclear Regulatory Commission (NRC), the rationale was that Yucca Mountain was not a workable option. In parallel with this withdrawal, therefore, the Blue Ribbon Commission on America's Nuclear Future (BRC) was chartered to determine a workable path forward for nuclear waste management in the United States.

The BRC published its final report [1] in January 2012, and one of its major recommendations was that prompt efforts should be made to develop consolidated interim storage facilities for UNF. This would allow the consolidation of the UNF to one or more sites in the US from its current storage locations at the 65 operating commercial nuclear reactor sites (housing 104 reactors) and also at a number of shut down sites. Another BRC recommendation was that prompt efforts should be made to prepare for the eventual large scale transport of UNF to consolidated storage facilities when they become available.

As part of US Department of Energy’s (DOE) response to these recommendations, contracts were placed with three contractor teams, including one led by EnergySolutions, to produce design concepts to support the future selection of a consolidated UNF storage option. These concepts were required to address all activities needed to take the UNF from its current storage modes and locations at both working and shutdown reactor sites, repack it as needed for transport, transport it to a consolidated interim storage location (the Consolidated Storage Facility, CSF), repack it as needed for storage, place it in storage and then operate and maintain the storage facility. The EnergySolutions team formed to do this work includes substantial actual working experience in all these requirements and comprises NAC International, Exelon Nuclear Partners, Talisman International, TerranearPMC, Booz Allen Hamilton and Sargent & Lundy. The work was carried out during the period July to December 2012 and resulted in a comprehensive report for the DOE. This paper summarizes the process that the EnergySolutions team used for its identification and analysis of the issues, the conclusions reached, and the recommendations that the team made.

OVERVIEW OF USED NUCLEAR FUEL STORAGE IN THE U.S.A.

Table 1 summarizes, to December 2012, all the UNF currently stored in the US in both wet (pool) and dry (cask) storage at the 65 operating sites that have the 104 operating reactors, at the nine shutdown reactor sites that have solely “stranded fuel” located at them and the one shutdown reprocessing site (Morris) at which reprocessing was never started and that will likely continue to retain pool storage.

TABLE 1 Summary of All Used Nuclear Fuel in Storage in the U.S.A – to December 2012

Reactor Site Type	Number of Sites	Pool Storage		Dry Cask Storage	
		Number of UNF Assemblies	Metric Tons	Number of Dry Storage Casks	Metric Tons
Operating Sites with solely Pool Storage	21	58,935	18,514	--	--
Operating Sites with Pool & Dry Cask Storage	44	121,866	33,460	1,144	13,458
Totals for Operating Sites	65	180,801	51,974	1,144	13,458
Shutdown Sites with solely Pool Storage ¹	2	5,443	1,693	--	--
Shutdown Sites with solely Dry Cask Storage	8	--	--	198	1,794
Totals for Shutdown Sites	10	5,443	1,693	198	1,794
Overall Totals	75	186,244	53,667	1,342	15,252

Note 1: The Zion IL site, which currently has all its UNF in pool storage, is expected to have moved all of it into dry storage by the time the CSF is in operation. The Morris IL site is expected to keep its fuel in pool storage until it is moved to the CSF.

The total stored UNF amounts to almost 69,000 metric tons (MT). It can be seen that most of this UNF (53,667 MT or 78w% of the total) is currently still in pool storage as 186,244 assemblies, while the remaining 15,252MT or 22w% is in 1,342 dry storage casks. Of the 1,144 dry storage casks located at the operating sites, only some 146 are suitable also for transport to the CSF. At the shutdown sites, only the 6 casks at Humboldt Bay, CA, out of the total of 198 are suitable also for transport. These 152 transportable storage casks are thus ready for transport off-site, only requiring craning onto suitable rail, barge or heavy road haul equipment. The rest of the casks are unsuitable for transport, so the majority of the UNF canisters within them will need to be removed and placed in transport casks before the UNF can be moved to the CSF. There is a minority of casks and canisters at operating plants for which either repackaging of the UNF within them, or one-time transport licenses, will be required before the UNF can be moved, via a transport cask, to the CSF. For the operating sites, the equipment, infrastructure and trained and experienced workforce for packaging and loading operations are available on site, employed by the power utility operating the site. For the purposes of this study, therefore, we assumed that the power utilities will be responsible for re-packaging their UNF ready for transport to the CSF and that they will do this using existing infrastructure. The shutdown sites present a different challenge because they now typically lack direct rail connections, skilled operating personnel and the infrastructure needed to repackage and transport the UNF.

The shutdown sites and their UNF holdings are shown in Table 2. Of the eight sites with dry cask storage, seven use vertically orientated casks. Only Rancho Seco, CA, uses horizontally orientated casks and these are not transportable. Only Humboldt Bay, CA, uses storage casks that are also licensed for transportation. The Zion site, which currently has all its UNF in pool storage, and is in the process of being decommissioned, is expected to have moved all the UNF into dry storage by the time the CSF is in operation. The Morris site, which also currently has all its UNF in pool storage, is not expected to use dry storage. It will retain its UNF handling infrastructure and will send its UNF directly to the CSF during the period when the bulk of the operating reactor UNF will be sent to the CSF.

