Task Order 12 – Standardized Transportation, Aging, and Disposal Canister Feasibility Study

RPT-3008097-000

Prepared by: AREVA Federal Services LLC

REVISION LOG

Rev.	Date	Affected Pages	Revision Description
1	6-21-13	2, 5, E-28	Changes DOE nomenclature on page 2 Replaced Figure 2 in Executive Summary; Deleted Section E.2.1.2..

DISCLAIMER

Under the Standard Contract (10 CFR 961.11), DOE is obligated to accept only bare spent nuclear fuel. Acceptance of canistered spent nuclear fuel would require an additional amendment to the Standard Contract.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF TABLES

LIST OF ACRONYMS

A&A	Advisory and Assistance
AAR	Association of American Railroads
AFS	AREVA Federal Services
AHP	Analytical Hierarchy Process
ALARA	As Low As Reasonably Achievable
BWR	Boiling Water Reactor
CHC	Cask Handling Crane
CHF	Cask Handling Facility
CoC	Certificate of Compliance
CSF	Consolidated Storage Facility
D&D	Decontamination and Decommissioning
DCSS	Dry Cask Storage System
DOE	Department of Energy
DOE EM	Department of Energy Environmental Management
DOE NE	Department of Energy Office of Nuclear Energy
DOE UFD	Department of Energy Office of Used Nuclear Fuel Disposition
DSC	Dry Storage Canister
EBS	Engineered Barrier System
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FA	Fuel Assembly
FFBD	Functional Flow Block Diagram
GTCC	Greater-than-Class-C
GWD	Gigawatt/day
HLW	High-level Waste
HSM	Horizontal Storage Module
ID	Inside Diameter
INTEC	Idaho Nuclear Technology and Engineering Center
ISFSI	Independent Spent Fuel Storage Installation
ISG	Interim Staff Guidance
LLW	Low-level Waste
MTU	Metric Tons Uranium
NFST	Nuclear Fuel Storage and Transportation
NMSS	Nuclear Material Safety and Safeguards (NMSS)
NP	Nuclear Plant
NRC	Nuclear Regulatory Commission
NWTRB	Nuclear Waste Technical Review Board

LIST OF ACRONYMS (cont.)

OD	Outside Diameter
OD/C	Outside Diameter/Consolidated
OD/U	Outside Diameter/Unconsolidated
PA	Protected Area
PWR	Pressurized Water Reactor
R&D	Research and Development
RAI	Request for Additional Information
RP	Radiation Protection
RTD	Resistance Temperature Detector
SE	Systems Engineering
SFP	Spent Fuel Pool
SFST	Spent Fuel Storage and Transportation
SME	Subject Matter Expert
SNM	Special Nuclear Materials
SOW	Scope of Work
SQ/C	Square/Consolidated
STAD	Standard Transportation, Aging, and Disposal
TAD	Transportation, Aging, and Disposal
TAN	Test Area North
TN	Transnuclear
TPC	Total Project Cost
TRIZ	Theory of Inventive Problem Solving
tUNF	Tons of Used Nuclear Fuel
UNF	Used Nuclear Fuel
U.S.	United States
VSM	Vertical Storage Module

Executive Summary

Under Task 12 of the industry Advisory and Assistance (A&A) Contract to the Department of Energy (DOE) DE-NE0000291, the AREVA Team has conducted a systems engineering (SE) evaluation in accordance with DOE order 413.b in which we evaluated the alternatives for developing a Standard Transportation, Aging, and Disposal (STAD) canister for handling used nuclear fuel (UNF) stored and generated at United States (U.S.) reactor sites. The study, based on specific criteria and requirements for the U.S., considered numerous credible canister options for a STAD and selected those that best met the needs of the country when multiple geological repository options were considered. Based on a projected timeline of activities for UNF management through to placement in a geological repository, the AREVA Team reviewed and identified various options for loading the STAD at a reactor site and a consolidated storage facility (CSF), as well as managing STADs at a geological repository.

To complete the SE evaluation successfully, we assembled a team of subject matter experts (SMEs) that could draw on a wide range of relevant U.S. and international experience in managing UNF. The AREVA Team used senior SMEs from AREVA Federal Services (AFS), AREVA Nuclear Plant (NP), Transnuclear (TN) URS, the U.S. utilities Duke Energy and Dominion, and a woman-owned small business, Coghill Communications, Inc. The technical team of SMEs joined together to conduct this study represents 250 years’ experience in the nuclear industry.

The AREVA Team has more than 50 years’ experience conceptualizing, planning, designing, and implementing complex engineering and SE for the nuclear industry using state-of-the-art tools and processes. This experience includes first-of-a-kind projects like designing the TAD canister at Yucca Mountain for DOE, participating in the Multi-Purpose Canister System Evaluation for DOE, and performing Task 11, Development of Consolidated Storage Facility Design Concept. Since this task and Task 12 are closely linked and to ensure continuity between Tasks 11 and 12, the technical resources were predominantly the same. Our utility partners operate some of the largest dry UNF storage facilities in the U.S. and have U.S. experience managing and transporting UNF between operational reactors.

Purpose of the Study

The UNF dry storage industry is mature. Since the mid-1980s, 8 cask vendors have provided approximately 12 cask systems comprising more than 30 different cask types, none of which have been considered for disposal in a geological repository. A variety of dry fuel storage systems have been, and continue to be developed and deployed with a trend moving to larger and larger canisters. Of the more than 65,000 Metric Tons Uranium (MTU) of UNF generated to date, approximately 24 percent is stored in more than 1,500 dry storage canisters (DSCs). The amount of fuel transferred from wet to dry storage is expected to increase to a rate of approximately 100 DSCs per year. The nuclear industry is currently using large dry storage systems with canister capacities of up to 37 pressurized water reactor (PWR) or 89 boiling water reactor (BWR) fuel assemblies. These systems are either single purpose (storage only) or dual purpose (storage and transportation). None are currently licensed for disposal.

In contrast to UNF storage and transportation regulations and performance expectations, regulatory and performance requirements for UNF disposal are uncertain. Direct disposal of the large canisters currently used by the commercial nuclear power industry is beyond the current experience base globally and represents significant engineering and scientific challenges. There is also a real risk that many of these larger-canister designs will not be suitable for some of the geological repository types currently under consideration. As a point of reference, it took more than 20 years to develop the design and technical basis for the relatively high-temperature disposal concept pursued in the U.S. until 2010. That design used large waste packages accommodating 21 PWR or 44 BWR assemblies. This can be compared to the smaller waste packages analyzed in *Generic Repository Design Concepts and Thermal Analysis (FY11)* that would be needed to implement the disposal concepts for clay/shale and crystalline media (Table 1). Repackaging of fuel from larger to smaller canisters for disposal may be required to avoid extensive surface decay storage, to meet physical constraints on disposal systems, or because additional criticality controls are necessary.

Table 1. Cask Capacity Comparison

<table>
<tr><th colspan="4">Existing DSC Systems</th></tr>
<tr><td colspan="4">24 – 37 PWR or 52 – 89 BWR assemblies</td></tr>
<tr><th colspan="4">DOE 2008 TAD Canister System*</th></tr>
<tr><td colspan="4">21 PWR or 44 BWR assemblies</td></tr>
<tr><th colspan="4">Generic Repository Design Concepts**</th></tr>
<tr><td>Mined Crystalline</td><td>Mined Clay/Shale</td><td>Mined Bedded Salt</td><td>Deep Borehole</td></tr>
<tr><td>4 PWR or 9 BWR assemblies</td><td>4 PWR or 9 BWR assemblies</td><td>4+ PWR or 9+ BWR assemblies</td><td>1 PWR or 1 BWR assembly</td></tr>
<tr><td colspan="4">**Transportation, Aging, and Disposal Canister System Performance Specification*, WMO-TADCS-000001, Rev. 1, ICN 1, Department of Energy 2008.
***Generic Repository Design Concepts and Thermal Analysis (FY11)*, FCRD-USED-2011-000143 Rev.0, August 2011.</td></tr>
</table>

The DOE Office of Nucler Energy, Office of Fuel Cycle Technologies, Nuclear Fuel Storage and Transportation (NFST) Planning Project sought input from industry to conduct a formal SE analysis related to the study for the feasibility of development, loading, and licensing of STADs for managing UNF in the U.S. The canister system is the fundamental link that integrates UNF storage at the utilities to ultimate disposal at the geological disposal site; hence, the canister design is dependent upon the collective functional needs and requirements of all anticipated operations within the waste management system and will be a function of the final geological repository selected.

Timeline for UNF Consolidation

An important concept that must be understood when conducting a study of this type is the timeline associated with the proposed management of UNF in the U.S. The management of UNF will take many decades to accomplish and even under the best scenarios will last past the end of this century. For example, based on recent DOE statements, a geological repository will be identified, designed, licensed, and operational by the year 2048. By that time, we will have close to 140,000 tons of UNF (tUNF) in storage. Figure 1 illustrates that if we move UNF at the rate of 3,500 tUNF per year to the geological repository, it will take 30 to 40 years to position the UNF in the repository. This places us around the year 2100. The current fleet of light water reactors in the U.S. will undergo a further round of licensing extensions in the next 20 years and, in the time frame we considered in this study, we expect all of the current reactors to shut down. This lengthy time frame presents risks and uncertainties, but also opportunities in the management strategy proposed for UNF.

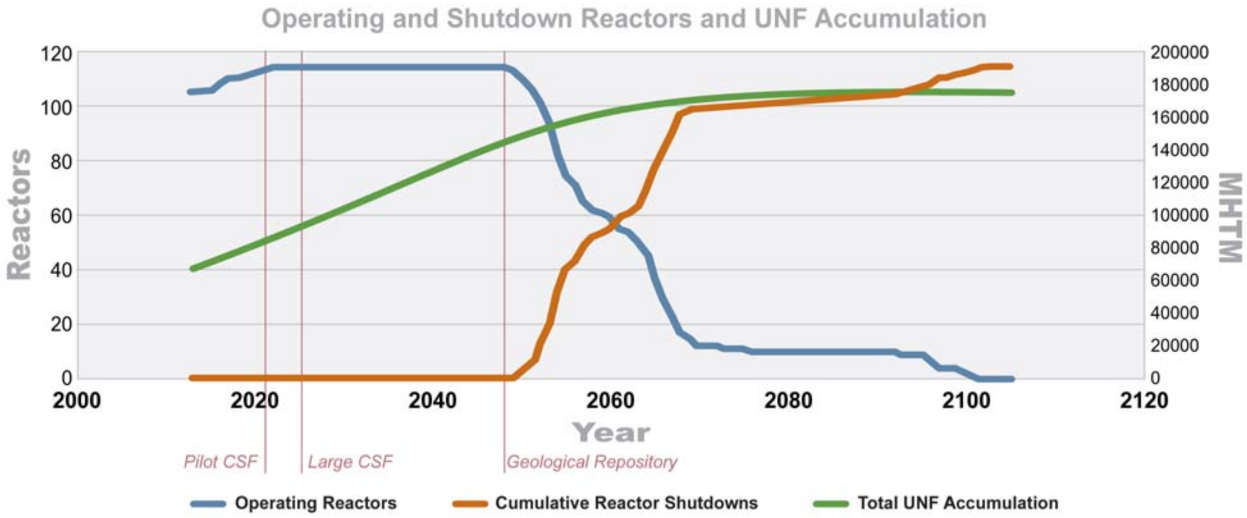


Figure 1. Concept Timeline for UNF Management in U.S.

Overview of Project Execution

To conduct the SE evaluation, the AREVA Team developed a problem definition and viable technical options and then conducted the SE evaluation of the options considering five types of geological repositories. At the same time, and based on industry and utility experience, we considered loading options for the canister at the reactor site, the CSF, and the benefits to the geological repository when handling a single canister design.

It is important to recognize that until a geological repository is selected, the final design of the STAD that is optimized for the geological repository cannot be created. Therefore, the design licensing manufacture of the STADs is linked to the repository selection. During this time, utilities will continue to load UNF into large 10 CFR Part 72-licensed DSCs. At each stage of the study, research and development (R&D) needs were captured and a rationale developed for the optimum loading strategy for each loading location assuming:

- Pilot CSF opens in 2021.
- Large CSF opens in 2025.
- No geological repository will be available until 2048.
- Site selection for the geological repository occurs in 2026 allowing the final design and licensing of the STAD to commence.
- Current loading of the UNF fuel in 10 CFR Part 72-licensed DSCs continues until such time as an alternative is available.

For the immediate future, there is a perceived difficulty with loading small STADs at a reactor site. However, this is tempered by the fact that, for the time frame we are discussing (Figure 1), if staged correctly, STADs could be loaded at a reactor site once the reactor is closed for decontamination and decommissioning (D&D).

- Unloading 10 CFR Part 72-licensed DSCs and loading STADs at a CSF for most of the UNF already in storage is a viable option until such time as reactors start to shut down when loading at the reactor site could be considered.
- R&D associated with automating the loading of casks at the reactor site, CSF, or geological repository will make the STAD concept more appealing to industry by reducing risk and dose associated with handling UNF.
- The development of a dry unloading system for repackaging UNF at a reactor site will not be viable if implemented at all reactor sites in the U.S. However this may be viable if utilities or regions of the country are willing to consolidate UNF at a site making the economics of dry unloading at the reactor site more attractive.

The Team conducted the study and SE evaluation to better integrate storage (standardized canister concepts) into the UNF management system for the back end of the fuel cycle.

