Nuclear Industry Study on the Feasibility of Standardized Transportation, Aging and Disposal Canisters for Used Nuclear Fuel - 14011

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ABSTRACT

Energy*Solutions* and its team partners, NAC International, Exelon Nuclear Partners, Talisman International, TerranearPMC, Booz Allen Hamilton and Sargent & Lundy, have carried out a feasibility study on the development and licensing of Standardized Transportation, Aging and Disposal (STAD) canisters for Used Nuclear Fuel (UNF). The study was funded by the United States (US) Department of Energy (DOE) in order to support a future decision regarding the development and licensing of a standardized canister system. The study determined that pursuing a single STAD canister design was not feasible at this time because the repository geologic characteristics, particularly heat load capacity, will not be known until a US repository site is selected. Instead, the study found that the development of three STAD canister size options should be pursued, with a down-select for fabrication of the largest canister size consistent with the heat dissipation requirements being made after a repository site is chosen and the heat dissipation capacity of its geology is known.

In addition, the study recognized that requiring nuclear power utilities to use any of these three STAD canister sizes, which are smaller than the large capacity canisters that they currently use (up to 37 PWR or 89 BWR fuel assemblies) for either initial packaging of UNF assemblies removed from pools, or as a re-packaging operation, would be highly labor intensive and thus likely unacceptable to them. It would have negative impacts on utility resources and their ability to produce power. So, a second recommendation from the study was that the UNF should not be removed from a site to a Consolidated Interim Storage Facility (CISF) until that site is shutdown and the reactor operations have permanently ended. Delaying required removal of UNF in this way thus removes the need for sites that are operating to undertake the labor-intensive packaging or re-packaging of UNF into STAD canisters. However, the study also found that operating plants which could benefit from shipping “bare” (i.e. uncanistered) UNF from spent fuel pools to a future CISF or Repository, rather than expanding their on-site dry storage, should still have that option. Packaging into STADs could then be done at the CISF as soon as the repository geology and its disposal regulations were known.

In support of the recommended development of the three STAD canister sizes, design concepts were developed, and structural, shielding, criticality and thermal scoping analyses were performed, for each option. Options for the transfer to the CSIF and the storage there of multiple numbers of the smaller STAD canisters were also identified and analyzed, as part of scenarios that covered moving UNF from both operating and shutdown reactors. The objective of this work was to ameliorate the logistical disadvantages associated with lower capacity canisters and to understand more fully the effect of moving UNF from shutdown and operating reactors, or only shutdown ones, on the complete system. This analysis was done using the “Total System Model” that was originally developed to optimize movements of UNF to the Yucca Mountain repository and which was modified to support the STAD study. In conjunction with the design and engineering work, an understanding was developed of the regulatory design constraints and how the design and licensing of multiple STAD canister sizes can be progressed absent a selected site for the repository and its associated disposal regulations. This was done by considering the main drivers for the long term performance of a disposal package and the use of a disposal overpack or waste package in conjunction with the STAD canister.

INTRODUCTION

In early 2010 the Blue Ribbon Commission on America's Nuclear Future (BRC) was chartered by the President to determine a workable path forward for the disposition of used nuclear fuel (UNF) from the nation's civil nuclear reactors and other nuclear wastes within the United States.

The BRC published its final report [1] in January 2012, and two of its major recommendations were that prompt efforts should be made to develop consolidated interim storage facilities for UNF, and similar efforts should be made to develop one or more geologic disposal facilities. Consolidated storage 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, 5 of which have recently been slated for closure) and also at the sites of already shutdown reactors. The DOE's response to these recommendations was a Strategy Document published in January 2013 [2]. This document recommended that, with appropriate authorizations from Congress, a program should be implemented over the next 10 years that:

- Sites, designs and licenses, constructs and begins operation of a pilot consolidated interim storage facility (PISF) by 2021 with an initial focus on accepting "stranded" UNF from shutdown reactor sites;
- Advances toward the siting and licensing of a larger consolidated interim storage facility (CISF) to be available by 2025 that will have sufficient capacity to provide flexibility in the waste management system and that allows for acceptance of enough UNF to reduce expected government liabilities under the Nuclear Waste Policy Act (NWPA);
- Makes demonstrable progress on the siting and characterization of geologic repository sites so as to facilitate the construction and commencement of operations of a geologic repository by 2048; with the repository site selected by 2026, and the site characterized, designed and licensed by 2042.

To assist in realizing these goals DOE placed two contracts with several industrial teams, one of which was led by Energy*Solutions* and included NAC International, Exelon Nuclear Partners, Talisman International, TerranearPMC, Booz Allen Hamilton and Sargent & Lundy. The first of these contracts was completed during the period July 2012 to January 2013. This work developed a design concept for all activities needed to take UNF from its current storage modes and locations at both operating and shutdown reactor sites, repack it as needed for transport, transport it to a CISF, repack it as needed for storage, place it in storage and then operate and maintain the facility. This study is described in detail in a separate paper [3].

The second contract, which is the subject of the present paper, was completed from September 2012 to June 2013. This study looked at the feasibility of the development, licensing and use of Standardized Transportation, Aging and Disposal (STAD) canisters and casks. These would ultimately replace the significant range of canisters and casks currently in use at the nuclear reactor sites that are currently, and increasingly, being used by the utilities to move UNF presently stored in reactor pools into dry storage so as to make space available in the pools for newly discharged UNF.

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 (canister-in-cask) storage at the 65 operating sites that have the 104 operating reactors, and at the eight shutdown reactor sites that have solely "stranded" UNF located at them in dry cask storage. This balance will now change due to recently announced reactor shutdowns at San Onofre CA (2 reactors), Kiwaunee WI, VermontYankee VT and Crystal River FL. These reactors will, during decommissioning, move all their UNF to dry storage so that the fuel pools can be decommissioned.