TABLE 2 Details of Shutdown Reactor Sites at which UNF is Stored

Site	Pool or Dry Cask Storage?	Storage Cask			MT of UNF
		Type	Quantity	Transportable?	
Big Rock Point, MI	Dry cask	W-150	8	No ²	57.9
Haddam Neck, CT	Dry cask	NAC STC-26	45	No ²	412.3
Humboldt Bay, CA	Dry cask	HISTAR HB	6	Yes	28.9
LaCrosse, WI	Dry cask	NAC LACUMS	5	No ²	38.0
Maine Yankee, ME	Dry cask	NAC UMS-24	64	No ²	542.3
Morris, IL ¹	Pool	--	--	No ²	674
Rancho Seco, CA	Dry cask	NUHOMS 24	21	No ²	228.4
Trojan, OR	Dry cask	HISTORM 24	34	No ²	358.9
Yankee Rowe, MA	Dry cask	NAC MPC-36	15	No ²	127.1
Zion, IL	Pool	--	--	No ²	1019
Totals			198		3487

Note 1: Morris, IL is not a reactor site but is a planned reprocessing site that did not operate. UNF was sent there in anticipation of reprocessing and has remained there ever since. The site is included in the Table as it is shutdown and because this UNF will ultimately need to be moved to a CSF.

Note 2: All of the canisters inside storage casks at shutdown sites are transportable, but require a separate transport cask. Some fuel at operating plants is not stored in a canister that is licensed for transport even with a transport cask.

The total amount of UNF stored at the shutdown sites is, at 3,487MT, only about 5w% of the total UNF in storage, though of course it will grow as other reactors are shutdown between now and the year 2025, which is our earliest estimated date to establish a fully operating CSF. Although it is a small proportion of the total, it nevertheless warrants the most initial attention because of the significant cost savings if the shutdown sites are completely closed. The range of different design dry casks used at each shutdown site is also noted – this means that different fuel removal and handling equipment will be needed at many sites.

SCOPE OF AND PROCESS FOR THE WORK

In placing the contracts with industry, DOE was seeking new industry ideas and insights to augment the significant amount of work on consolidated fuel storage and transport already completed by the US National Laboratories. The DOE brief for this study thus included the following major requirements:

- The concept for the CSF must be developed using a Systems Engineering approach.
- The concept developed must address all activities required to take the commercial used nuclear fuel from its current location and configuration, transport it to a location of consolidated storage, prepare the fuel as needed and place it in storage, and address the subsequent facility storage operations and maintenance.
- The CSF must not be part of a DOE facility, must be constructed in accordance with industry standards, and must be licensable by the Nuclear Regulatory Commission (NRC).
- It is anticipated that construction of the facility will begin before the end of the current decade; most likely in 2018 to 2020, and it is anticipated to be operational for a period of 100 years.
- Defense nuclear waste, DOE UNF, and Naval Nuclear Power Propulsion UNF are excluded from this study. Greater than Class C (GTCC) waste stored at the commercial nuclear reactor sites is, however, included in the study.

The Systems Engineering approach originally was planned to comprise four major steps. These were subsequently condensed to three by combining Steps 3 and 4 (Figure 1):

Step 1 was a Workshop, attended by all team partners, which developed a Function Analysis System Technique (FAST) diagram, the screening criteria for all options to be considered, and weighting factors to be used. Options for readying and transporting UNF to the CSF and for the design of the CSF were brainstormed and then ranked and rated. For UNF transport, effort focused on options for the shutdown sites and four schemes were developed, all of which are needed to cover the differing requirements of the nine sites that will have UNF in dry storage by the time the CSF is operational. For the CSF itself, five options were selected from a total of ten identified, and it was recognized that, rather than being alternates, all of them could be used, along with the four transport options, to provide a staged approach to the consolidation of UNF at the CSF.

Step 2 developed the four shutdown site options and five CSF options to gather and assess essential information on design; licensing; transportation and routing; emergency planning; security planning; railroad car design, testing and procurement; UNF cask lead times; and potential prioritization of sites for UNF pickup. During this step also, some basic constraints were recognized and assumptions made:

- Heat limits for transport of UNF are more restrictive than those for dry storage and are thus the limiting factor in determining how quickly fuel can be shipped, once out of the reactor.
- The start date for CSF operations was assumed to be 2022 for UNF already in transportable casks and 2025 for full operation with all other UNF.
- The CSF would be used as a ‘gateway’ to the geologic repository - all UNF would pass through the CSF and, if required, would be repackaged there. This eliminates the need for water filled pools or hot cells at the repository.
- Illustrative dates for the start of use of the geologic repository were selected as 2035 and 2040.

These and other assumptions provided the basis for modeling the operation of the total CSF system using the “Total System Model” (TSM) that had been previously developed for the Yucca Mountain repository system.

Step 3 was a combination of the originally planned Steps 3 and 4 and used the TSM to examine a range of operating scenarios of the UNF transport and CSF system, optimize operations and provide the information necessary to develop life cycle costs for these scenarios.