Conclusions

The AREVA Team of SMEs conducted an SE evaluation in accordance with the procedure in DOE order 430.B that considered the use of eight different designs of STADs loaded wet and dry at the reactor site, CSF, geological repository, or a combination of all loading options while optimizing the system to take account of one of five final geological repositories. The study considered loading the STAD while the reactor was still in operation and when it was shut down. The AREVA Team’s recommendation is to carry forward three canister options (one small, one medium, and one large) to the conceptual and preliminary design phases. We further recommend that STAD options and the path forward be re-assessed at the completion of the conceptual and preliminary design phases as regulatory and performance requirements for UNF disposal mature and become more certain.

Based on the timeline outlined by DOE, a pilot facility in 2021, CSF in 2025, a geological repository by 2048, and assuming a licensing timeline similar to Yucca Mountain, the site selection process would be complete in early 2026. Assuming optimum parallel development and licensing for the STAD, it is possible that the STAD could be licensed for use by the end of 2026. At this time a significant amount of UNF will be located at the CSF and it is recommended that this fuel be loaded into the STADs and shipped to the geological repository. Figure 2 provides a graphical depiction of this timeline.

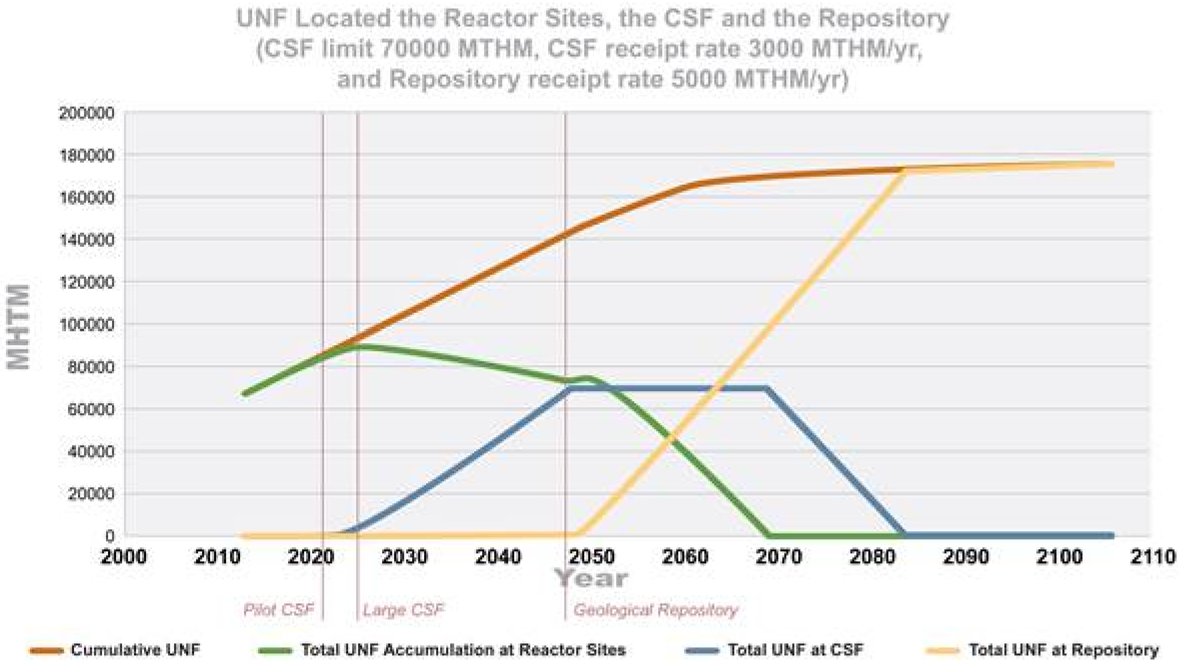


Figure 2. UNF Management Scenario Assuming Operational Reactors Operate for 80 Year

Extensive studies were conducted and documented in white papers to explore loading STADs in normal operations at the plant. The Team spoke with a large cross section of utilities to develop a time and motion study and identify areas where we could speed up the process. In the large majority of cases, the current physical constraints of the spent fuel pool (SFP) and the surrounding infrastructure was the limiting factor that stopped the processing of multiple STADs at once without redesigning the SFP building and associated infrastructure.

A lot of discussion with our utility partners and advisory panel revolved around the use of STADs at the reactor site. Common ground was found when considering loading the STADs in the SFP when the reactor shuts down and the utility has a financial incentive to load fuel quickly into dry storage and close the SFP. Loading UNF STADs during reactor shut down could allow approximately 40 percent of the UNF generated to be loaded at the reactor site. This number should be caveated with the fact that this is highly dependent on when reactors shut down and the individual utility.

Several of the utility partners we discussed STADs with have made the offer to consider loading STADs now. We strongly encourage DOE to continue the study to explore this in more detail and develop a business plan that would consider a demonstration of STAD loading to proceed.

Recommendations

The AREVA Team suggests that DOE:

- Continue the design of small, medium, and large STADs until such time as the repository is selected.
- Develop a business plan for the adoption of the STAD when the reactor enters D&D.
- Enter into discussions with the utility partners that have offered to load STADs as a demonstration of the technology. After discussing the STAD concept with utility partners, we have made a lot of progress. It is important that we maintain this momentum.

1.0 INTRODUCTION

The UNF dry storage industry is mature. Since the mid-1980s, 8 cask vendors have provided approximately 12 cask systems comprising more than 30 different cask types, none of which have been considered for disposal in a geological repository. A variety of dry fuel storage systems have been, and continue to be developed and deployed with a trend moving to larger and larger canisters. Of the more than 65,000 MTU of UNF generated to date, approximately 24 percent is stored in more than 1,500 DSCs. The amount of fuel transferred from wet to dry storage is expected to increase to a rate of approximately 100 DSCs per year. The nuclear industry is currently using large dry storage systems with canister capacities of up to 37 PWR or 89 BWR fuel assemblies. These systems are either single purpose (storage only) or dual purpose (storage and transportation). None are currently licensed for disposal.

In contrast to UNF storage and transportation regulations and performance expectations, regulatory and performance requirements for UNF disposal are uncertain. Direct disposal of the large canisters currently used by the commercial nuclear power industry is beyond the current experience base globally and represents significant engineering and scientific challenges. There is also a real risk that many of these larger-canister designs will not be suitable for some of the geological repository types currently under consideration. As a point of reference, it took more than 20 years to develop the design and technical basis for the relatively high-temperature disposal concept pursued in the U.S. until 2010. That design used large waste packages accommodating 21 PWR or 44 BWR assemblies. This can be compared to the smaller waste packages analyzed in *Generic Repository Design Concepts and Thermal Analysis (FY11)* that would be needed to implement the disposal concepts for clay/shale and crystalline media. Repackaging of fuel from larger to smaller canisters for disposal may be required to avoid extensive surface decay storage, or to meet physical constraints on disposal systems, or because additional criticality controls are necessary. The AREVA team conducted an SE evaluation in accordance with the procedure in DOE order 430.B that evaluated the optimum size and deployment of STAD canister for handling UNF stored and generated at U.S. reactor sites.

In the initial phase of the SE evaluation the team of SMEs carefully reviewed the work scope prepared by DOE and identified eight credible options for the STAD, five potential geological repositories, and identified supporting white papers that would be prepared to support the decision process in the SE evaluation. Options for loading the STADs wet or dry at a centralized interim storage site, CSF, at the reactor site, and at the geological repository were documented. Extensive discussions were held with our utility partners and numerous other utilities on the use of the STAD at the reactor site and at the CSF. This input from the utility partners continued for the entire duration of the study and provided significant input and guidance to the SE evaluation.

Based upon the DOE response to the Blue Ribbon Commission (BRC) on the future of nuclear energy in the U.S. several UNF scenarios were considered that assumed:

- Pilot CSF opens in 2021.
- Large CSF opens in 2025.
- No geological repository will be available until 2048.
- Site selection for the geological repository occurs in 2026 allowing the final design and licensing of the STAD to commence.

- Existing reactor fleet continued operating until they reached the age of 60 to 80 years when they would shut down.

The SE approach conducted was divided into three major phases:

- Problem Definition
- Initial Investigation
- SE Analysis, Conclusion, and Recommendations

The formalized SE approach was used to consider the options identified against the scenarios available to the Team to determine the optimum size of the STADs that should be carried forward and the location where the STADs should be loaded based upon a credible timeline for the U.S. nuclear industry over the next 100 years. Because the Team used this formal approach, external reviewers can recreate the thought process used when we rejected options considered as non-feasible, developed evaluation criteria, weighted evaluation criteria, performed evaluations, and made recommendations. The following sections of the report and associated appendices describe in detail the SE process that was conducted by the AREVA Team, our conclusions, and recommendations to DOE NE.

1.1 Compliance with the Scope of Work (SOW)

Table 1-1 provides a crosswalk between the required DOE SOW and where our response is provided within this report.

Table 1-1. SOW Crosswalk

No.	SOW Requirement	Section
1	The DOE is seeking technical ideas and recommendations, supported by evaluations/analyses on approaches to better integrate storage (standardized canister concepts) into the waste management system. For example, things we would like evaluated include, but are not limited to: how can we standardize given the current situation described above, especially with respect to disposal unknowns.	6.0, App D
2	The DOE is seeking technical ideas and recommendations, supported by evaluations/analyses, on approaches to better integrate storage (standardized canister concepts) into the waste management system. For example, things we would like evaluated include, but are not limited to: should we carry different standardized canister sizes forward depending on disposal unknowns.	6.0, App D
3	The DOE is seeking technical ideas and recommendations, supported by evaluations/analyses, on approaches to better integrate storage (standardized canister concepts) into the waste management system. For example, things we would like evaluated include, but are not limited to: are there only certain elements of the total waste management system where standardization is feasible.	6.0, App D
4	The DOE is seeking technical ideas and recommendations, supported by evaluations/analyses, on approaches to better integrate storage (standardized canister concepts) into the waste management system. For example, things we would like evaluated include, but are not limited to: thermal limits have been set, but are they really an issue, etc.	6.0, App D 10.0
5	This work will require coordination with and input from work that is being conducted	10.0

No.	SOW Requirement	Section
	by the UFD Campaign National Laboratories and Industry Support Contractors regarding the Systems Architecture work, ongoing generic geologic disposal evaluations, and Consolidated Storage Facility Design Concepts (Task Order 11).	
6	This work will input from the nuclear utility industry and cask vendor community.	6.0
7	It is important that any STAD canister be consistent with the nuclear industry's high level of plant operability.	9.0
8	In addition to the physical constraints below, functional analyses should include evaluation of operational throughput needs associated with managing their UNF pools to maintain plant operations.	6.0, App D
9	The management, planning, loading, and transfer of UNF from pools to dry storage systems can be a complex process and involve the use of plant resources that have other competing demands on their time as well as dose considerations. These competing demands can impact the canister-loading throughput.	7.0
10	In order to facilitate utility acceptance of STAD canisters, impacts on utility resources and ability to produce power must be minimized and eliminated.	6.0, App D
11	Applicable laws, rules, directives, and standards with which the project must comply will be identified.	11.0
12	Specific items for consideration will include but are not limited to: Licensing Requirements for the Independent Storage of UNF, High Level Radioactive Waste, and Reactor Related Greater than Class C 10 CFR 72.	6.0 11.0
13	Specific items for consideration will include but are not limited to: Storage Handling Requirements, At reactor.	6.0
14	Specific items for consideration will include but are not limited to: Storage Handling Requirements, At ISFSI.	6.0
15	Specific items for consideration will include but are not limited to: Storage Handling Requirements, At repository.	6.0
16	Specific items for consideration will include but are not limited to: Transportation Requirements. • 10 CFR 71	6.0 11.0
17	Specific items for consideration will include but are not limited to: Transportation Handling Requirements.	6.0
18	Specific items for consideration will include but are not limited to: Repository Issues.	6.0
19	The technical services includes technical ideas and recommendations supported by analysis and evaluation that are provided in a report format necessary to support a future DOE decision regarding the development and licensing of a standardized canister system.	6.0
20	Things that should at a minimum be considered in development of this report include: 1) ongoing UFD Campaign work related to Systems Architecture (including draft Concept of Operations), Generic Geologic Disposal Evaluations, and Consolidated Storage Facility Design Concepts (points of contact for the National Labs and UFD Consolidated Storage Design Concepts A&AS Contractors will be identified).	6.0

No.	SOW Requirement	Section
21	Things that should at a minimum be considered in development of this report include: 2) identification and consideration of site-specific limitations that may impact the various STAD-related storage and transportation options at each nuclear utility.	6.0
22	Things that should at a minimum be considered in development of this report include: 3) utility canister and loading campaign approaches and strategies.	2.0-6.0
23	Things that should at a minimum be considered in development of this report include: 4) assessment of STAD canister impacts on the total waste management system for scenarios that include consolidated interim storage facilities.	6.0
24	Things that should at a minimum be considered in development of this report include: 5) regulatory requirements (including assumed disposal requirements).	6.0, 11
25	Things that should at a minimum be considered in development of this report include: and 6) development of assumed goals, objectives, and functional requirements of a STAD system.	2.0 3.0
26	STAD Feasibility Report identifying, as a minimum: 1) identification of STAD system scenarios considered (including canister sizes);	5.0, App A-D
27	STAD Feasibility Report identifying, as a minimum: 2) overall impacts (including advantages and disadvantages) of each scenario.	5.0, App A-D
28	STAD Feasibility Report identifying, as a minimum: 3) specific advantages and disadvantages of switching to a potentially smaller standardized canister (e.g., cost, time, dose, transportation, etc.) including how these advantages and disadvantages change with time of implementation.	5.0, App A-D
29	STAD Feasibility Report identifying, as a minimum: 4) proposed innovative solutions, if any, to addressing disadvantages and an assessment of canister size limitations versus level of difficulty to overcome disadvantages/challenges.	5.0, App A-D
30	STAD Feasibility Report identifying, as a minimum: 5) feasibility/trade studies to address the following: a) if and when to transition to using standardized canisters.	5.0, App A-D
31	STAD Feasibility Report identifying, as a minimum: 5) feasibility/trade studies to address the following: b) where to deploy them within UNF management system.	5.0, App A-D
32	STAD Feasibility Report identifying, as a minimum: 5) feasibility/trade studies to address the following: c) what standardized canister concept, is most feasible.	5.0, App A-D
33	STAD Feasibility Report identifying, as a minimum: 5) feasibility/trade studies to address the following: d) what should be done with fuel already stored in non-standardized canisters. Included in this deliverable will be a recommended path forward regarding standardization with supporting rationale as well as identification of areas for additional research.	5.0, App A-D
34	Recommended path forward regarding standardization with supporting rationale as well as identification For additional research.	10.0

2.0 SYSTEMS ENGINEERING APPROACH

This section describes the SE approach used to identify a recommended option. The AREVA Team used a formalized SE approach to ensure the development of a solid basis for recommendations made under this task. Because the Team used this formal approach, external reviewers can recreate the thought process we used when we rejected options considered as non-feasible, developed evaluation criteria, weighted evaluation criteria, performed evaluations, and made recommendations.