The Table also shows two shutdown sites with UNF in pool storage. One of these is the Zion site in Illinois which is currently undergoing decommissioning and which will also ultimately move all its UNF to dry cask storage. The other is the Morris IL reprocessing site at which reprocessing was never started and that will likely continue to retain pool storage.

The UNF is currently stored at the reactor sites in four systems:

1. Transportable Storage Cask (TSC)
The cask and inner canister can be transported to the CISF and stored there without need for repackaging. There are only a limited number of reactor sites that store UNF in this way - and re-canistering will likely still be required for repository disposal.

2. Single Purpose Canister (SPC)
The canister can be used only for UNF storage – within a concrete cask. It is not suitable for transportation so re-canistering will be needed before the UNF can be moved away from the reactor site. Further re-canistering may be required again for repository disposal unless STADs are used for the reactor site re-canistering.

3. Dual Purpose Canister (DPC)
The canister can be used for transport and storage, but must be transferred from storage cask to transport cask before movement to the CISF – and then transferred to a new storage cask. Re-canistering may again be required for repository disposal.

4. Bare Fuel
These are UNF assemblies in pool storage or in transport casks that can be moved to the CSIF as they are, but must be placed into a canister and enclosed by a storage cask before dry storage at the CISF.

The bare fuel represents the biggest opportunity for the use of STADs. If these can be provided so that the first and only move of the UNF assemblies, either at the reactor site or the CISF, is into a STAD, all subsequent needs for repackaging are avoided.

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 CISF is in operation. The Morris IL site is expected to keep its fuel in pool storage until it is moved to the CISF.

The total stored UNF amounts to almost 70,000 metric tons (MT). It can be seen from Table 1 that most of this UNF (53,667 MT or 78w% of the total) is currently still in pool storage as 186,244 bare fuel assemblies, thus potentially representing a good opportunity to use STADs. The remaining 15,252MT or 22w% is in 1,342 dry storage casks. However, pool storage is almost maxed out across the reactor fleet, so the ~2000 MT of “new” UNF that arises annually and has to go to pool storage, will displace an equal amount of UNF annually into new dry storage, again presenting a potential opportunity to use STADs. However, the dry storage canisters currently in use by the power utilities were developed by them around their specific needs and the applicable licensing requirements. As a consequence, existing dry storage systems have not been designed to meet any specific geologic repository disposal criteria, and the utilities are currently using various designs of large dry storage systems with canister capacities up to 37 pressurized water reactor (PWR) or 89 boiling water reactor (BWR) fuel assemblies. The installed base of dry storage systems includes both single purpose (storage only) and dual purpose (storage and transportation), although all of the newer generation of dry storage system are dual purpose. These storage canisters are significantly larger than any STAD that is likely to be designed, the Utilities favoring such large canisters because they reduce the effort required, and worker does uptake incurred, to load a given amount of UNF.

In the absence of clear plans for the movement of this dry stored fuel to consolidated storage or a repository and for the use of STADs, the power utilities will continue to use these large canisters and casks, so as to minimize their own effort required to canisterize UNF and place it into the casks. Although an evaluation is in progress by the US National Laboratories of the suitability of these large canisters for repository disposal, the thermal management constraints of the disposal concepts under consideration [4] do generally limit the number of UNF assemblies per canister to a smaller number than contained in the large canisters. This is of course dependent on the geology and hence heat dissipation characteristics of the repository but, with the cessation of the Yucca mountain project, this geology is currently unknown. Therefore the casks and canisters being used by the power utilities will be at least partially, and maybe largely, incompatible with future transport and repository requirements, meaning that some if not all, of the UNF that is moved to dry storage by the utilities will ultimately need to be repackaged. This situation will unfortunately continue into the future until a repository is identified and a STAD design can be finalized.

For the operating sites, this repackaging and cask loading can be accomplished using the equipment, infrastructure and trained and experienced workforce that are available on site, employed by the power utility operating the site. 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.

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	Potentially[2]	57.9
Haddam Neck, CT	Dry cask	NAC STC-26	45	Potentially[2]	412.3
Humboldt Bay, CA	Dry cask	HISTAR HB	6	Yes[3]	28.9
LaCrosse, WI	Dry cask	NAC LACUMS	5	Potentially[2]	38.0
Maine Yankee, ME	Dry cask	NAC UMS-24	64	Potentially[2]	542.3
Morris, IL[1]	Pool	--	--	Potentially[2]	674
Rancho Seco, CA	Dry cask	NUHOMS 24	21	Potentially[2]	228.4
Trojan, OR	Dry cask	HISTORM 24	34	Potentially[2]	358.9
Yankee Rowe, MA	Dry cask	NAC MPC-36	15	Potentially[2]	127.1
Zion, IL	Pool	--	--	Potentially[2]	1019
Totals			**198**		**3,487**

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 CISF.

Note 2: All of the canisters inside storage casks at the shutdown sites are transportable, but they will need to be removed from their storage cask and placed in overpacks before they can be transported.

Note 3: The UNF at Humboldt Bay is stored in canisters and casks that are suitable for transport without modification.

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, when the full CISF is planned to be operational. 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 can be 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.
It is against this complex situation that the design and use of STADs needs to be considered. Three goals were identified for this study:

Goal 1: Minimize impacts on reactor utilities as they perform their primary function of safely producing electricity,

Goal 2: Minimize wasted investment in large UNF canister and cask storage systems where the canisters are not suitable for repository disposal and the casks are not suitable for transport,

Goal 3: Maximize the operating efficiency of the integrated waste management system by centralizing repackaging functions as much as possible.