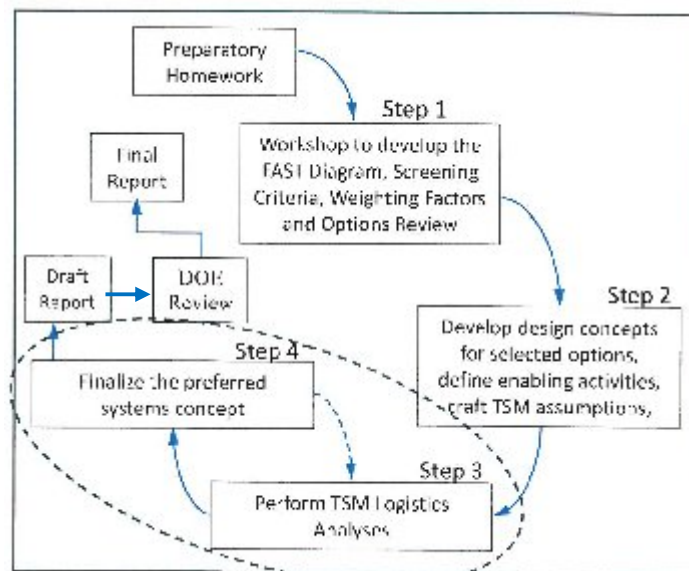


Figure 1 Systems Engineering Approach

PREFERRED UNF SYSTEM CONCEPT

UNF Retrieval from the Shutdown Sites

The four options for retrieving UNF canisters and, where applicable, GTCC waste canisters from the nine shutdown sites with fuel in dry storage are:

- The Humboldt Bay site in California is the only shutdown site that has UNF canisters stored in casks that are also licensed for transportation. This UNF can thus simply be retrieved by using a mobile crane to move the casks from their storage location to a suitable rail, barge or road heavy haul vehicle. A complication with this site is that it no longer has a railroad connection, so that heavy haul and probably sea transport will be required to get to a railhead for final transport to the CSF.
- The Rancho-Seco site in California has its UNF canisters stored in horizontally oriented concrete storage modules. A transport cask can be moved horizontally into contact with the storage module and the UNF canisters withdrawn into it (Figure 2).
- The Big Rock Point site in Michigan has its UNF canisters stored in vertical concrete casks and has existing equipment [2] to move these casks to the horizontal position. A transport cask is then moved into contact with the storage cask and the UNF canister withdrawn into it in a similar way to Ranch Seco (Figures 3 and 4).
- The remaining six reactor sites (see Table 2) all have UNF canisters in vertical storage casks that cannot be moved to the horizontal position. For these a stationary structure that supports an elevated and fixed shielded transfer cask can be used (Figure 5). The storage cask lid is removed, rigging is attached to the canister and a specially designed adapter plate is attached to the cask. The cask is then positioned under the fixed transfer cask and the UNF canister is hoisted into the transfer cask. The storage cask is then moved away and replaced with the transport cask - in a vertical orientation.



Figure 2 Horizontal Transfer at Rancho Seco



Figures 3 and 4 Horizontal Transfer at Big Rock Point



Figure 5 – Vertical Transfer using Shielded Transfer Cask System

The UNF canister can then be lowered into the transport cask and the lid bolted in place. A crane is then used to move the transport cask onto the rail or heavy haul vehicle, re-orientating it to the horizontal as it does so.

In all cases, impact limiters and a personnel barrier have to be added before the transport casks can be shipped.

Consolidated Storage Facility Concept

The five options for the CSF identified by the Systems study are:

1. Store UNF in canisters in above-grade storage casks. Use a water-filled pool or dry hot cell for repackaging UNF as required, either on receipt of the UNF or prior to its dispatch to the geologic repository.
2. Receive UNF in transportable storage casks and store as-is.
3. Receive “bare” (un-canistered) fuel, place it into canisters using a pool or hot cell and then into storage casks that can also be used for subsequent transport to the repository
4. Receive bare fuel and transfer it, via pool or hot cell to storage-only casks. This will require the UNF to be repackaged before transport to the repository.
5. Store the UNF in canisters in above-grade storage casks. No pool or hot cell would be provided at the CSF so it would be necessary to place all UNF in canisters at their origin sites where the shipping site retained the necessary facilities and also provide a pool or hot cell at the repository to handle un-canistered fuel sent directly to it.

It was recognized that all these options represented viable solutions, that they were not mutually exclusive and that a number of elements from all of them could be selected and combined into the following three-stage plan to establish the CSF, expanding its capabilities over a time period (Figure 6):

Stage 1: This is the receipt at the CSF of transportable storage casks only. This requires the construction at the CSF site of only a rail receipt interface and storage pad large enough for the number of casks that will be received. This stage allows the receipt of UNF and GTCC waste from the Humboldt Bay shut down site and from the seven currently operating sites that store UNF in transportable casks. This stage would enable 201 casks and approximately 2,780 MT of UNF to be moved to the CSF.

Stage 2: Construction of the CSF Canister Handling Facility, the Storage Cask Fabrication Facility, the Cask Maintenance Facility and supporting infrastructure is completed for Stage 2. Additionally the storage pad is expanded. This allows receipt of the UNF in canisters and the transfer of them from transport to storage casks. This construction can of course proceed during the operation of Stage 1. Stage 2 allows the receipt at CSF of all canistered fuel from both the shutdown and operating sites and it is proposed that receipt would be ramped up to provide a throughput of 400MT, 800MT, 1200MT, 1200MT per year and then to the maximum rate of either 2,000 or 3,000MT per year. This would enable the movement of all 3,600MT of “stranded” UNF at the shutdown sites within the first four years of CSF operation, including that from the currently operating Oyster Creek site which is expected to be shutdown in 2019. Following that, canistered UNF from all operating sites would be progressively moved to the CSF.