The SE approach can be divided into three major phases:

- Problem Definition
- Initial Investigation
- SE Analysis and Recommendations

Figure 2-1 illustrates the SE Planning Model used for this process and identifies the three phases and the activities within each phase. Each activity is designated a name, numerical sequence identifier, a set of controls, a set of resources, inputs and outputs, and a due date.

Throughout the remainder of this section, we use Figure 2-1 as a reference to describe the SE approach as it applies to each phase. Sections 3.0, 4.0, and 6.0 present the results of Problem Definition, Initial Investigation, and SE Analysis and Recommendation phases, respectively.

2.1 Problem Definition

The initial phase of the SE approach is termed “Problem Definition.” The Problem Definition phase is crucial in establishing the parameters governing all downstream activities. During the initial planning activity (Activity 1) our Team developed the first SE Planning Model (Figure 2-1) and defined the phases of the approach, activities within each phase, duration and sequencing of activities, and activity details (e.g., input, output, controls, and resources). The SE Planning Model was a living document throughout the execution of the SE approach and was revised as necessary by the Team.

The approach was validated with stakeholders (DOE) (Activity 2) as far as practical, the Planning Model updated with any changes, and a Problem Statement and Mission/Charter developed for the Team (Activity 3). After this point, activities generally included all members of the Core AREVA Team. After a Core Team Orientation in the SE Approach (Activity 4), the Core Team utilized the Problem Statement and Mission/Charter to identify functions required to execute the mission.

Functional analysis, decomposition, and functional allocation techniques were used to develop a functional hierarchy and functional flow block diagram (FFBD) (Activity 5). The Core Team developed performance requirements and design constraints (e.g., regulatory requirements, consensus code requirements, stakeholder requirements, etc.) associated with the collective set of functions. Performance requirements and constraints developed under Activities 6 and 7 were considered the screening criteria for all options (i.e., options were not considered if they did not have a high confidence rating against these criteria). These screening criteria, when feasible, were reviewed with the stakeholders and finalized (Activities 8 and 9).

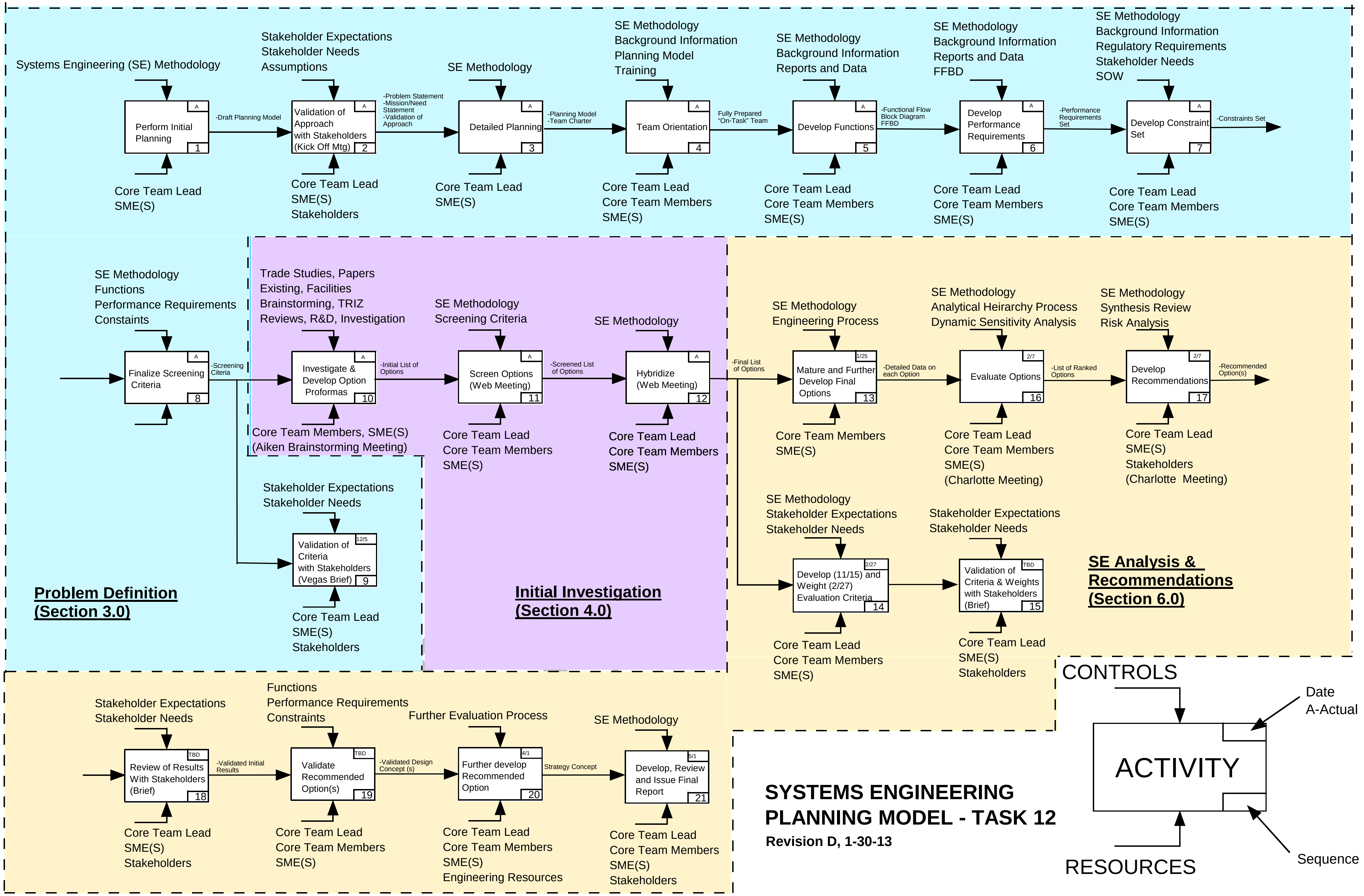


Figure 2-1. Systems Engineering Planning Model

2.2 Initial Investigation

The Initial Investigation phase activity (Activity 10) utilized Team expertise to brainstorm possible options for performance on the required mission. We used existing studies, reports, and data along with subject matter expertise and brainstorming techniques to identify potential options. These options were then documented in summary on pro formas. After completing the pro formas, the Core Team eliminated the options that did not have a high confidence rating against the screening criteria (Activity 11). After screening, any useful aspects of the failing options were identified and added, where helpful, to the passing options. This is known as hybridization (Activity 12). We then used a list of final options in the SE Analysis and Recommendation phase.

2.3 SE Analysis and Recommendation

The SE Analysis and Recommendation phase began with the assignment of options to the Team for development in more detail (Activity 13). As part of this phase, we developed and weighted evaluation criteria important to the mission and discriminating among the options (Activity 14).

The data developed on each of the options was targeted towards each of the evaluation criteria. This allowed the Team to utilize the data in support of the preference decisions made during the evaluation of options (Activity 16). During this evaluation, the Team used an analytical hierarchy process to achieve a relative ranking of options based on the evaluation with respect to the criteria and their weights. The Team performed a sensitivity analysis to ensure that with a reasonable variance in evaluation criteria weights, the highest-ranked option score did not drop below any of the other options.

The Team performed risk assessments on the recommended options and documented risks and opportunities associated with the options (Activity 17). In parallel with these activities, we presented evaluation criteria, criteria weights, and results, as far as practical, to stakeholders and gained their acceptance prior to a more detailed development of the recommended options (Activities 15 and 18).

Prior to, and in certain cases at the end of the development of the recommended options, the Team performed a confirmatory review against the screening criteria (Activity 19). This ensured that as more information became available on the recommended options, the selections were not unknowingly invalidated.

3.0 PROBLEM DEFINITION

This section describes how an SE approach was used to define the problem and develop a set of functions, performance requirements, and screening criteria that the solution must satisfy. We describe how our AREVA Team developed the Problem and Mission/Charter Statements, which directed and guided the SE approach. We also present functional analyses results in a hierarchy and match performance requirements and screening criteria to each identified function.

3.1 Developing Problem and Mission Statements

In this section, we describe the initial SE process steps used to develop a problem and mission statements.

After reviewing the statement of work[1] and associated Reports[2] [3] the following Problem Statement was extracted:

> *The canister system is the common link between used fuel storage at the reactor sites and ultimate disposal. Therefore, the canister design is dependent upon the collective functional needs and requirements of all anticipated operations within the used fuel management stream. To further complicate matters, no permanent repository has been identified, nor do any (non Yucca Mountain) site specific repository regulations exist.*

Based on the above problem, the statement of work for this task specifies the following Mission/Charter Statement:

> *Provide technical ideas and recommendations, supported by analysis and evaluation, which formulate a basis for a future DOE decision regarding the development and licensing of a standardized transportation, aging, and disposal canister system.*

---

[1] Task Order 12 Statement of Work, Standardized Transportation, Aging, and Disposal Canister Feasibility Study, Office of Nuclear Energy, Department of Energy.

[2] FCRD-USED-2011-000143, Generic Repository Design Concepts and Thermal Analysis (FY11), Rev 0, August 2011.

[3] FCRD-UFD-2012-000155, Preliminary Used Fuel Management System Concept of Operations Including Options for Standardized Transportation, Aging, and Disposal Canisters and Direct Disposal of Dual Purpose Canisters, Rev 0. June 29, 2012.

3.2 Functions

The Mission/Charter Statement, mentioned in the previous section, was analyzed to identify a set of functions to perform the mission. The functional analysis results are documented in a Functional Hierarchy (Figure 3-1).

3.3 Performance Requirements/Screening Criteria

For each of the functions identified in the previous section, the Team identified performance requirements. In addition to performance requirements, there are general requirements imposed by adopted National consensus Codes and Standards and from regulatory and permitting requirements. Performance requirements and general requirements are shown in Appendix D.

DOE Orders and requirements were not considered applicable to any of the options as the Statement of Work specified 10 CFR Part 71 and 10 CFR Part 72 transportation and licensing requirements, respectively.

Performance requirements and general requirements identified by the Team are those that a STAD option must be capable of meeting to be considered any further. STAD options not considered capable of meeting these requirements were screened out of the evaluation and selection process.