The study described in this paper set out to achieve these goals, recognizing that they are partially in opposition to each other. However, it is possible to identify an order of priority for removing UNF from reactor sites that provides the best balance of achievement for the three goals:

1. Remove UNF from shutdown reactor sites, repackaging if required at the CSIF; preferably using STADs, if these are available,
2. Remove bare UNF from pools at operating reactor sites, transport it to the CISF and package it there; preferably into STADs, if these are available,
3. Remove bare UNF from pools at recently retired reactors, package it preferably into STADs, if these are available; doing so either at the reactor site or at the CISF,
4. Remove dry-stored UNF from recently retired reactors, re-packaging it into STADs as necessary and when these become available; doing so either at the reactor site or at the CISF,
5. Remove dry-stored UNF from operating reactors, re-package if it is necessary to do so for transport, transport it to the CSIF and re-package it as necessary into STADs, when these become available.

A Systems Engineering multi-step approach was used for this study, and included a detailed consideration of STAD optimum sizes, their design, criticality assessment, materials of construction, regulatory compliance, lifecycle costs and timelines for their introduction.

INTEGRATION OF STADs WITH THE CONSOLIDATED STORAGE SCHEME

The Consolidated Storage Scheme developed by Energy*Solutions* and its team partners under a previous DOE contract, and reported in a separate paper [3], is shown in Figure 1. It comprises three stages, with the intention of spreading the capital cost over a number of years, and enabling UNF that is already in transportable containers to be moved to the CISF as quickly as possible. The present study considered the use of STADs in conjunction with this scheme for the CSIF.

Stage 1: This is the receipt at the CISF of transportable storage casks only. This requires the construction at the CISF 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 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 CISF.

Stage 2: Construction of the CISF 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 all 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 CISF of all DPC 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 CISF operation, including that from the currently operating Oyster Creek site which is expected to be shutdown in 2019. Following that, DPC canistered UNF from all operating sites would be progressively moved to the CISF.

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 STADs as soon as these become available, placement into storage casks and pad storage. It also allows UNF already on the storage pad in large canisters to be repackaged into STADs as required for ultimate repository storage. Both a pool and a hot cell were considered as options to provide this capability and a pool selected because of the likely need to inert a hot cell and because of the familiarity of designers and industrial operators with handling UNF in pools.

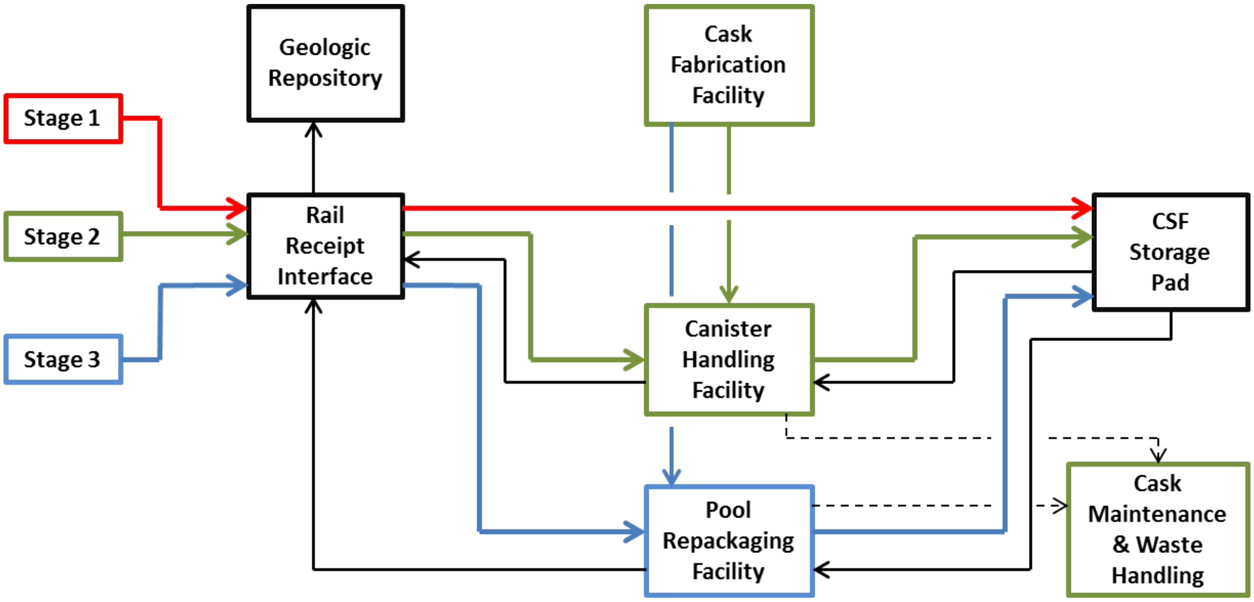

Figure 1 The Three Stages of CISF Construction

THE SYSTEMS ENGINEERING APPROACH

A five-step Systems Engineering approach was used to perform the STAD canister feasibility study:

Step 1: Review existing information, define functional criteria, establish framework
Step 2: Brainstorm options and downselect to a shortlist of STAD canister systems
Step 3: Develop the selected STAD canister systems
Step 4: Assess the system-wide implications and impacts of the selected options
Step 5: Assess how, where, when the selected STAD canister systems could be deployed.

Steps 1 and 2 quickly showed that pursuing a single design of STAD, in the absence of a known repository location and design, and hence knowledge of its geology and heat dissipation performance, was not feasible. Repository types under consideration for the US [4] include ‘open’ designs with ventilation and formed in unbackfilled granite or shale, backfilled sedimentary rock (which uses pre-closure ventilation while the drifts remain open and uses low permeability buffer/backfill at closure) and unsaturated hard rock. These repositories can generally deal with higher heat loads per UNF canister than can the ‘enclosed’ unventilated repositories also under consideration and formed in crystalline rock (eg granite), clay/shale and salt, though of these three, salt has the highest heat tolerance.