Stage 3: Construction and placement into operation of a water-filled pool repackaging facility is completed for Stage 3. This allows the receipt of uncanistered “bare” fuel, its packaging into canisters, placement into storage casks and pad storage. It also allows UNF already on the storage pad to be repackaged, if required, into suitable canisters for repository storage and disposal prior to export to the repository. The study considered both a pool and a hot cell as options to provide this capability. Ultimately the pool option was selected because of concerns about the risk in a hot cell if the fuel pellets of uranium dioxide (UO_2) in damaged fuel pins oxidize to U_3O_8 . The U_3O_8 is a fine powder and much more easily released from damaged fuel cladding than the sintered pellets of UO_2 , raising the possibility of significant radioactive contamination of a hot cell over time. Recovering the U_3O_8 powder for disposal

is also problematic. Although this issue could be mitigated by using an inert atmosphere in the hot cell, this adds complexity to the design and operations. In contrast there is a large amount of successful experience in the design, operation and maintenance of water-filled pools that can be drawn on.

By using this staged approach, the capital cost of the CSF is spread over a number of years. It also allows more time for a final decision on the geologic repository to be made. Selection of a repository will identify the appropriate disposal canister requirements. The disposal canister design may affect the design of the Pool Repackaging Facility.

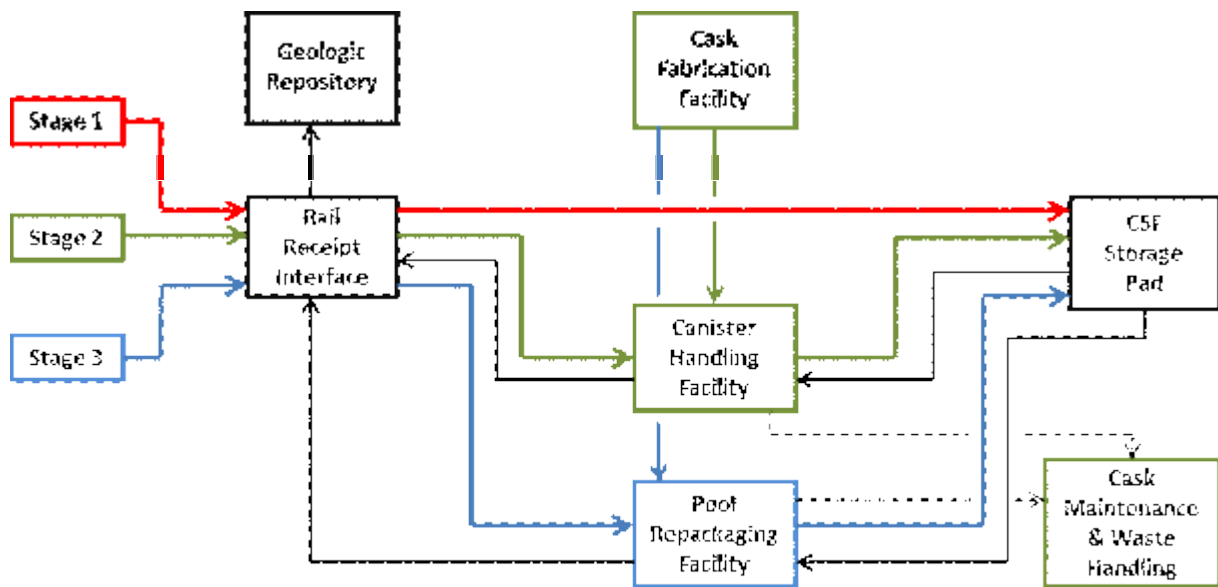


Figure 6 The Three Stages of CSF Construction

Transportation Challenges and Optimization

An analysis was carried out of the main challenges in planning and developing the transportation system to get the UNF from the utility sites to the CSF. This identified four major issues that will need careful resolution during the CSF design phase:

- Transport infrastructure (rail and road) around the shutdown sites has not been consistently maintained. In the case of rail, the infrastructure has often been abandoned when the need to routinely ship heavy equipment in or out of the site ceased, following reactor shutdown.
- The preferred transport method for UNF is rail, but the national rail network has changed, and in some cases parts have ceased to exist, since the last formal updates were completed in 2004 by the Office of Civilian Radioactive Waste Management. In other cases, new rail lines are being considered by municipalities hoping to support more economic activity.
- Acquisition and licensing of suitable railcars, escort and buffer cars for UNF transport that meet the Association of American Railroads standard S 2043 [3] present challenges. Such development and licensing is estimated to take at least 48 months.
- The order quantities for the railcars are likely to be very small in comparison with typical orders to railcar manufacturers (quantities of 10 or so against typical orders of thousands for the coal industry for example). Thus, either small specialist manufacturers will need to be used (with risks about their business stability) or the UNF railcar orders will need to be fitted in around larger manufacturers' big order schedules, potentially extending procurement times.

Optimization of the order of pickup of UNF is important, especially for the shutdown sites, and can have a range of driving factors such as minimizing the time to clear the shutdown sites, minimizing capital investment, minimizing transport casks required, and minimizing the number of rail routes required. If optimization is based on clearing the shutdown sites as quickly as possible, then a significant number of new transport casks would need to be purchased. However our analysis based on minimizing capital expenditures showed that a scheme could be devised that would still clear all the shutdown sites of UNF and GTCC three years after the start of CSF operations, significantly reducing cask costs, and would still consolidate 3,600MT of UNF at the CSF.