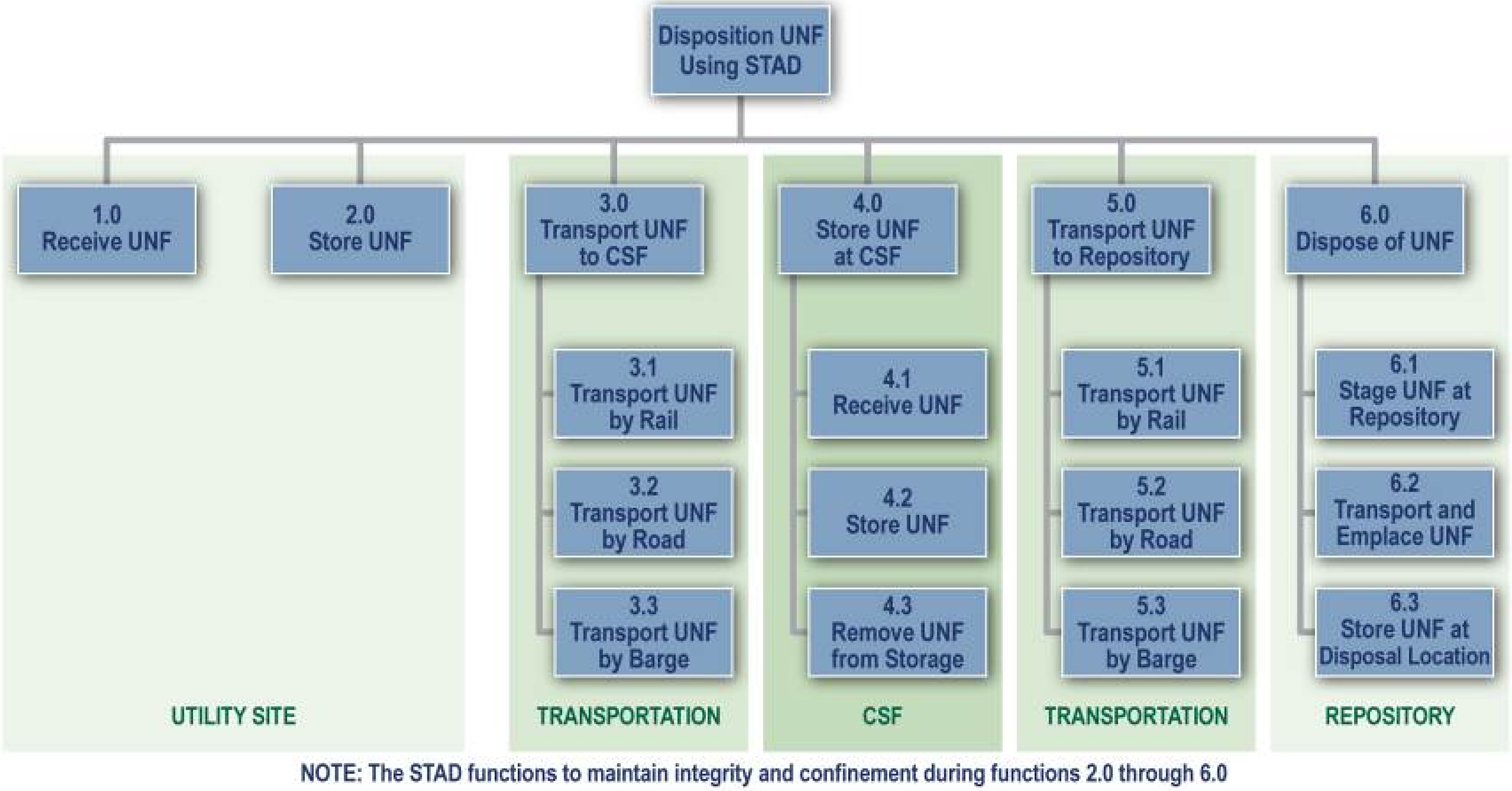


Figure 3-1. Functional Hierarchy

4.0 INITIAL INVESTIGATION

This section describes the results of the Initial Investigation phase. In this phase, the Team identified possible STAD options, screened out those that were not considered capable of achieving mission objectives, and optimized acceptable STAD options as appropriate to arrive at a final list of STAD options for evaluation. After applying screening criteria to nine initial options, only one STAD option was rejected due to corrosion issues.

4.1 Investigation of Options

The requirements and functions developed in the previous section provided the basis for the design of the STAD. Any STAD option selected had to satisfy those requirements. With this in mind, the Team and SMEs identified possible STAD options through a brainstorming session. At this point any realistic option identified was considered feasible and documented. The Team reviewed existing configurations for storing UNF worldwide and discussed potential new configurations and the consolidation of fuel rods into hexagonal configurations.

After we developed a list of potential options, the Team assigned owners (champions) for each potential solution. The owners then developed pro formas (descriptions and high-level discussions) for each of the potential options identified in Table 4-1 below. The pro formas are included in Appendix A.

Table 4-1. Initial List of Potential Options

ID	STAD (Note 1)
1	1 PWR/1 BWR/13.4 OD/U
2	2 PWR/2 BWR/13.4 OD/C
3	1 PWR/1 BWR/13.1 OD/U
3a	1 PWR/2 BWR/15.0 OD/U
4	2 PWR/4 BWR/8.4 SQ/C
5	4 PWR/9 BWR/31.0 OD/U
6	12 PWR/24 BWR/43.2 OD/U
7	21 PWR/44 BWR/66.2 OD/U
8	42 PWR/88 BWR/63.0 SQ/C

Note 1: The following nomenclature (Figure 4-1) was developed for ease of understanding the options.

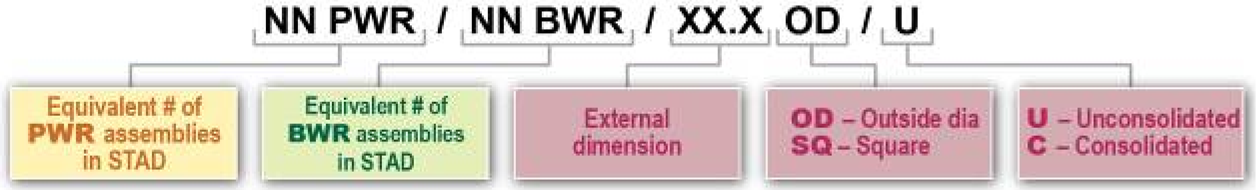


Figure 4-1. STAD Nomenclature

4.2 Screening of Options

The criteria developed in Section 3.3 defined the requirements, which had to be satisfied before an option was considered viable. The STAD options that passed the screening were then subjected to further evaluation.

The Team applied the screening criteria to each of the initial nine options. If the option being reviewed met all screening criteria or if the Team had a high confidence level that the option could be easily matured such that it would meet the screening criteria, then the option passed. If not, the option was rejected.

The thermal load of the STAD determined the type of repository the STAD option could be placed in and the transportation requirements limited the physical size of the STAD. Therefore, as expected, the brainstorming session produced few failing options.

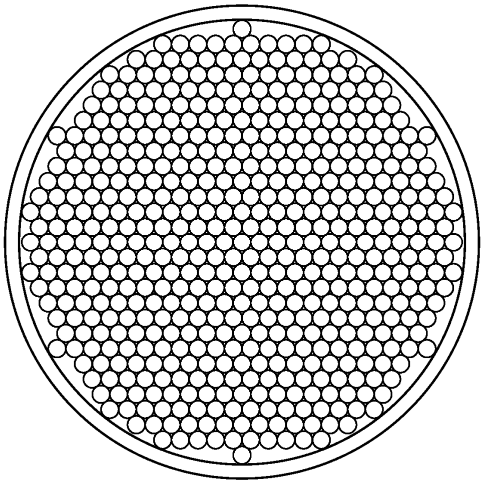
Only one STAD option was rejected after screening. Option 1 was rejected due to the corrosion issues in using a carbon steel well pipe to house the UNF. As Option 3 is essentially Option 1 with a thinner stainless steel wall, representing a similar configuration, it was preferred and represented the better application of this configuration.

It must be noted that the use of a borehole as a repository would rule out the larger STAD options, if the solution were feasible for all repository types. Repository type was not, therefore, used as a screening criterion other than binning which STAD configurations can be matched with which repository type. This is discussed in detail in Section 6.0.

5.0 EVALUATED OPTIONS

This section provides a summary of the information used to evaluate the options in the SE process. For each option, we present a description, costs, dose, repository robustness, utility impact, CSF impact, transportation, and licensing information. Costs breakdown are given in section 12 of this report. Detailed information upon which the SE evaluation and these summaries are based is contained within Appendix C.

5.1 OPTION 2 (2 PWR/4 BWR/13.4/C)



DESCRIPTION

Configuration

2 PWR or 4 BWR consolidated assemblies, in a 0.39-inch (wall thickness) stainless steel cylinder with an outside diameter of 13.4 inches. This single STAD configuration can also be optimized in a package which groups together up to 19 individual STADs.

Transportation

19 STADs per transportation cask.

COST

Up-Front:	$220,000,000
Operations:	$18,173,000,000
D&D:	$452,000,000

DOSE

The dose potential is greater at the CSF as a number of small STADs are manipulated. However, as multiple STADs can be transported, the number of shipments is low, which reduces the transportation dose potential.

REPOSITORY ROBUSTNESS

Option 2 can be used in all repositories.

UTILITY IMPACT

As consolidation occurs at the CSF there are no additional utility impacts.

CSF IMPACT

Larger pool facilities are required with increased storage operations and additional low-level waste (LLW) is generated.

TRANSPORTATION

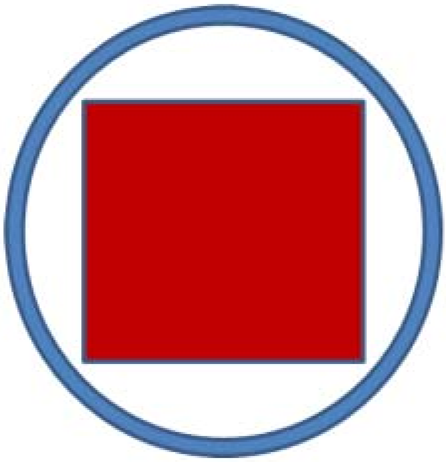
210 estimated cask deliveries per year.

LICENSING

Difficulty of licensing the CSF may be marginally increased due to the additional activity of consolidation taking place. However, the consolidated waste package may be easier to license at the repository as criticality potential is reduced.

5.2 OPTION 3 (1 PWR/1 BWR/13.1/U)

DESCRIPTION



Configuration

1 PWR or 1 BWR unconsolidated assemblies, in a 0.25-inch (wall thickness) stainless steel cylinder with an outside diameter of 13.1 inches. This single STAD configuration can also be optimized in packages which groups together up to 12 individual STADs.

Transportation

12 STADs per transportation cask.

COST

Up-Front:	$220,000,000
Operations:	$32,942,000,000
D&D:	$1,149,000,000

DOSE

The dose potential is greater at the utilities and CSF as a number of small STADs are manipulated. Also, although multiple STADs can be transported, the number of shipments is the highest of all the options, which greatly increases the transportation dose potential.

REPOSITORY ROBUSTNESS

Option 3 can be used in all repositories.

UTILITY IMPACT

As some STADs may be loaded at the utility facilities, additional utility operations are required.

CSF IMPACT

Due to the large number of STADs, additional storage space and larger cask handling facilities are required.

TRANSPORTATION

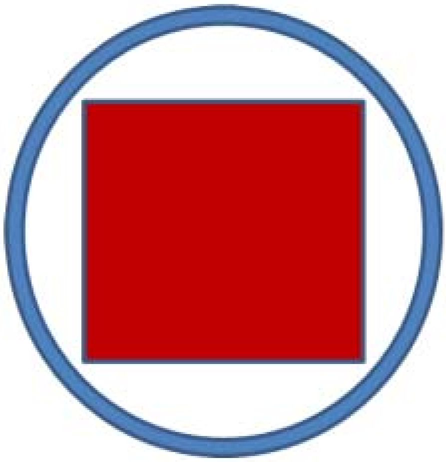
619 estimated cask deliveries per year.

LICENSING

As some STADs may be loaded at the utility facilities, additional licensing work is required at multiple nuclear power plants.

5.3 OPTION 3a (1 PWR/2 BWR/15.0/U)

DESCRIPTION



Configuration

1 PWR or 2 BWR unconsolidated assemblies, in a 0.25-inch (wall thickness) stainless steel cylinder with an outside diameter of 15.0 inches. This single STAD configuration can also be optimized in packages which groups together up to 12 individual STADs.

Transportation

12 STADs per transportation cask.

COST

Up-Front:	$220,000,000
Operations:	$26,118,000,000
D&D:	$822,000,000

DOSE

The dose potential is greater at the utilities and CSF as a number of small STADs are manipulated. Also, although multiple STADs can be transported, the number of shipments remains high, which increases the transportation dose potential.

REPOSITORY ROBUSTNESS

Option 3a can be used in all repositories.

UTILITY IMPACT

As some STADs may be loaded at the utility facilities, additional utility operations are required.

CSF IMPACT

Due to the number of STADs, additional storage space and larger cask handling facilities are required.

TRANSPORTATION

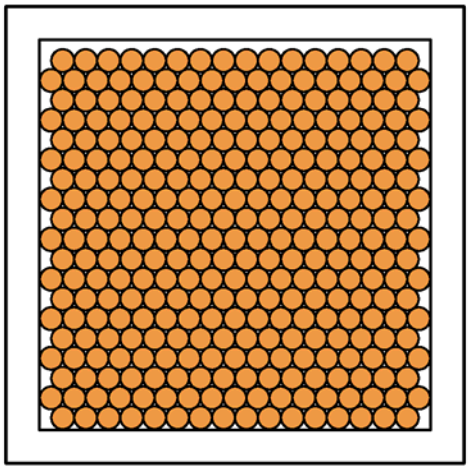
420 estimated cask deliveries per year.

LICENSING

As some STADs may be loaded at the utility facilities, additional licensing work is required at multiple nuclear power plants.

5.4 OPTION 4 (2 PWR/4 BWR/8.4/SQ/C)

DESCRIPTION



Configuration

2 PWR or 4 BWR consolidated assemblies, frame-supported in a square section stainless steel tube with a width of 8.4 inches. This single STAD configuration can also be optimized in a package which groups together up to 21 individual STADs.

Transportation

21 STADs per transportation cask.

COST

Up-Front:	$220,000,000
Operations:	$24,010,000,000
D&D:	$258,000,000

DOSE

The dose potential is greater at the CSF as a large number of small STADs are manipulated. However, as multiple STADs can be transported, the number of shipments is the lowest of all the options, which reduces the transportation dose potential.

REPOSITORY ROBUSTNESS

Option 4 can be used in all repositories.

UTILITY IMPACT

As consolidation will occur at the CSF, there are no additional utility impacts.

CSF IMPACT

Larger pool facilities are required with increased storage operations and additional LLW is generated.