If it is required that a STAD should be compatible with the most restrictive enclosed repositories, namely those in enclosed granite or clay/shale, then if long (>100years) pre-emplacement storage times to allow cooling are to be avoided, the STAD could contain no more than 4 PWR or 12 BWR UNF assemblies. An enclosed repository in a salt medium would allow canisters containing up to 12PWR or 32BWR UNF assemblies, while open repositories in unbackfilled granite or shale could accept canisters containing up to 24PWR or 68 BWR UNF assemblies. By way of comparison, the ventilated ‘open’ Yucca Mountain repository was being designed to accept Transport Aging and Disposal canisters containing 21 PWR or 44 BWR UNF assemblies with a maximum heat load of 18kW.

Of course, a STAD containing 4 PWR or 12 BWR UNF assemblies would be compatible with any future geologic repository but, if its relatively lower heat output was not required, it would be an inefficient canister to use – unnecessarily increasing the number of operations and the amount of material needed to canisterize a given amount of UNF, increasing transport costs, and increasing the space required for storage at the CSIF. The study showed that it would take 5 times longer to package a given amount of UNF in the small STADs than it would when using large STADs, underlining the incentive to use larger STADs if the repository medium and its design allows it. Therefore, this study selected three STAD sizes for development in Steps 3 through 5:

Small:	(4 PWR or 9 BWR UNF assemblies)
Medium:	(12 PWR or 32 BWR UNF assemblies)
Large:	(24 PWR or 68 BWR UNF assemblies

The study showed that it would be cost effective to immediately carry out design and licensing work for all three sizes of STAD and then, once the geologic repository and its geology and heat dissipation characteristics are known, to downselect to the largest size possible. That way only the fabrication time would remain before STADs could be put into use.

STAD CANISTER SYSTEM CONCEPTS

The small, medium and large STADs identified in this study are illustrated in Figure 2, which shows how they would be used for both PWR and BWR UNF assemblies. These STADs can accept PWR and BWR UNF assemblies with fuel burnups up to 80GWD/ton and 70GWD/ton respectively, and with fuel initial enrichments in U-235 of up to 5wt%. In addition to intact PWR and BWR assemblies, the STADs will also accommodate partial, damaged and Mixed Oxide fuel assemblies.

The STADs consist of right circular cylinder shaped shell assemblies with shielded top ends and a tube-and-disk style basket assembly to hold the UNF. The top end shield plug and top plate provide structural support and shielding to reduce operator dose rates during canister closure operations. The inner basket design can be modified to introduce more neutron absorbing material for the medium and large STADs that will contain PWR UNF, providing the additional criticality control required by these UNF assemblies and by the larger STADs that have reduced radial neutron leakage. Borated stainless steel is used in ‘egg-crate’ basket designs to provide long-term criticality control in the repository. The basket design is such that no structural credit is taken for this material for storage and transportation certification, and no bending or welding of it is required, in accordance with the DOE TAD specification [5].

Due to the small size and low payload capacities of small STAD canisters (4 PWR and 9 BWR), the total quantity of these required to accommodate the entire used fuel inventory will be significantly larger than that for the larger STAD canister concepts. However, due to the small diameter of the small STAD canisters, it is possible to package multiple small STAD canisters in a storage and transportation overpack. This would go some way towards mitigating the transport disadvantages of the small STAD canister. For example, up to four small STAD canisters will fit within a large DPC-sized transportation cask having a 72-inch diameter cavity. Within such a transportation cask cavity, the four STAD canisters would be supported by an internal basket structure with a relatively thick top shield plate to provide shielding of radiation streaming axially between the canisters during canister loading operations. A similar configuration of three small STAD canisters within a transportation cask may be used if a smaller transportation overpack is required.

Criticality Analysis

Scoping level criticality assessments were performed using the industry standard Monte-Carlo N-Particle code [6], and based on the bounding characteristics of all UNF currently in storage in the US. For this study, the analysis was confined to intact, undamaged fuel. Some degree of burnup credit was assumed in a conservative actinide-only basis for transportation licensing, this being the limiting criticality condition because of the condition that ingress of water to the canister interior must be assumed to occur. For repository disposal, the STADs conform to the Yucca Mountain TAD specification requirements.