Licensing and Security

The CSF will be an NRC licensed facility and must “provide high assurance that activities at the facility do not constitute an unreasonable risk to public health and safety or the common defense and security”, as mandated in NRC regulation 10 CFR 73.51(b) [4]. The security program will thus need four major parts:

- Fixed site physical security plan (including training and qualification plan)
- Integrated contingency response plan
- Fuel transfer and receipt plan (including division of responsibilities between shipper and receiver)
- Safeguards Information protection plan.

Unlike the security organizations at the nation’s nuclear power plants, the CSF is not required to have an onsite armed response force. Response to unauthorized activities thus will rely more heavily on offsite forces; therefore liaison agreements and training for these offsite responders are critical.

Operational Secondary Waste

Only small amounts of Class A low level waste are expected to be generated by CSF operations. This will include building ventilation exhaust filters, spent ion exchange media from pool water clean-up, pool water filtering media, and liquid and solid wastes from decontamination of tools and equipment.

Decommissioning of the CSF

During the design of the CSF it will be necessary to take account of several issues that could impact decommissioning. These include using steel liners for casks to prevent contamination of the cask structure, using epoxy or other suitable materials to coat floor and wall surfaces for ease of subsequent decontamination, maintaining control of materials and consumables used so as not to create mixed wastes, and the selection of suitable casks materials to minimize the formation of activation products when they are in use.

CSF TOTAL LIFECYCLE COSTS FOR DIFFERENT OPERATING SCENARIOS

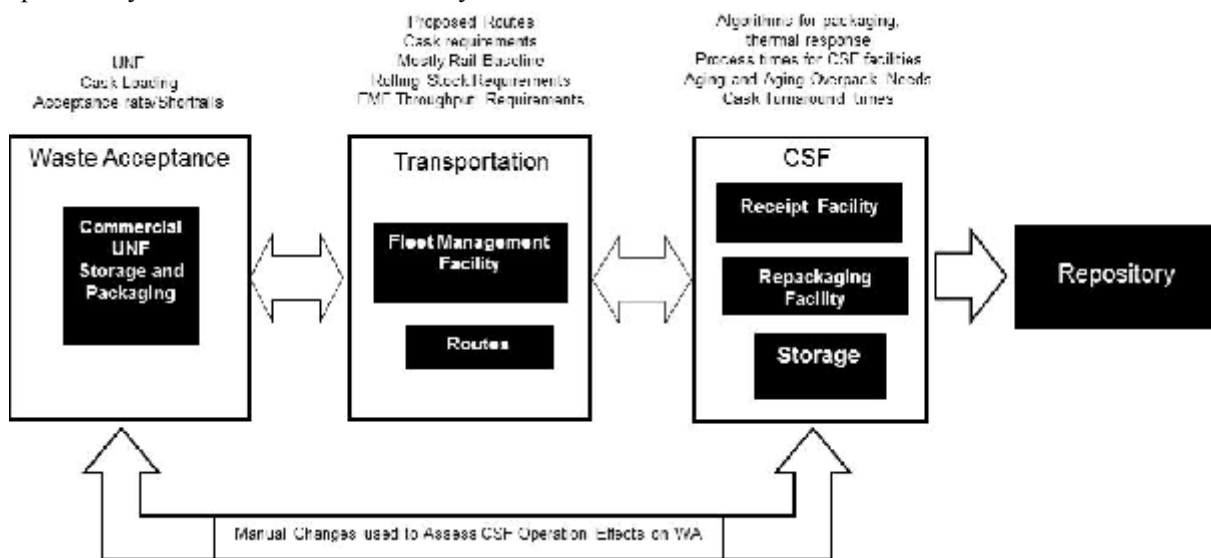
The Total System Model (TSM) [5] was used to perform a logistical analysis of six selected operating scenarios to enable a comparison of the total life cycle costs for each scenario to be made. These six scenarios are based on a range of assumptions including the number of CSF sites (1 or 2), UNF pickup order, CSF operational start date(s), UNF acceptance rates at the CSF, and the acceptance at the CSF of only canistered fuel, or acceptance of bare fuel also. During the present study the TSM was adapted from its previous form, which covered transport to the Yucca Mountain repository, so as to cover movement of UNF to the CSF or CSFs, and then movement onto an undefined repository. The six scenarios analyzed by the TSM for the present study are illustrative - in its adapted from the TSM can analyze any scenario constructed by varying the assumptions noted. Additional TSM analysis, beyond these six scenarios, will be required to optimize operations on the attributes and assumptions ultimately selected by DOE.

The Total System Model

The TSM was originally developed to simulate the Civilian Radioactive Waste Management System (CRWMS) mission for the Yucca Mountain project. The TSM, in its adapted form for this study, tracks UNF from discharge from the reactor, through transport, to receipt at the CSF. It also calculates the

various costs associated with onsite storage, transportation, and CSF storage. The TSM is an “event driven” simulator, which means that it models movement of objects in a sequentially connected series of processes or activities based on the events that occur. The main event that occurs is that the time of the simulation is continuously incremented in 8-hour time steps. The simulation progresses through the 8-hour steps until all waste cask loads are shipped, the cask loads are processed into waste packages, and the waste packages are emplaced at the CSF.