TRANSPORTATION

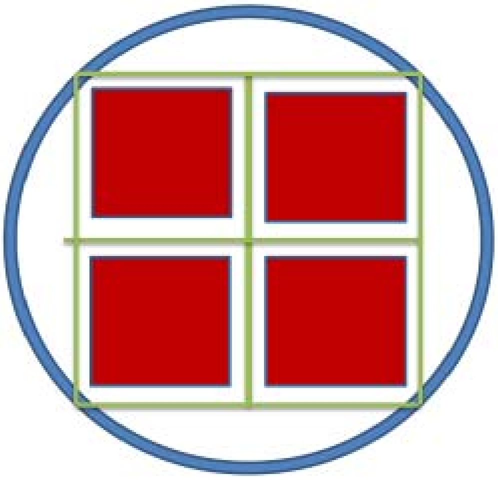
120 estimated cask deliveries per year.

LICENSING

Difficulty of licensing the CSF may be marginally increased due to the additional activity of consolidation taking place. However, the consolidated waste package may be easier to license at the repository as criticality potential is reduced.

5.5 OPTION 5 (4 PWR/9 BWR/31.0/U)

DESCRIPTION



Configuration

4 PWR or 9 BWR unconsolidated assemblies, frame-sup
stainless steel cylinder with an outside diameter of 31 inc
can also be optimized in a package, which groups togeth

Transportation

3 STADs per transportation cask.

COST

Up-Front:	$220,000,000
Operations:	$19,623,000,000
D&D:	$785,000,000

DOSE

Some reduction in dose is achieved with multiple STADs in the transportation cask. However; the number of STADs in the lifecycle is significant, which increases the dose potential.

REPOSITORY ROBUSTNESS

Option 5 can be used in all repository types with the exception of the borehole.

UTILITY IMPACT

As some STADs may be loaded at the utility facilities, additional utility operations are required.

CSF IMPACT

Due to the number of STADs, additional storage space and larger cask handling facilities are required.

TRANSPORTATION

398 estimated cask deliveries per year.

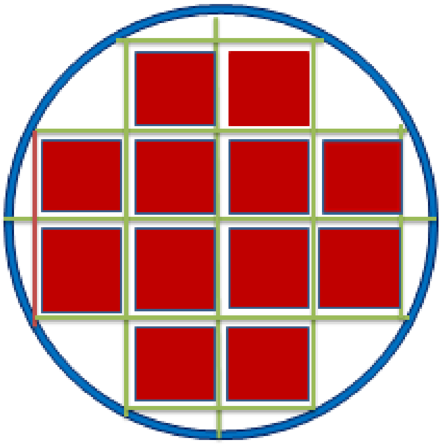
LICENSING

As some STADs may be loaded at the utility facilities, additional licensing work is required at multiple nuclear power plants.

5.6 OPTION 6 (12PWR/24BWR/43.25/U)

DESCRIPTION

Configuration



12 PWR or24 BWR unconsolidated assemblies, frame-supported in a 0.62-inch (wall thickness) stainless steel cylinder with an outside diameter of 43.25 inches.

Transportation

1 STAD per transportation cask.

COST

Up-Front:	$220,000,000
Operations:	$11,722,000,000
D&D:	$616,000,000

DOSE

With only one STAD in the transportation cask, the number of STADs in the lifecycle is large, which increases the dose potential during transportation.

REPOSITORY ROBUSTNESS

Option 6 is feasible for disposal in salt and un-backfilled crystalline and volcanic repositories.

UTILITY IMPACT

As some STADs may be loaded at the utility facilities, additional utility operations are required.

CSF IMPACT

Due to the number of STADs, additional storage space and larger cask handling facilities are required.

TRANSPORTATION

420 estimated cask deliveries per year.

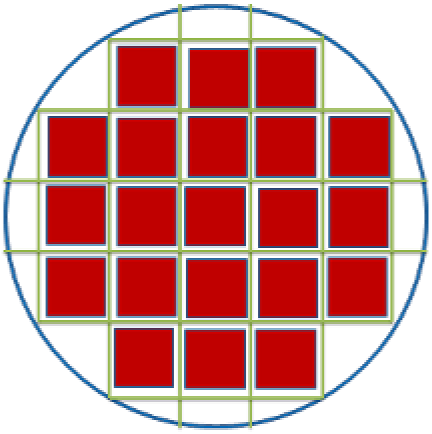
LICENSING

As some STADs may be loaded at the utility facilities, additional licensing work is required at multiple nuclear power plants.

5.7 OPTION 7 (21 PWR/44 BWR/66.25/U)

DESCRIPTION

Configuration



21 PWR or 44 BWR unconsolidated assemblies, frame-supported in a 0.75-inch (wall thickness) stainless steel cylinder with an outside diameter of 66.25 inches.

Transportation

1 STAD per transportation cask.

COST

Up-Front:	$220,000,000
Operations:	$8,026,000,000
D&D:	$346,000,000

DOSE

Even though unconsolidated, a low number of STADs are required for the lifecycle. Therefore, the dose potential is low.

REPOSITORY ROBUSTNESS

Option 7 is only feasible for disposal in un-backfilled crystalline and volcanic repositories.

UTILITY IMPACT

As some STADs may be loaded at the utility facilities, additional utility operations are required.

CSF IMPACT

Some additional storage space and slightly larger cask handling facilities are required.

TRANSPORTATION

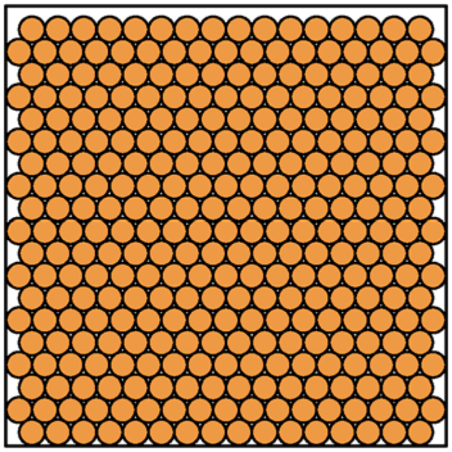
235 estimated cask deliveries per year.

LICENSING

As some STADs may be loaded at the utility facilities, additional licensing work is required at multiple nuclear power plants.

5.8 OPTION 8 (41 PWR/88 BWR/63.0/SQ/C)

DESCRIPTION



Configuration

21 frame-supported square section stainless steel tubes (each containing 2 PWR or 4 BWR consolidated assemblies) enveloped within a standard circular cask with a diameter of 63inches.

Transportation

1 STAD per transportation cask.

COST

Up-Front:	$220,000,000
Operations:	$6,048,000,000
D&D:	$185,000,000

DOSE

With consolidation occurring at the CSF and the small number of STADs in the lifecycle, this option has extremely low dose potential.

REPOSITORY ROBUSTNESS

Option 8 is only feasible for disposal in un-backfilled crystalline and volcanic repositories.

UTILITY IMPACT

As consolidation occurs at the CSF, there are no additional utility impacts.

CSF IMPACT

Larger pool facilities are required with increased storage operations and additional LLW is generated.

TRANSPORTATION

117 estimated cask deliveries per year.

LICENSING

Difficulty of licensing the CSF may be marginally increased due to the additional activity of consolidation taking place. However, the consolidated waste package may be easier to license at the repository as criticality potential is reduced.

6.0 SYSTEMS ENGINEERING ANALYSIS AND RECOMMENDATIONS

In this section, we describe how the Team of representatives from AFS, AREVA Nuclear Plant, AREVA TN, Dominion, and URS applied the SE process to options that passed through screening. We describe how the criteria were developed, weighted, and evaluated and discuss the results, our risk assessment and analysis, and recommendations.

6.1 Criteria Development

The Team developed specific evaluation for the options. Unlike screening criteria, evaluation criteria are considerations important to the stakeholder. They help discriminate between the options and must be as independent of each other as reasonably achievable.

Initially, the Team identified seven top-level criteria:

- Lifecycle Cost
- Dose
- Repository Robustness
- CSF Impact
- Utility Impact
- Ease of Transportation
- Ease of Licensing

When analyzing each individual criterion, several had major elements that were considered to be of differing importance. For example, cost could be split into upfront, operations, and D&D costs. Figure 6-1 illustrates the analytical hierarchy the Team developed with sub-criteria where these splits occurred.

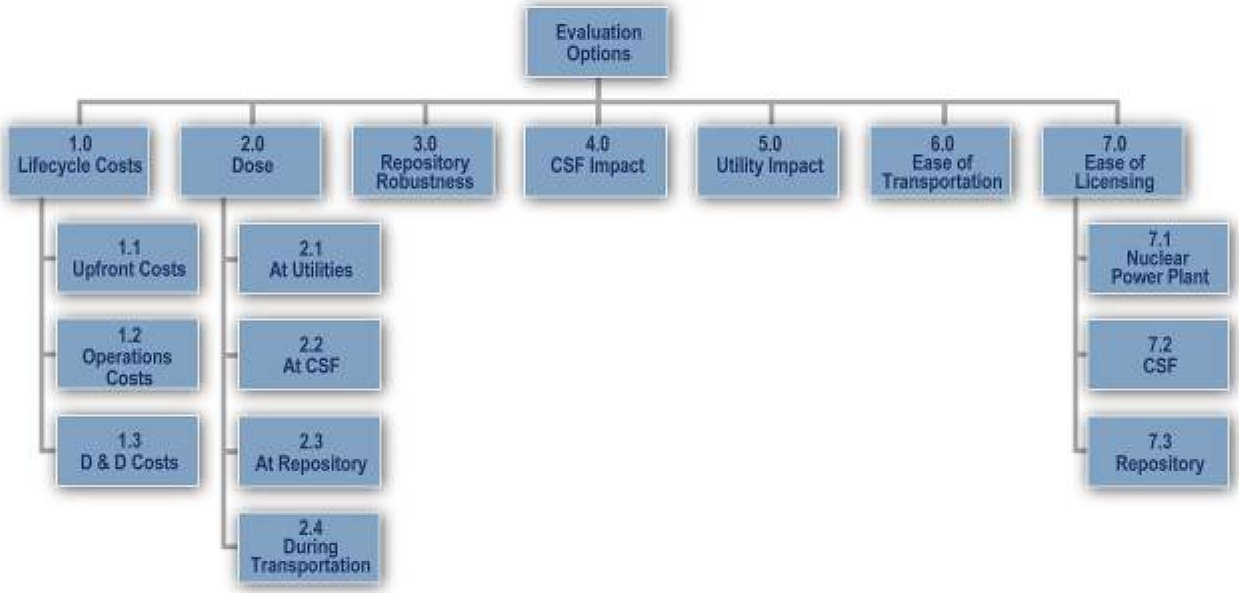


Figure 6-1. Analytical Hierarchy (Evaluation Criteria)

Each of the top-level criteria and sub-criteria were further defined by the Team in terms of specific considerations to be evaluated for each of the options and also as to which trend was considered more favorable under each specific criteria or sub-criteria.

The Team defined the following criteria and sub-criteria considerations and preferences:

1.0 Lifecycle Costs

This criterion addresses the total cost of the STAD lifecycle. As various elements of the STAD lifecycle has vastly different costs between each option, cost as a criterion was broken into three individual sub-criteria to create granularity on each of the various elements:

1.1 Upfront Costs

This sub-criterion addresses the initial cost of the STAD. This cost is basically a Total Project Cost (TPC) to provide the first licensed STAD. Upfront costs typically comprise the following elements:

- Design
- Prototype Testing
- Licensing

The lower the upfront costs, the more preferred the option.

1.2 Operations Costs

This sub-criterion addresses the operations costs of the STAD. These costs typically comprise the following elements:

- Hardware
- Dose
- Loading/unloading
  - Utility
  - CSF
  - Repository (STAD from shipping container only)
- Transportation (including rail cars, etc.)
- Infrastructure (if applicable)
- Utility storage cost
- CSF storage
- Repository storage (staging)
- Repository placement
- Fuel consolidation
- Material accountability
- Quality assurance inspection/record keeping
- LLW disposal

The lower the operations costs, the more preferred the option.

1.3 D&D Costs

This sub-criterion addresses the D&D costs of the STAD. These costs include:

- Temporary overpacks
- Handling frames

The lower the D&D costs, the more preferred the option.

2.0 Dose

This criterion addresses the total potential collective dose received by workers from the STAD during its lifecycle. As various elements of the STAD lifecycle have vastly different potential collective doses, dose as a criterion was broken into four individual sub-criteria to create granularity on each of the elements.

2.1 Dose at Utilities

This sub-criterion addresses the potential dose received by workers during operations at the utility site involved with loading the STAD, short-term storage of the STAD, and preparing the STAD for transportation.

The lower the potential dose, the more preferred the option.

2.2 Dose at CSF

This sub-criterion addresses the potential dose received by workers during operations at the CSF involved with receiving and/or loading the STAD, long-term storage of the STAD, and preparing the STAD for transportation.

The lower the potential dose, the more preferred the option.

2.3 Dose at Repository

This sub-criterion addresses the potential dose received by workers while receiving, handling, and emplacing the STAD for permanent disposition at the repository.

The lower the potential dose, the more preferred the option.

2.4 Dose during Transportation

This sub-criterion addresses the potential dose received by workers during the transportation of the STAD.

The lower the potential dose, the more preferred the option.

3.0 Repository Robustness

This criterion addresses the compatibility of the STAD with the repository type or types being evaluated. A larger package is desirable. For salt only, a hotter package is also desirable.

The more compatible with the repository, the more preferred the option.