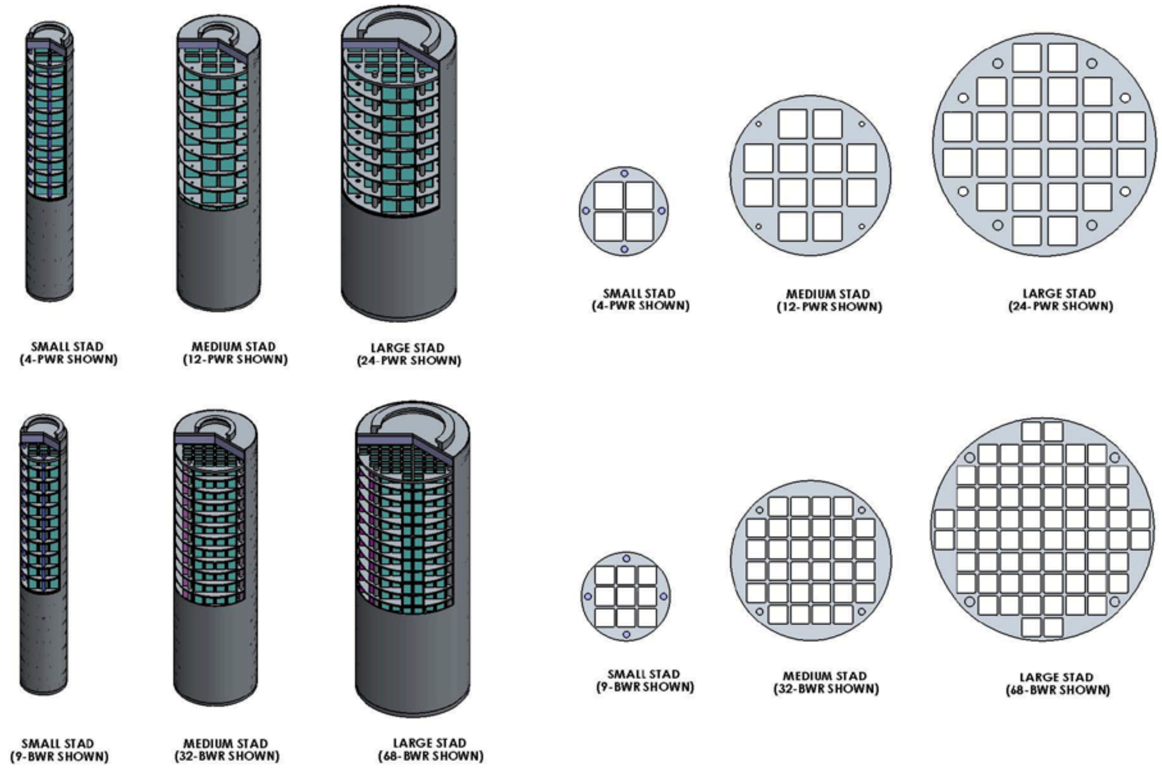

Figure 2: The Three Sizes of STADs

Structural Design and Evaluation

The STAD designs are based on existing Dual Purpose Canister designs with component thicknesses for the large STAD held at the values used for the larger DPCs, and reduced proportionally for the medium and small STADs. Lifting ring sizes for the large STAD are the same as for the DPC and as specified in the DOE TAD specification, but are scaled down for the medium and small STADs to reflect the smaller diameters and reduced weights of these STADs. For the internal basket designs, scoping level structural evaluations were carried out using Finite Element Analysis methods for a conservative upper bound equivalent static side drop load of 75g. During detailed design more exhaustive evaluations of the STAD canister designs will be required, but the current evaluations provide a good level of assurance that the STAD conceptual designs are acceptable for the full range of design loadings that they will experience during transportation and on-site storage.

Shielding Evaluation

The STAD internal spacer plate designs are very similar to those used in DPCs, which provide adequate shielding for payloads that are larger than those for the STADs, so the neutron dose outside the STADs is expected to be lower than that outside DPCs. External gamma dose rates are relatively insensitive to canister size or payload, so again the STADs are expected to perform similarly to, or better than, the DPCs. For storage there is effectively no limit on the cask wall thickness that can be used to reduce external dose rates further. For transportation however, strict size and weight limits do limit the thickness of extra shielding that can be used. For small and medium STADs this will not be an issue because of their relatively small size. In these two cases, limitation on the number placed in single transport casks will enable adequate shielding to be used so that relatively short cooled UNF can be transported. For the large STAD, however, the larger diameter and weight of the STAD will limit transport cask shielding, thus potentially imposing quite long cooling times for the UNF before it can be transported. An option if these STADs are to be used would be to ship bare fuel to the CISF and place it into STADs there, so that the longer cooling time could take place at the CSIF rather than the reactor site.

Thermal Evaluation

The current generation of large DPCs accommodates between 32 and 37 PWR assemblies per canister, compared with 16 PWR assemblies in four small STADs that could be transported in one transport cask, 12 PWR assemblies for medium STADs and 24 PWR assemblies for large STADs. So the already acceptable DPC thermal characteristics for transport will bound those for the STADs and in fact there is potential for the heat load per UNF assembly to be allowably higher when using STADs than when using DPCs, possibly allowing UNF with shorter cooling times to be transported. However, as is indicated in the Shielding Evaluation section, the required assembly cooling times for transport are more likely to be bounded by shielding and allowable external dose rates, so in practice it will likely not be possible to realize this advantage of the STADs.

REGULATORY COMPLIANCE

Developing viable concepts for a new STAD canister that could be used for transportation, storage and disposal requires an understanding of the regulatory design constraints. The regulations that apply to transportation (10 CFR 71) and storage (10 CFR 72) are well understood and have been in common use for many years, even though the licensing requirements under the two parts are not perfectly harmonized. For example, the licensing Certificate of Compliance (COC) period for a transportation cask is five years, but the COC period for a storage cask is up to 40 years. These disconnects have been addressed through amendments and other efforts by the licensing applicants over the years, and this has made the licensing system workable. Now the Nuclear Regulatory Commission (NRC) is considering changes to the regulations to better harmonize the requirements for transportation and storage. Both transportation and storage cask licenses are based on a set of deterministic performance requirements that make the design process fairly straightforward. The regulatory changes being contemplated do not appear to change the basic design and safety requirements.

Regarding regulations for disposal, unfortunately no new generic regulations have been promulgated. Some portions of the existing 10 CFR 60 and 10 CFR 63 would be considered for any new rulemaking but it is not currently clear what approach would be taken for a new generic disposal regulation. Long term performance of a disposal package is determined more by corrosion performance and criticality prevention than by anything else. In the Yucca Mountain license application, no corrosion protection credit was assigned to the canister in the disposal configuration and instead all of the corrosion credit was provided by the disposal overpack, which was to be made of highly corrosion resistant INCONEL (alloy 22). Regardless of the geologic media selected for future repositories in the US, a similar assumption could be made regarding STAD canister design requirements but, in the absence of a repository scheme and its licensing, this is not certain.

If the long term corrosion performance requirements were to be met by a disposal overpack or waste package, and the STAD canister system only had to deal with thermal and criticality issues in the disposal environment, there is a path forward for design of the STADs prior to development of new repository licensing requirements. That approach would be to design the three STAD canister sizes previously described to meet the deterministic requirements for transportation and storage. Designing and licensing a small, a medium, and a large canister would bound the acceptable ranges of thermal loading for any repository geology that is selected. These initial STAD canister designs would also be engineered to meet the worst case criticality constraints for ultimate disposal.