The modified TSM architecture is shown in Figure 7. Waste Acceptance (WA) is limited to commercial UNF, and the original repository model was modified to simulate the functions of the CSF. The repository element is modeled as a “black box” that merely receives output from the CSF. Two possible CSFs were assumed; one in the Western U.S. and one in the Eastern U.S. The modified TSM tracks the heat for each assembly from discharge to the reactor pool through receipt at the CSF; assembly heat is not tracked during storage at the CSF or repackaging for shipment to the repository. Since the scope of this present study is limited to CSF design and operation, transportation from the CSF to the repository is not specifically modeled but this can readily be added at a later date.



WA: Waste Acceptance
 FMF: Fleet Management Facility

Figure 7 Architecture of the Total System Model

The CSF Operating Scenarios

The six CSF operating scenarios studied in this work are shown in Table 3. The base case and the major changes from it are shown in bold italics. Key findings from this study were:

- The five scenarios which have a 3,000 MT/year nominal shipment rate, (1, 2, 4, 5 and 6), demonstrate similarly shaped throughput profiles (see example in Figure 8): a rapid build-up of storage at the CSF, followed by a gradual drawdown once shipment begins to the repository, until about 2077 for an assumed 2035 repository start (2083 for the assumed 2040 repository start for Scenario 5), after which the CSF serves as a repackaging facility for the repository.
- Scenario 3, which has a 2,000 MT/year nominal acceptance rate at the CSF (which does not reduce the inventory of UNF at operating sites, but does clean out shutdown sites and keep up with annual discharges), demonstrates a quite different profile (see Figure 9). The combination of a 2,000 MT/year acceptance rate and a 3,000 MT/year shipment rate from the CSF to the repository results in a smaller CSF storage buildup, followed by a rapid draw down of the CSF storage inventory once shipment to the

repository begins. By 2054, the CSF inventory is exhausted, and from that time on, the CSF serves as a repackaging facility for the repository.

- The perceived benefit of scenario 3 is that it cleans up the shutdown sites and keeps up with annual discharges thereby avoiding additional utility storage costs, while the CSF design has to provide storage for less than 20,000MT, this reducing CSF costs. However, the 2,000 MT/year shipment rate, while it stops the accumulation of UNF at reactor sites (and the increase in reactor storage costs), does not reduce the inventory in reactor storage until after 2035, when a significant number of reactors begin to shut down.

TABLE 3 Operating Scenarios for the CSF

Scenario	# CSFs (Sites)	Pickup Order	CSF Start	Receipt Rate	Acceptance Types	Repository Start
1 (Base Case)	1 CSF	Stranded Sites First	2025	3,000 MT/yr Maximum	TSCs and DPCs only	2035
2	1 CSF	TSCs First	2022	3,000 MT/yr Maximum	TSCs and DPCs only	2035
3	1 CSF	Stranded Sites First	2025	2,000 MT/yr Maximum	TSCs and DPCs only	2035
4	2 CSFs (1 East, 1 West)	Stranded Sites First	2025	3,000 MT/yr Maximum	TSCs and DPCs only	2035
5	1 CSF	Stranded Sites First	2025	3,000 MT/yr Maximum	TSCs and DPCs only	2040
6	1 CSF	Stranded Sites First	2025	3,000 MT/yr Maximum	TSCs, DPCs, and Bare UNF	2035

TSC – Transportable Storage Cask. (Cask and canister can be stored and transported without any repackaging)

DPC – Dual Purpose Canister. Canister can be used for storage and transport, but must be moved from storage cask into a transport cask before movement to CSF

Bare Fuel – UNF assemblies in a transport cask that must be moved into a canister and then a storage cask before they can be emplaced at the CSF

Life Cycle Cost Estimates

Each of the six CSF operating scenarios was analyzed to estimate its life cycle cost and hence cost per MT of UNF stored. The overall life cycle costs varied between about \$5Bn and \$7Bn with the cost per MT varying between \$38,000 to \$54,000. These costs are shown as multiples or fractions of the Base Case Scenario 1 costs in Table 4. A summary analysis of these cost estimates is as follows:

Scenario 1: The life cycle cost range at this pre-conceptual stage for the base case is estimated to range between 0.86 and 1.5 of the base figure used in Table 4, thus putting into perspective the variations shown for the other scenarios. Major cost drivers for scenario 1 include rail access design and construction, cask procurements, rail car procurements, transportation services, facility operations, and deactivation & decommissioning.