4.0 CSF Impact

This criterion addresses the impact when introducing a STAD into the CSF operations lifecycle. Elements considered include:

- Larger storage area
- Additional loading/unloading operations
- Additional UNF pool capacity
- Additional or increased volume of LLW stream
- Additional loading/unloading facilities

The smaller the impact, the more preferred the option.

5.0 Utilities Impact

This criterion addresses the impact when introducing a STAD into the utility operations lifecycle. Elements considered include:

- Pool time
- Additional loading/unloading operations
- Additional rad protective measures
- New shielded storage overpack/transport containers
- Fuel consolidation
- Storage footprint
- Additional or increased volume of LLW stream

The smaller the impact, the more preferred the option.

6.0 Ease of Transportation

This criterion addresses the ease with which the STAD can be transported. Elements considered include:

- Ability to design, test, and qualify
- Number of shipments
- Type of shipments
- Type of transportation equipment used
- Public perception
- Security concerns
- Overweight Federal/local permits

After reviewing the criteria, the Team found that only the ability to design, test, and qualify and the numbers of shipments were discriminators. The easier to design, test, and qualify and the fewer the shipments, the more preferred the option.

7.0 Ease of Licensing

This criterion addresses the ease with which the STAD can be licensed for use. As differing aspects of licensing were considered, ease of licensing as a criterion was broken into three individual sub-criteria to create granularity on each of the differing elements.

7.1 Nuclear Power Plant

This sub-criterion addresses the ease with which a STAD can be licensed for use at a nuclear power plant. Considerations included:

- Regulatory: 10 CFR Part 72; General or Site Specific ISFSI, 10 CFR Part 71
    - Unique design parameters not enveloped by storage/transportation overpacks
    - Functional processes (load, dry, inert, close, handle supporting storage consolidation)
- Onsite storage/aging (potentially mitigates a transportation thermal constraint)
- Timing of transportation to CSF (assumes a CSF exists)

The easier to license at a nuclear power plant, the more preferred the option.

7.2 CSF

This sub-criterion addresses the ease with which a STAD can be licensed for use at the CSF. Considerations included:

- Regulatory: 10 CFR Part 72; Site Specific ISFSI, 10 CFR Part 71
- Storage/aging (potentially mitigates a repository constraint; thermal or configuration)
- Transportation time to a repository location for staging/disposal

The easier to license at the CSF, the more preferred the option.

7.3 Repository

This sub-criterion addresses the ease with which a STAD can be licensed for use at the repository. Considerations included:

- Regulatory: 10 CFR Part 60 regulates disposal using waste package

The easier to license for use at the repository, the more preferred the option.

6.2 Weighting of Criteria

After the development of evaluation criteria and hierarchy, the Team weighted the criteria relative to their importance using Expert Choice Pro© (EcPro©) Software. The analytical hierarchy process (AHP) methodology was applied by first creating a model for the evaluation criteria and then performing a pairwise comparison for each of the criterion beginning with the main criteria and then each sub-criteria group. During the pairwise comparison process, the Team compared each criterion one-by-one to each of the other criteria. After discussion of the relative importance of the two criteria being compared and arriving at a consensus on the relative importance of one with respect to the other, the Core Team recorded a preference judgment for each comparison.

As part of the pairwise judgment process, an inconsistency ratio was developed by the software to ensure judgments were relatively consistent. The inconsistency ratio played a minor role in the pairwise comparison of evaluation criteria as these judgments were extremely subjective and during the dynamic sensitivity analysis were varied significantly to simulate a wide range of judgment. The inconsistency ratio did play a significant role during the pairwise evaluation of options and is discussed in Section 6.3.

After completing this process for the top-level criteria, the Team repeated the process for each of the sub-criteria groups under the top-level criteria. The software synthesized each of the judgments to arrive at a weight for each top-level criterion and sub-criterion, which reflected their overall relative importance. The more important a criterion or sub-criterion, the greater its respective weight. Figure 6-2 presents the top-level criteria and sub-criteria weights developed by the Core Team.

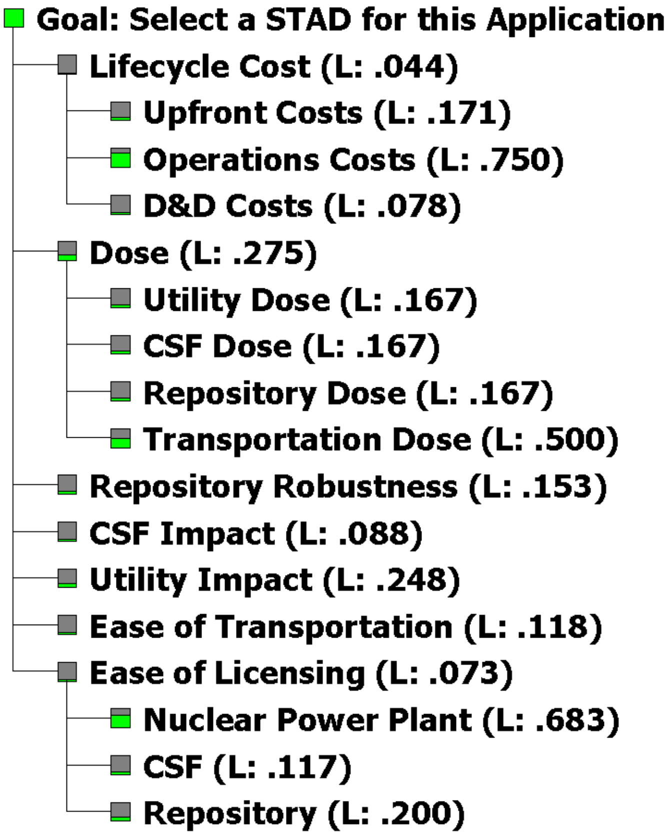


Figure 6-2. Evaluation Criteria and Sub-Criteria Weights

As shown, all main criteria weights and each set of sub-criteria weights are normalized. The following is a discussion of the Team's judgments and the basis for the resulting criteria and sub-criteria weights.

6.2.1 Main Criteria

Figure 6-3 shows the results of weighting the main criteria.

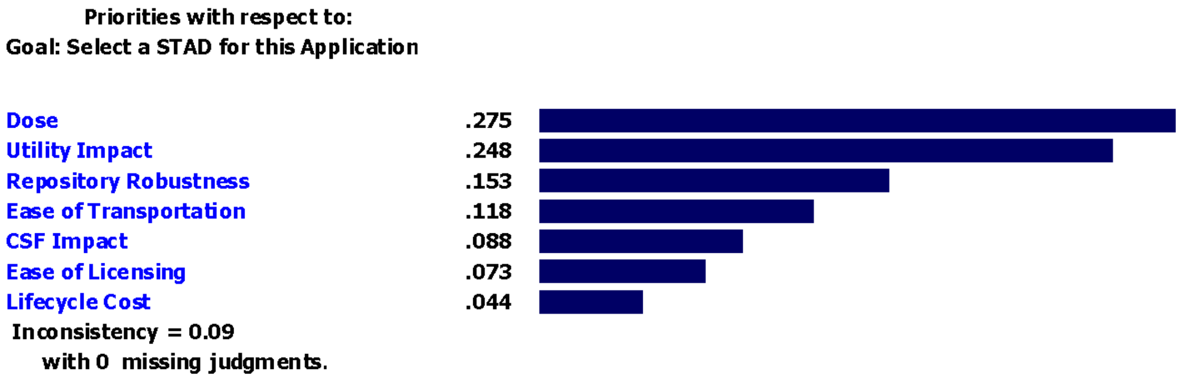


Figure 6-3. Main Criteria Weights

Of the seven main criteria, dose was weighted highest at 28 percent. The Core Team considered this to be the most important criteria, as stakeholders would be more willing to tolerate a more costly and operationally complex STAD option that may have impacts to the repository, CSF, or utilities if it were to reduce the dose to workers and the public.

Utility impact was the second highest weighted criterion at 25 percent. The Core Team considered this to be the second most important criteria, as impacts at utilities can directly and negatively impact the utilities as commercial enterprises and would be strongly resisted.

The next highest weighted criterion was repository robustness at 15 percent. Being able to easily dispose of the STAD in a repository was considered more important than one-time ease of licensing, transportation, impact at CSF, or cost.

Ease of transportation was considered the next highest weighted criterion at 12 percent as difficulties associated with transportation are not easily resolved. Although the transportation strategy will be feasible, the difficulty may persist throughout the lifecycle.

CSF impact was weighted lower than the other impact criteria at 9 percent. Any impacts to the configuration of the CSF could be accommodated during the design phase with less effort than at a repository or existing transportation network.

Ease of licensing was weighted at 7 percent as this is a one-time effort and once completed, it will qualify the STAD for its entire lifecycle.

Lifecycle Cost, at 4 percent, was the lowest weighted criteria. Developing a STAD is a key element of providing the U.S. with a complete fuel cycle, which is a national concern, high on the Government priority list. Therefore, cost alone is not considered to be a primary driver for the STAD selection.

6.2.2 Sub-Criteria

6.2.2.1 Lifecycle Cost

The results of weighting the lifecycle cost sub-criteria are shown in Figure 6-4.

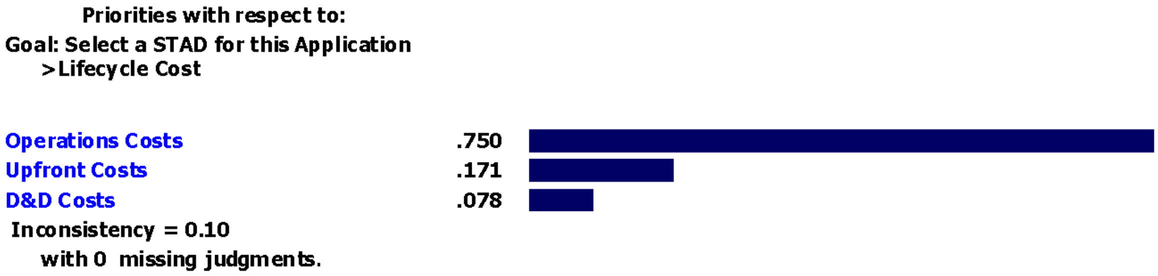


Figure 6-4. Lifecycle Cost Sub-Criteria Weights

Operations costs were weighted highest at 75 percent as this is by far the greatest cost element for the lifecycle, and any small variations in this far surpass in magnitude any significant variations in other cost elements. Upfront costs were weighted at 17 percent higher than D&D costs, which were weighted at 8 percent. Upfront costs were considered more important than D&D, as the upfront costs play such a significant role in the early lifecycle during acquisition.

6.2.2.2 Dose

Figure 6-5 shows the results of weighting the dose sub-criteria.

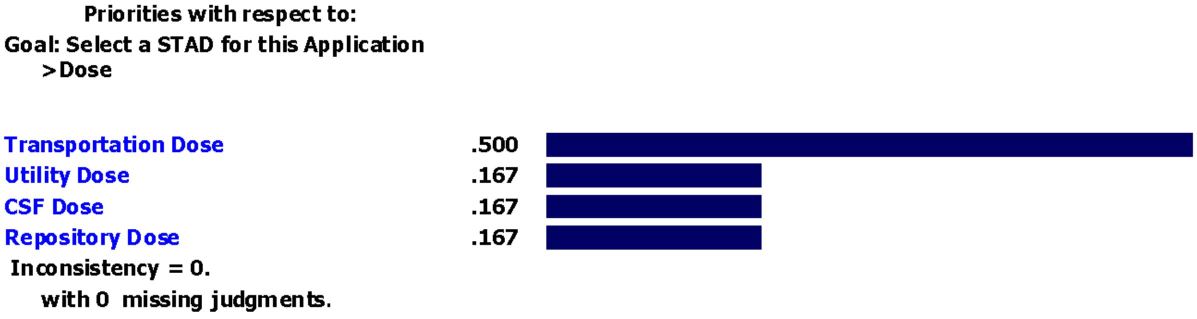


Figure 6-5. Dose Sub-Criteria Weights

Transportation dose was weighted highest at 50 percent because this dose, however small, relates to the public. The smaller the cumulative dose to the public, the much easier all aspects of approving transportation of the STADs would be.

All other dose criteria (at the CSF, utilities, and repository) were weighted equally at 17 percent. At these locations, the dose potential would only affect skilled rad worker operations where procedures would be appropriately developed and significant control and monitoring employed.

6.2.2.3 Ease of Licensing

Figure 6-6 shows the results of weighting the sub-criteria for ease of licensing.

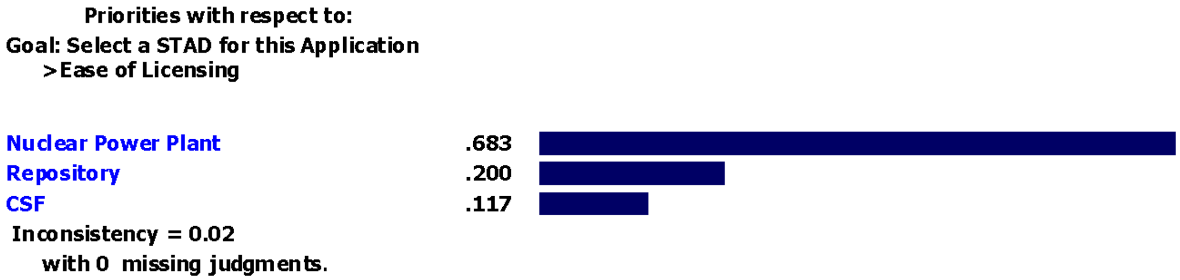


Figure 6-6. Ease of Licensing Sub-Criteria Weights

The ease of licensing at a nuclear power plant was weighted highest at 68 percent, as this would be the most difficult location to license a new-design STAD. Ease of licensing at the repository was weighted at 20 percent, as there is less flexibility when compared to the CSF. The CSF received the lowest weight at 12 percent, as during the design process it is easier to build in allowances to facilitate licensing of a new-design STAD.