The use of such conservative STAD canister designs would minimize the disposal licensing risk, particularly since the STAD canister is likely to be a minor component in the overall engineered barrier system. To expedite STAD canister development, topical reports could be submitted to the NRC describing an integrated approach to meeting disposal requirements for the selected STAD canister size. These topical reports would help map the process for adding disposability to the canister licenses as part of the overall repository engineered barrier system. Interactions with the NRC over those topical reports would be beneficial for both the canister disposal licensing and development of the engineered barrier disposal system. This approach would allow the deterministic licenses for storage and transportation to proceed under 10 CFR 72 and 10 CFR 71, with conservative enveloping design approaches to criticality prevention over the long term and would provide material compatibility with potential disposal overpack (or waste package) designs.

Once a future UNF repository is licensed for initial operations, refinements to the repository design might be pursued that would have operational safety and cost benefits. Continuous advancements in modeling, in materials science and in other aspects of repository design should be incorporated through license amendments during the repository’s operational life. Evolutionary improvements to the STAD canister design should be contemplated as changes to the initial license are proposed.

ANALYSIS OF STAD CANISTER SYSTEM SCENARIOS USING THE TOTAL SYSTEM MODEL

A range of STAD canister system concepts and CSIF UNF acceptance scenarios were analyzed using the Total System Model (TSM) with the aim of identifying how the variables affect overall lifecycle costs. The TSM was originally developed for the Civilian Radioactive Waste Management System and used extensively for evaluations of the Yucca Mountain operating strategies. It was modified and adapted for this work, and for the previous study [3], to enable it to be used to evaluate scenarios that include STADs and the CSIF. The scenarios studied assumed the PISF, CSIF and Repository start dates indicated in the DOE’s strategy document [2] and covered variations in three key parameters:

1. Acceptance by the CSIF of UNF from (i) both operating and shutdown reactors, or (ii) only from shutdown ones
2. Acceptance by the CSIF of UNF (i) in DPCs & TSCs only, (ii) as bare fuel and in DPCs & TSCs, or (iii) in STADs and then in DPCs & TSCs
3. STAD canister size - small, medium, large, plus the Yucca Mountain size 21PWR/44BWR canister.

Scenarios which accept from both operating and shutdown reactors DPCs & TSCs only, correspond to the 'Baseline Schedule' (Figure 3), while all other scenarios correspond to the 'Cost Optimized Schedule' (Figure 3). The major conclusions from this TSM analysis were:

1. Decreasing STAD sizes increases, as would be expected, the processing time at reactors, the number of shipments, the number of CISF storage casks required, the receipt and processing requirements at the CSIF, and the radiation dose to the workforce. The incentive is therefore to use as large a STAD as the repository geology allows, once it is known, which for this study is assumed to be 2026 when the repository is sited.
2. Shipping bare UNF in casks from operating reactors and from shutdown reactors that still have pools, instead of placing it in existing large capacity DPC canisters first, increases the number of shipments and hence transport costs, but significantly shortens the receipt period, because there is no need to open DPCs at the CSIF. This also allows the UNF to be loaded into STADs at the CSIF as soon as the repository geology is known, thus minimizing wasted expenditure on canisters that are not compatible with the repository and the consequent re-packaging that would be required.
3. Waiting until reactors are shutdown, but still have their pools, before shipping fuel from them to the CSIF enables smaller STADs to be used rather than larger DPCs (once the repository geology is known). This does increase transport costs but results in shorter acceptance periods (because no repackaging is required), shorter storage periods (because more of the storage time is at the reactor) and eliminates the cost of using and then disposing of the large DPCs.
4. The lower the canister heat limit imposed by a future repository, the longer will be the transportation period of the greater number of canisters from CSIF to the repository, and the longer the CSIF will be required to operate, increasing costs for both.

TIMELINE FOR STAD CANISTER INTRODUCTION

The TSM analysis led to two STAD canister development schedules being developed during this study: (i) "Baseline" and (ii) "Cost Optimized". As a starting point for the production of a detailed STAD canister development schedule, the Team used the key milestone dates from the DOE's strategy document [2] in conjunction with the following assumptions about how current elements of the waste management system would work in the future:

- Operating nuclear reactor sites will not accept packaging UNF into any canister that requires more labor and takes more time per ton of fuel collected than the dry storage canister systems currently being used;
- Operating nuclear reactor sites may, nevertheless, be willing to load bare UNF from spent fuel pools into bare UNF transportation casks and should be supported if they wish to do this;
- No repackaging of existing transportable dry storage systems using welded canisters will be done at reactor sites. All of these canisters will be shipped to the CSIF or repository for any repackaging required;
- Shutdown reactor sites that still have spent fuel pools and other plant capabilities should have the option of packaging bare UNF from pools into STAD canisters or loading bare UNF into bare UNF transportation casks;
- Shutdown reactor sites that still have spent fuel pools and other plant capabilities may be willing to re-package UNF from bolted lid dry storage systems into STAD canisters for shipment to a CISF or repository;
- The cost of designing and licensing STAD canisters is small compared with the overall waste management system and the cost of delays to final waste disposition;
- Design and licensing of any new STAD canister based system will take 3+ years, followed by an initial fabrication lead time of 2 years.