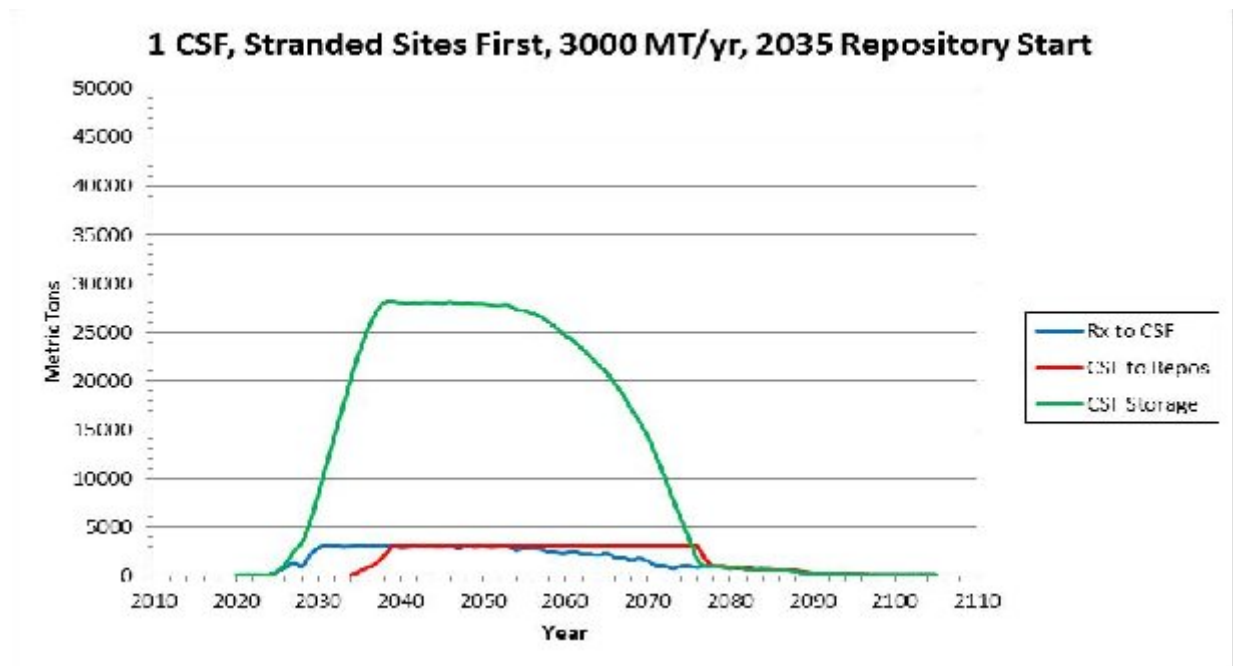


Figure 8 CSF Operating Scenario 1

“Rx to CSF” means receipt of UNF to CSF
 “CSF to Repos” means transfer of UNF from the CSF to the Geologic Repository
 “CSF storage” means the amount of UNF in storage at the CSF

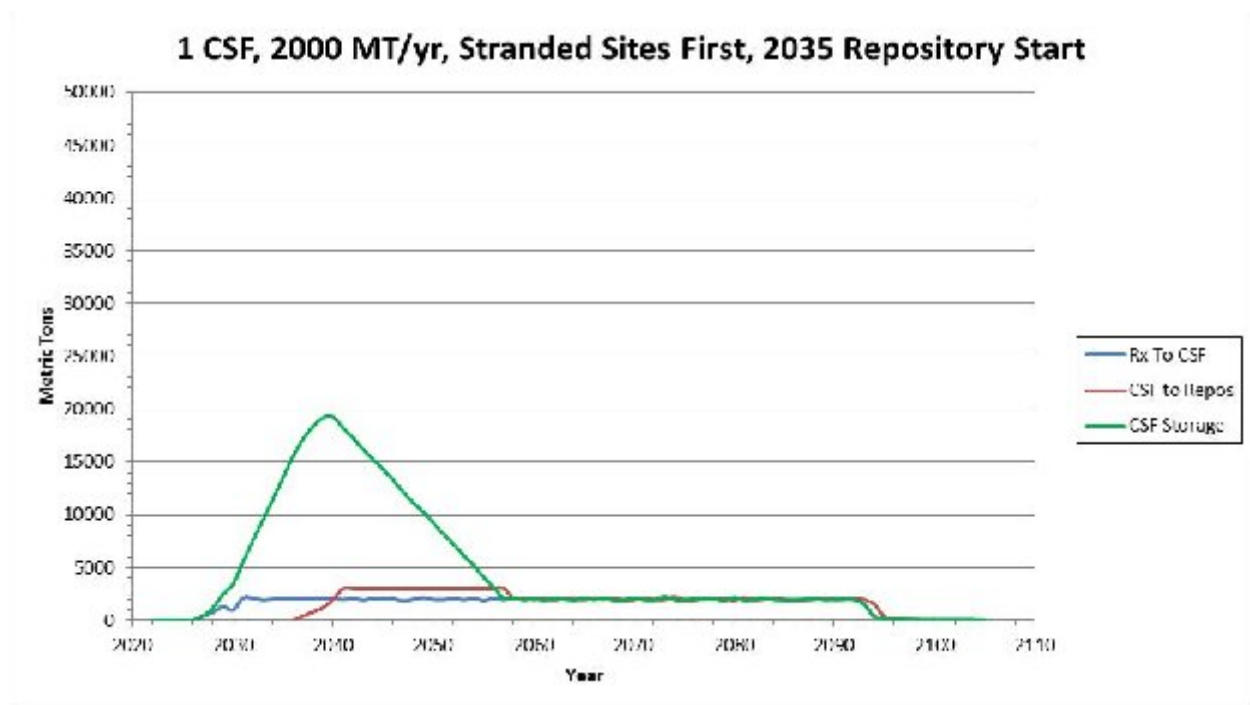


Figure 9 CSF Operating Scenario 3

Table 4 Comparison of Life Cycle Costs for the CSF

Stage	Phase	Description	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1	0	Front End Authorizations & Acquisitions	1	1.27	0.94	1.46	1.00	1.36
	II	Receive Canistered UNF in TSCs	1	1.00	1.00	1.61	1.00	1.00
2	III	Receive Canistered UNF in DPCs	1	1.12	0.89	1.66	1.18	0.99
3	IV	Receive Canistered & Uncanistered UNF	1	1.00	1.00	1.33	1.00	1.00
	V	UNF System Operations	1	1.04	0.90	1.08	1.07	1.50
4	VI	CSF Deactivation & Decommissioning	1	1.00	1.00	1.53	1.00	1.00
TOTAL CSF Life Cycle Cost			1	1.07	0.95	1.19	1.05	1.40

Scenario 2: This represents an increase from the base case due primarily to higher rail car requirements as well as increases in the number of storage casks at the CSF to accommodate the higher maximum storage at the CSF.