6.3 Evaluation

The process of evaluating the STAD options was complex due to the unknown characteristics of the repository in which it will be placed. The STAD options are likely to have different thermal capacities, which may preclude certain STAD options from being placed in particular repository types. In addition, considering a borehole repository imposes physical limitations due to its small size. Prior to embarking on the evaluation, it was necessary to develop an SE Evaluation roadmap to allow for the evaluation of STADs by repository type and optimization of STADs between evaluations. Figure 6-7 shows the SE Evaluation roadmap.

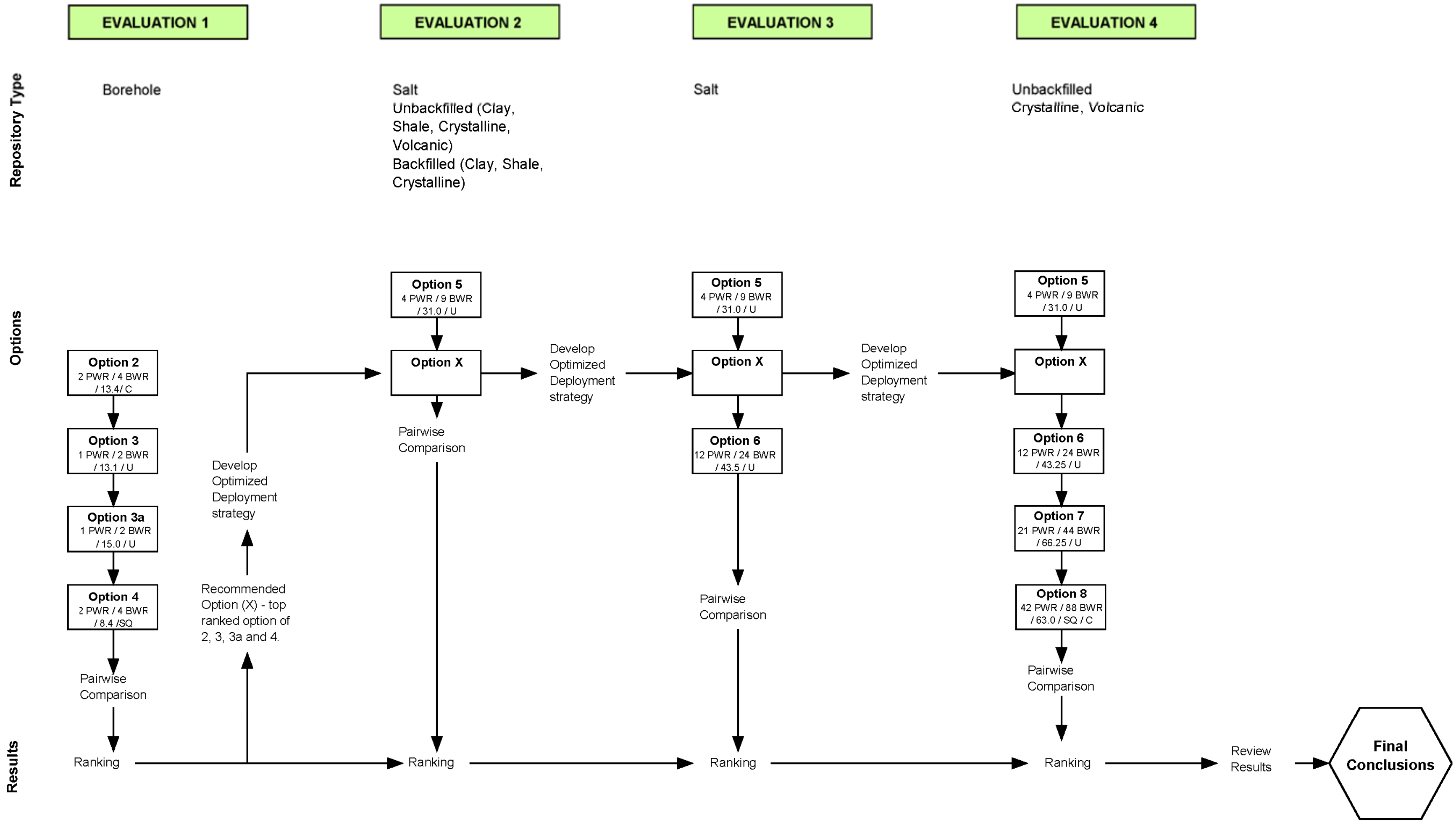


Figure 6-7. SE Evaluation Roadmap

The approach was targeted at maximizing the potential for arriving at a point solution. First the borehole was separated as a repository type and the STAD options that were capable of being placed in the borehole were evaluated using the evaluation criteria. After a single option was identified for recommended use in the borehole, it was optimized for use in each of the other repository types and evaluated against the other options in each of these groups.

The Core Team performed each of the repository group evaluations in a pairwise comparison process by utilizing the weighted criteria discussed in Section 6.2.

For the main criterion or sub-criterion being considered, each STAD option was compared against each other STAD option. Through consensus the Core Team arrived at a preference judgment value. This was performed in a similar manner to the pairwise comparison of criteria described in Section 6.2.

For these pairwise comparisons, the inconsistency ratio developed by the software played a greater role since a dynamic sensitivity of judgments was not performed. The inconsistency ratio in judgments was maintained below 0.1 (recommended by EcPro©).

The Core Team made preference judgments based on data developed by SMEs for each option under each evaluation criterion. Appendix C describes a specific criterion as it relates to each option.

The following sections (6.3.1 through 6.3.4) describe the evaluations of STAD options by repository type.

6.3.1 Evaluation 1

The first evaluation targeted options that were feasible for disposal in a borehole repository. Size was the major limitation in identifying feasible options for this evaluation group. The following options were evaluated:

- Option 2 – 2 PWR/4 BWR/13.4/C
- Option 3 – 1 PWR/1 BWR/13.1/U
- Option 3a – 1 PWR/2 BWR/15.0/U
- Option 4 – 2 PWR/4 BWR/8.4/SQ/C

6.3.1.1 Pairwise Comparison Results

The Core Team completed a pairwise comparison of the options for all evaluation criteria and sub-criteria.

6.3.1.2 Synthesis of Results

After the Core Team completed the pairwise comparison of the options for all evaluation criteria and sub-criteria, they synthesized the input through the EcPro© software to converge on scores for each of the options. Figure 6-8 illustrates the scores that resulted from the synthesis of the data.

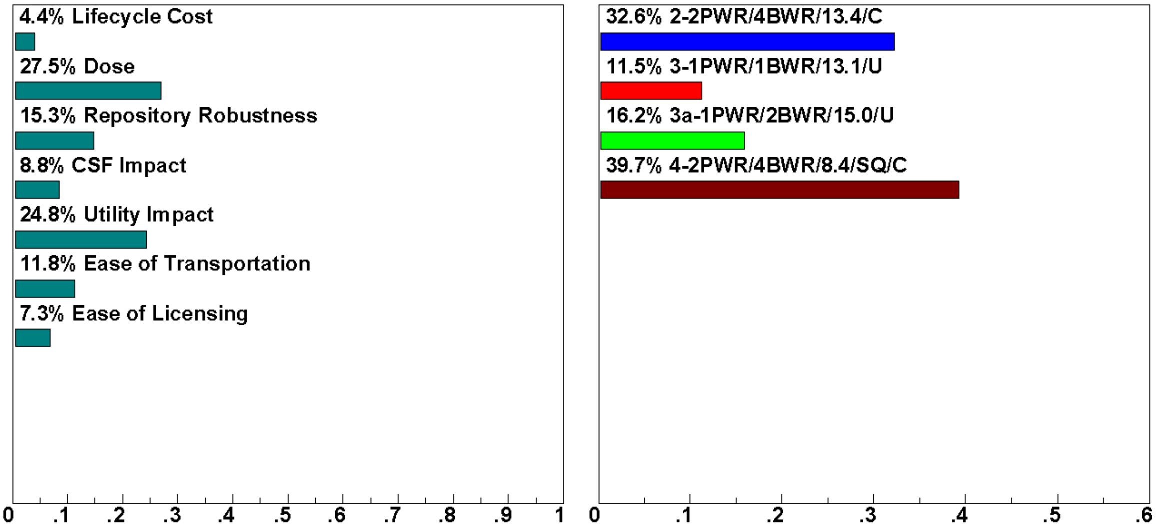


Figure 6-8. Evaluation 1 Synthesized Results

As can be seen from Figure 6-8, STAD Option 4 scored highest, closely followed by STAD Option 2.

6.3.1.3 Dynamic Sensitivity

The synthesized results, (shown in Figure 6-8), use criteria weights developed by the judgment of the Core Team (as described in Section 6.2). With any analytical hierarchy analysis, the potential exists for a change in the weight of an individual criterion to alter the result in such a way that the highest scoring option is displaced by one of the others. It is a general practice to alter the weights by +/-10 percent and re-synthesize the results. If the highest scoring option remains in that position for all changes, the model is considered robust.

The EcPro© software allowed our Team to perform a dynamic sensitivity analysis during which each weight was increased or decreased to the point that the highest scoring option changes places with one of the others.

The results of this process showed an extremely robust model to support the selection of the top ranking option. Criteria that, during the evaluation, were determined to be non-discriminating were also removed and although the model became marginally more responsive, the option ranking remained the same.

Also, utility impact was taken to zero weighting because a case could be made that all packaging could be performed at the CSF. This did not change the ranking of the options.

6.3.2 Evaluation 2

The second evaluation targeted options that were feasible for disposal in salt, un-backfilled (clay, shale, crystalline, and volcanic), and backfilled (clay, shale, and crystalline) repositories. As the recommended option from the first evaluation could be optimized, a configuration of two Option 4 STADs was used in this evaluation. The Team evaluated the following options.

- Option 4 – 2 x 2 PWR/4 BWR/8.4/SQ/C
- Option 5 – 4 PWR/9 BWR/31.0/U

6.3.2.1 Pairwise Comparison Results

The Core Team completed a pairwise comparison of the options for all evaluation criteria and sub-criteria. These results are shown in Appendix B.

6.3.2.2 Synthesis of Results

After the Core Team completed the pairwise comparison of the options for all evaluation criteria and sub-criteria, the input was synthesized through the EcPro© software to converge on scores for each of the options. Figure 6-9 shows the scores that resulted from the synthesis of the data.

As can be seen from Figure 6-9, Option 4 scored higher.

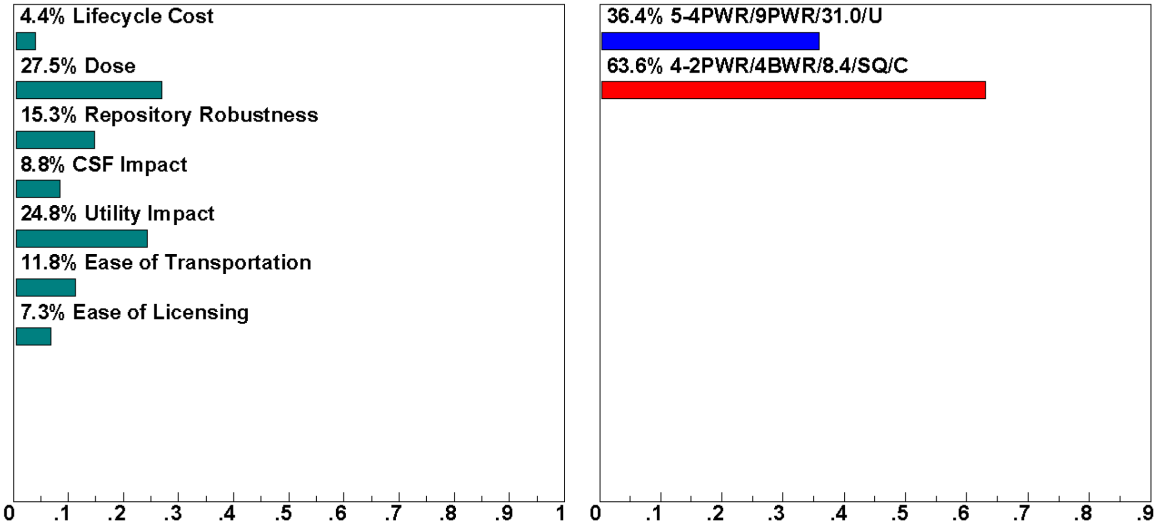


Figure 6-9. Evaluation 2 Synthesized Results

6.3.2.3 Dynamic Sensitivity

The synthesized results, (shown in Figure 6-9), use criteria weights developed by the judgment of the Core Team (as described in Section 6.2). With any analytical hierarchy analysis, the potential exists for a change in the weight of an individual criterion to alter the result in such a way that the highest scoring option is displaced by one of the others. It is a general practice to alter the weights by +/-10 percent and re-synthesize the results. If the highest scoring option remains in that position for all changes, the model is considered robust.

The EcPro© software allowed our Team to perform a dynamic sensitivity analysis during which each weight was increased or decreased to the point that the highest scoring option changes places with one of the others.

The results of this process showed an extremely robust model to support the selection of the top ranking option. Criteria that, during the evaluation, were determined to be non-discriminating were also removed and although the model became marginally more responsive, the option ranking remained the same.