The Baseline development schedule (Figure 3) assumes a desire to minimize the project scope risk associated with pursuit of canister designs before all repository requirements are identified and understood. This results in acceptance of higher life cycle waste management costs. The Cost Optimized development schedule is an alternative approach to interim management of UNF pending the opening of a repository, which accelerates the expenditure of capital funds on CISF repackaging facilities and on the development of STADs, and offers an accelerated shift to storage technologies that directly support disposal. However, the Cost Optimized approach does carry project scope and schedule risk, if the final licensing of the STADs, once the repository characteristics are known, requires modification to the already existing STAD designs and licensing assumptions. This might be, for example, because the expectation that overpacks could take care of disposal requirements turns out to be incorrect. Keys to the success of the Cost Optimized case are the following four pre-requisites:

1. Design and licensing (but not fabrication) of all three STAD canister sizes (a small, medium and large STAD) before the repository host site is selected (as opposed to the Baseline Case where the STAD canister configuration is not established until the repository site is selected).
2. Earlier construction of the spent fuel pool and wet repackaging capability at the CISF;
3. Contract negotiations with the utilities to support packaging bare UNF into STAD canisters after each reactor ceases power production permanently;
4. Design and licensing of dry storage and transportation systems that can accommodate UNF in a STAD canister configuration.

Overall the two STAD canister development schedules analyzed by the Team each have advantages and disadvantages. Figure 3 shows the key elements of the two options side by side.

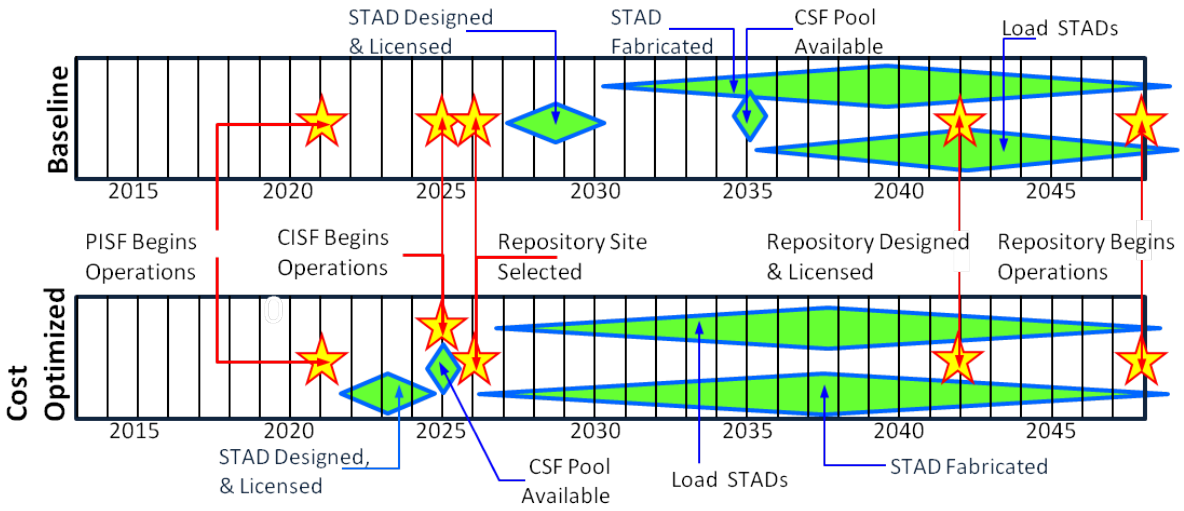

Figure 3: Comparison of Key Milestones in the Baseline and Cost Optimized STAD Canister Development Schedule

LIFECYCLE COSTS FOR DIFFERENT STAD INTRODUCTION STRATEGIES

The TSM analysis enabled lifecycle costs for the Baseline and Cost Optimized schedules (Figure 3) to be estimated. In the Baseline schedule, the capital costs for construction of major facilities at the CISF are spread out over a much longer time period. This would reduce annual operating costs by delaying construction of the CSIF pool until the latest time needed to accept bare fuel from the reactor operators, and to prepare STAD canisters for emplacement in the selected repository’s engineered barrier system. The downside of this approach is that utilities will continue loading UNF, removed from their pools to make room for newly discharged UNF, into large DPCs. Due to the heat load associated with their large storage capacity and the nature of their criticality controls, large DPCs are not likely candidates for direct disposal, so repackaging into STAD canisters is likely ultimately to be required. Each of these expensive canisters purchased therefore represents a large sunk cost that does not contribute to the permanent disposition of the UNF.

The Cost Optimized approach accelerates the expenditure of capital funds on CISF facilities and makes a repackaging pool available much sooner than in the Baseline schedule, thus enabling the CSIF to accept much sooner bare fuel from operating reactors and avoiding it being placed into large DPCs. Design, certification and fabrication of STAD canisters also should occur much faster in the cost optimized schedule. This adds to both the capital and operating costs in the near term. On the balance, this approach offers an accelerated shift to storage technologies that accommodate disposal requirements and limitations. The TSM model analysis showed that this accelerated move to a storage solution that is integrated with final disposition of the waste could reduce life-cycle costs within the range $340 to $670 million, although the need to design and license in advance all three STAD canister sizes instead of only one size as in the Baseline Case, would add an additional $13.1 million to the reduced cost. These life cycle cost savings realized by the Cost Optimized approach arise in three primary areas:

i. Fewer DPCs to purchase and load

   Assuming the dates in the DOE January 2013 Strategy Document [2], and the presently known plans for the existing reactor fleet shutdown are realized, fewer DPCs will ultimately need to be purchased and loaded with UNF if design and licensing for three STAD canisters commences before final selection of the repository site. STAD canister design and licensing is expected to take approximately three years, with an upper schedule estimate of five years, and will be done in parallel with the final work to site and characterize the repository. Procurement of the appropriate size STADs could then start immediately the repository geology was known. This would therefore cut the design and licensing time from the overall schedule duration. If STAD canisters are thus available for loading three to five years earlier, 400 to 650 fewer large DPCs will need to be purchased, respectively[1]. The cost savings from purchasing fewer DPCs could range from $320 - $520 Million.

ii. Fewer DPCs to dispose

   This STAD feasibility study has assumed that after the DPCs are unloaded they will have no future value and will have to be disposed. Having fewer DPCs to dispose will result in life-cycle cost savings of $20 to $32 Million.

iii. Fewer DPCs to unload and transfer fuel into STAD canisters at the CISF

   Operations at the CISF may or may not change significantly for the scenarios we have evaluated. When fewer DPCs need to be unloaded, life-cycle cost savings of $80 - $120 Million may be achieved.