Scenario 3: This represents a decline from the point estimate for the base case. This is driven by the lower maximum acceptance rate which results in reduced rail car requirements, lower storage pad costs, and fewer storage casks to accommodate reduced maximum storage at the CSF.

Scenario 4: This represents an increase from the point estimate for the base case. Overall cost increases are driven by the higher aggregation of costs over the two CSFs, which is only partially offset by lower costs for the individual components. Further, costs for rail cars and casks remain essentially the same as for the base case, but there is a substantial drop in transportation costs due to the shorter transportation distances with two CSFs.

Scenario 5: This again represents an increase from the point estimate for the base case. The main reason for this is to accommodate increased storage casks at the CSF as driven by the later repository acceptance date.

Scenario 6: This represents a more significant increase from the base case. The main reason for this is to accommodate the acceptance of bare (uncanistered) UNF in transportation casks, which is mostly due to the increased requirements for storage canisters that will be needed to store the bare UNF on the CSF pad. In addition, there is some tradeoff between the base case and Scenario 6 regarding storage casks that are used for DPCs versus storage casks that are used for bare UNF storage canisters.

RESEARCH AND DEVELOPMENT OPPORTUNITES

There was a requirement during the course of this work to identify research and development opportunities that would have the potential to increase efficiency of UNF transport and storage and hence reduce costs. Three such opportunities were identified:

- **Standardized Transportation Casks.** A recommended R&D project is to investigate the practicability of achieving one cask design per vendor, that could handle all of the canisters that vendor has licensed and sold, and to find a means of incentivizing the vendors to adopt these. With the innovative use of spacers, sleeves and other adjustments, the inventory requirements, as well as the size and complexity of the cask maintenance facility, could be significantly reduced.

- **Standardized UNF Canisters.** The delay in developing a repository may create options for developing standardized canisters that were not viable if Yucca Mountain had been licensed. All of the Yucca Mountain operating schedules involved shipment of UNF directly to the repository from the utility sites. Standardized canister approaches under that scheme required packaging by utilities, which eliminated many options, due to their potentially negative impacts on utility operations. With an operating CSF that includes a pool repackaging facility, transitioning to a standard canister design can be done at just one or two sites, away from the utility sites, and that creates increased opportunities for more innovative and involved solutions than utilities could consider.
- **Rod Consolidation.** Rod consolidation takes fuel rods from existing assemblies and packs them more tightly together in purpose-designed consolidation canisters, thereby reducing transport and storage volumes and potentially increasing cask capacities for UNF. Criticality restrictions may also be eased by the restriction of space for water moderator to occupy, and heat transfer will likely be improved by rod to rod contact providing conduction in addition to convective heat transfer. An R&D project that demonstrates the reliability and potential operating throughput of a rod consolidation system using dummy assemblies would be a valuable first step. Once complete, the loading of several standard HLW canisters with consolidated rods from high burn-up irradiated assemblies as part of the long term fuel storage R&D project would allow collection of valuable data to support a final decision on including rod consolidation as part of the used fuel disposition plan.

CONCLUSIONS AND RECOMMENDATIONS

The EnergySolutions team was tasked with providing DOE with industry experience and input on viable concepts for the consolidation and storage of commercial UNF. As this paper has shown, there is not a “one size fits all” solution to addressing the consolidation and storage of commercial UNF. However, by addressing the problem through the practical and cost-effective steps and the staged approach documented in this paper, it is believed that a practicable and workable solution can be implemented. The combination of extended delays to repository development, challenges to the NRC’s waste confidence rule, steadily increasing federal liabilities for interim storage at reactor sites and legal challenges to government inaction, all conspire to make consolidated interim storage an idea whose time has come. With shorter design and licensing times than for a repository, a CSF could be up and running before any repository construction begins. Using the CSF to repackage UNF into disposal canisters could also shorten the overall schedules for actual waste emplacement by loading waste packages in parallel with repository development. The CSF can also provide a test case for transportation of large amounts of UNF to a repository. By starting small, interactions with corridor states and native American tribes can be worked out and difficulties can be resolved before a repository becomes operational.

Finally, a CSF makes strong economic sense for the shutdown reactors. A CSF offers economies of scale compared to operating the 9 shutdown reactor storage facilities. Development of a CSF for the stranded fuel at shutdown reactors would pay for itself with the savings from closing those 9 sites and eliminating their average reported cost of \$8M/year. A policy decision to use the CSF to store all UNF and as a gateway to the repository has other benefits to the overall used fuel management program as described in this paper.

In addition to the R&D opportunities identified in this paper, recommended projects for further study in the near term are:

- A survey and site visits to update transportation infrastructure data at shipping sites, and for the connection between shipping sites and a CSF.
- As only a limited number of scenarios could be analyzed within the time available for this task, further work is recommended to analyze additional scenarios in order to optimize logistics and cost for the CSF.

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- For the canister systems that are currently in storage, but are not licensed for transport, it is recommended that a more detailed study be undertaken to develop strategies and detailed proposals for transporting the contents of these types of canisters.

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