The optimal schedule for STAD canister development is highly dependent on the Nation’s priorities, the actual dates that are achieved for repository siting and placing into service, the actual dates of shutdown of the existing reactor fleet, and the level of project scope and schedule risk that is considered acceptable. As previously noted, this scope and schedule risk concerns the early completion of STAD canister designs that could subsequently be affected by repository performance and licensing requirements and thus require rework. The schedule will also be affected by contract negotiations with the utilities, and on the timing for the required authorizing legislation.

DEVELOPMENT OPPORTUNITES

The National Laboratories are already doing studies on thermal load management in all possible repository geologies and the consequent potential for direct disposal of DPCs. This work has the potential

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[1] These purchases will not impact what has traditionally been DOE’s cost for the program because the utilities have been purchasing the DPCs, and then compensated for the purchase and storage of the DPCs from the Judgment Fund, a Department of Justice account. However, recent DOE Office of Nuclear Energy policy is to evaluate the true life-cycle cost to the taxpayer, so these savings should be considered.

ultimately to influence the STAD canister sizes that are selected. A part of the study described in this paper was to identify potential additional areas of development work that would augment the work already being done, and the following development areas were identified:

1. Development of a standardized storage and transport cask, and auxiliary systems for dry storage
2. Production of conceptual designs for engineered passive heat removal systems from the repository
3. Development of, and agreement on, a list of the most likely geological characteristics for a future repository – so as to assist in focusing the design and licensing of STADs
4. Investigation of the most economic means of disposing of DPCs after the UNF they have contained is transferred to STADs
5. Investigate opportunities for the containment of other wastes such as Greater Than Class C and secondary wastes, using STADs
6. Survey all existing reactor utilities to determine which would prefer to store UNF on site until their reactors are shutdown, and which would prefer to ship bare fuel direct from their pools for packaging at the CISF
7. Identify what incentives may be necessary to offer reactor utilities, and what amendments to the DOE standard contract might be required, to encourage as much bare UNF shipment from reactors to the CSIF as possible, and to support the use of STADs (when they become available) instead of DPCs where dry storage is required .
8. Verify crane capacities at all reactor sites to check the feasibility of loading medium, large or multi STAD canister configurations into transport casks.

CONCLUSIONS

1. This study concluded that, with the current reactor fleet UNF storage pools essentially full, all future arising of “new” UNF that goes into the pools will displace an equal amount of longer cooled UNF into dry storage. The utilities will therefore need to place into canisters an annual amount of UNF equal to the ~2000 tons of UNF that is discharged annually from all US nuclear reactors.

2. This study recommended that a single size of STAD canister cannot be adopted at this time, in advance of knowing the future repository site, its geology and hence its heat dissipation characteristics. These characteristics will dictate the number of UNF assemblies that can go into a STAD and hence its size. Although a small 4-UNF assembly STAD would likely be compatible with all repository geologies, using such small STADs would be wasteful, unless it is absolutely necessary, because of the increased numbers of STADs, increased work and radiation dose uptake, and increased materials required to package a given amount of UNF.

3. It was therefore recommended that three, (small, medium and large), STAD canister sizes should be designed and licensed, containing respectively 4PWR/9BWR, 12PWR/32BWR and 24PWR/68BWR UNF assemblies. It was also found that there are schedule advantages, and hence lifecycle cost savings, if the design and licensing is done for all three sizes of STAD in advance of the repository site being identified. Downselection to a single size and fabrication of these could then start immediately after the repository and its geology are identified.

4. It was found that requiring utilities to package all future UNF into small or medium STADs, once the repository had been sited, the STAD canister size fixed and their fabrication begun, but while their reactors were operating, would unacceptably absorb too many of their resources and place increased demands on their storage pools, because of the significantly larger number of canisters that they would have to handle. Packaging UNF into small or medium STADs should thus only be required after reactor shutdown.

5. However, utilities that wish to use STADs as soon as they become available, and those that wish to ship UNF bare for placing into STADs at the CISF should nevertheless be supported, as this would

help to minimize the number of large DPCs that the utilities will otherwise use and from which the UNF will ultimately have to be repackaged into STADs.

6. The optimum time to start designing, licensing, fabricating and then using STADs, and hence the optimization of lifecycle costs, is highly dependent on expectations for the date of placing into service a repository, and on the schedule for shutdown of the existing reactor fleet. Both of these are currently very uncertain, making it difficult to make a definitive optimization of lifecycle costs. This study's examination of both Baseline and Cost Optimized scenarios provides, in conjunction with the TSM, the means to re-examine and re-optimize as and when schedule expectations change or become firmer.
7. Whatever approach is ultimately adopted, it seems inevitable that some, or even most, UNF will need to be repackaged from the large DPCs used by the utilities into smaller STADs suitable for repository disposal. To mitigate the consequences of this it is recommended that (i) National Laboratory studies should continue to identify the feasibility of direct disposal of some DPCs to a repository and (ii) studies should be started to identify the most economic means of disposing of DPCs after their UNF has been transferred to STADs
8. The repackaging of UNF from DPCs to STADs should preferably be performed at the CSIF which can have facilities designed for this specific purpose, rather than at reactor sites, even when shutdown, that don't have such purpose-designed facilities.

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