Also, utility impact was taken to zero weighting as a case could be made that all packaging could be performed at the CSF. This did not change the ranking of the options.

6.3.3 Evaluation 3

The third evaluation targeted options that were feasible for disposal in salt repositories. As the recommended options from the second evaluation could be optimized, a configuration of six Option 4 STADs and three Option 5 STADs were used in this evaluation. The Team evaluated the following options.

- Option 4 – 6 x 2 PWR/4BWR/8.4/SQ/C
- Option 5 – 3 x 4 PWR/9BWR/31.0/U
- Option 6 – 12 PWR/24BWR/43.25/U

6.3.3.1 Pairwise Comparison Results

The Core Team completed a pairwise comparison of the options for all evaluation criteria and sub-criteria. These results are shown in Appendix B.

6.3.3.2 Synthesis of Results

After the Core Team completed the pairwise comparison of the options for all evaluation criteria and sub-criteria, they synthesized the input through the EcPro© software to converge on scores for each of the options. Figure 6-10 shows the scores that resulted from the synthesis of the data.

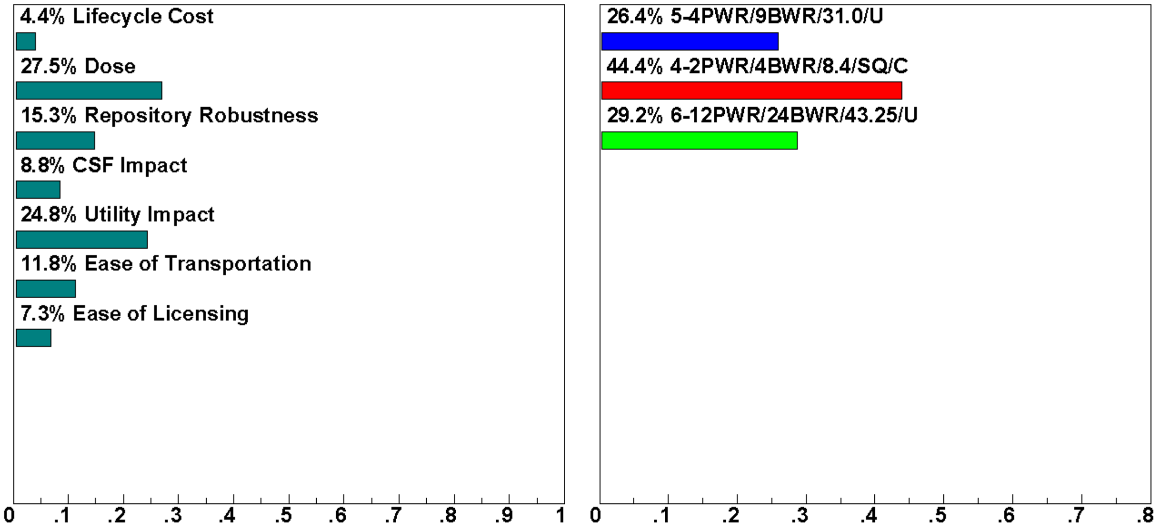


Figure 6-10. Evaluation 3 Synthesized Results

As can be seen from Figure 6-10, Option 4 scored highest, followed by Options 6 and 5 respectively.

6.3.3.3 Dynamic Sensitivity

The synthesized results (shown in Figure 6-10) use criteria weights developed by the judgment of the Core Team (as described in Section 6.2). With any analytical hierarchy analysis, the potential exists for a change in the weight of an individual criterion to alter the result in such a way that the highest scoring option is displaced by one of the others. It is a general practice to alter the weights by +/-10 percent and re-synthesize the results. If the highest scoring option remains in that position for all changes, the model is considered robust.

The EcPro© software allowed our Team to perform a dynamic sensitivity analysis during which each weight was increased or decreased to the point that the highest scoring option changes places with one of the others.

The results of this process showed an extremely robust model to support the selection of the top ranking option. Criteria that, during the evaluation, were determined to be non-discriminating were also removed and although the model became marginally more responsive, the option ranking remained the same.

Also, utility impact was taken to zero weighting as a case could be made that all packaging could be performed at the CSF. This did not change the ranking of the options.

6.3.4 Evaluation 4

The fourth evaluation targeted options that were feasible for disposal in un-backfilled crystalline and volcanic repositories. As Options 4 and 5 from the third evaluation could be optimized, a configuration of 21 Option 4 STADs and three Option 5 STADs were used in this evaluation. The following options were evaluated:

- Option 4 – 21 x 2 PWR/4 BWR/8.4/SQ/C
- Option 5 – 3 x 4 PWR/9 BWR/31.0/U
- Option 6 – 12 PWR/24 BWR/43.25/U
- Option 7 – 21 PWR/44 BWR/66.25/U
- Option 8 – 42 PWR/88 BWR/63.0/SQ/C

6.3.4.1 Pairwise Comparison Results

The Core Team completed a pairwise comparison of the options for all evaluation criteria and sub-criteria. These results are shown in Appendix B.

6.3.4.2 Synthesis of Results

After the Core Team completed the pairwise comparison of the options for all evaluation criteria and sub-criteria, they synthesized the input through the EcPro© software to converge on scores for each of the options. Figure 6-11 shows the scores that resulted from the synthesis of the data.

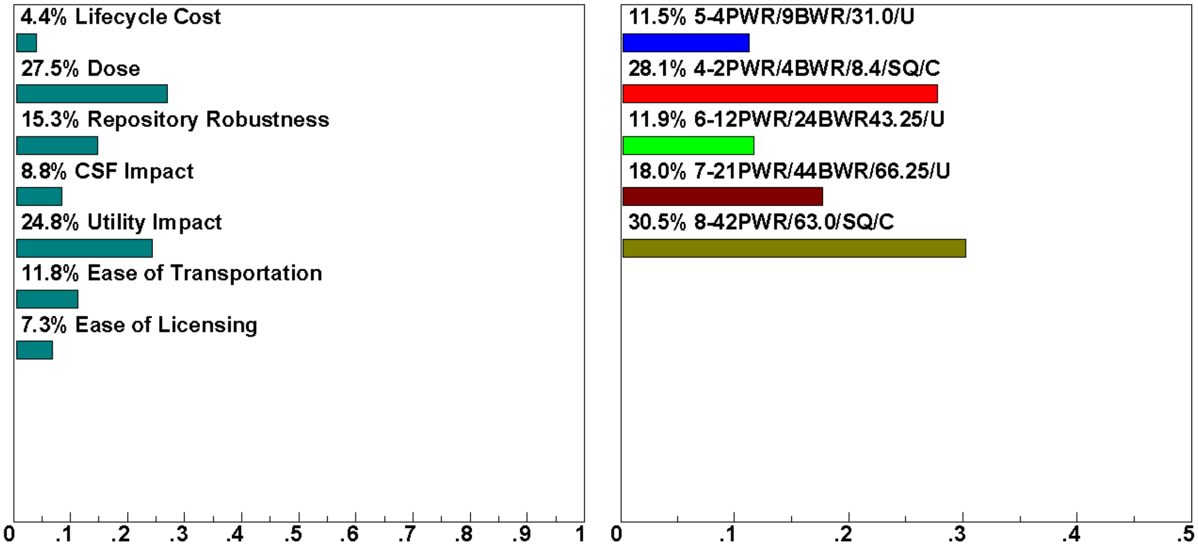


Figure 6-11. Evaluation 4 Synthesized Results

As can be seen from Figure 6-11, Option 8 marginally beat Option 4.

6.3.4.3 Dynamic Sensitivity

The synthesized results (shown in Figure 6-11) use criteria weights developed by the judgment of the Core Team (as described in Section 6.2). With any analytical hierarchy analysis, the potential exists for a change in the weight of an individual criterion to alter the result in such a way that the highest scoring option is displaced by one of the others. It is a general practice to alter the weights by +/-10 percent and re-synthesize the results. If the highest scoring option remains in that position for all changes, the model is considered robust.

The EcPro© software allowed our Team to perform a dynamic sensitivity analysis during which each weight was increased or decreased to the point that the highest scoring option changes places with one of the others.

The results of this process showed an extremely robust model to support the selection of the top ranking option. Criteria that, during the evaluation, were determined to be non-discriminating were also removed and although the model became marginally more responsive, the option ranking remained the same.

Also, utility impact was taken to zero weighting as a case could be made that all packaging could be performed at the CSF. This did not change the ranking of the options.

6.4 Results

Option 4 is feasible for all repository types and, when optimized, it ranked highest with the exception of Option 8 in un-backfilled crystalline and volcanic repositories. Although Option 8 did rank higher than Option 4, the un-backfilled crystalline and volcanic repositories are the only repositories Option 8 would be suitable for, as it is unsuitable for a borehole repository.

6.5 Risk Analysis

The Core Team used a formal risk identification process known as a “Premortem” to identify risks and opportunities on Option 4. The Premortem process used retrospective hindsight by placing the Team in a situation where the project has failed requiring them to identify the major causes of failure with SMEs in isolation. They then developed handling strategies using group synergy. Brainstorming was used to identify opportunities. Tables 6-1 and 6-2 present the risks, risk handling strategies, and opportunities, respectively.

Table 6-1. Option 4 Risks

ID	Risk Description	Risk Handling
1	Excessive rods damaged during operations	• Prototype. • Testing. • Test various fuel assemblies (types damaged). • Ensure “robustness” in design. • Use 3rd generation technology. • Investigate proving at a commercial plant. • Develop a comprehensive technology development plan including off-normal loading. • Explore the risks of fuel properties not supporting handling of the fuel for each option. • Investigate the potential of a percentage of fuel to be in a damaged fuel canister.
2	Fragile fuel prohibits extraction of pins	• Design STAD to allow an un-compacted fuel assembly. • Require utilities/fuel vendors to ID physical limitations/inadequacies in assemblies shipped to CSF. • Develop back up handling equipment and procedures.
3	CSF not built (i.e., repository is only facility)	• Apply CSF concept to repository design.
4	Lack of sufficient development of consolidation equipment/process	• Prototype. • Testing. • Test various fuel assemblies (types damaged). • Ensure “robustness” in design. • Use 3rd generation technology. • Investigate proving at a commercial plant. • Develop a comprehensive technology development plan including off normal loading. • Ensure funding for development. • Engage multiple independent reviewers.
5	Delay of licensing consolidation due to lack of criticality analysis, benchmarking criticality for this application, and methodology	• Use development program to have an agreed methodology. • Run agreed methodology upon benchmarks.

ID	Risk Description	Risk Handling
6	Consolidation density factors not being achieved raises questions on damage to fuel (licensing issue)	• Prototype. • Testing. • Test various fuel assemblies (types damaged). • Ensure “robustness” in design. • Use 3rd generation technology. • Investigate proving at a commercial plant. • Develop a comprehensive technology development plan including off normal loading.
7	Public resistance to large pools (Fukushima Daiichi accident)	• Enforce, circulate education (communication plan). • Meet or exceed new requirements. • Talk to each other. • Subgrade pool.
8	LLW at CSF raised public concerns (what is the disposal path?)	• Enforce, circulate education (communication plan). • Meet or exceed new requirements. • Talk to each other. • Subgrade pool. • Minimize generation/maximize recycling. • Design LLW-handling facilities in CSF.
9	Licensing requirements for fabrication of STADs results in fabricators not being able to meet demands	• Prototype a simple design that is easy to fabricate and meets requirements.
10	Public concern that anything new is costly and exceeds initial estimates, is perceived to be a failure, resulting in inaction by DOE	• Enforce, circulate education (communication plan). • Meet or exceed new requirements • Talk to each other. • Subgrade pool. • Investigate fed corporation as entity in control.
11	Making square STAD encounters technical difficulties	• Back up (e.g., tube steel, round, other). • Prototype well.
12	Fabricators are not qualified or available to meet demand	• Ensure fabricators understand requirements. • Correctly incentivize fabricators to ensure qualifications are met.
13	The long-term strategy for repository and short-term CSF/STAD implementation is enveloping multiple government administrations	• Develop an enforceable agreement. • Require consent-based siting.
14	Uncertainty of re-wetting fuel is an issue	• Prototype. • Testing. • Test various fuel assemblies (types damaged). • Ensure “robustness” in design.

ID	Risk Description	Risk Handling
		• Use 3rd generation technology. • Investigate proving at a commercial plant. • Develop a comprehensive technology development plan including off normal loading. • Perform test, R&D, and studies.
15	Multiple operations result in actual doses exceeding those anticipated	• Prototype. • Testing. • Test various fuel assemblies (types damaged). • Ensure “robustness” in design. • Use 3rd generation technology. • Investigate proving at a commercial plant. • Develop a comprehensive technology development plan including off normal loading. • Aggressive as low as reasonably achievable (ALARA) program. • Maximize remote operations. • Design to reduce background dose.
16	Regulatory framework precludes shipping (criticality controls/increased aging)	• Seek rulemaking and improvement in rule changes to minimize storage times/criticality evaluations/burnup credit.
17	Stakeholders resist implementation of a “new” strategy	• Enforce, circulate education (communication plan). • Meet or exceed new requirements. • Talk to each other. • Subgrade pool. • Advocate. • Publish to enforce acceptance of strategy.
18	Dose release impacts attainment (events) (Part 72)	• Prototype. • Testing. • Test various fuel assemblies (types damaged). • Ensure “robustness” in design. • Use 3rd generation technology. • Investigate proving at a commercial plant. • Develop a comprehensive technology development plan including off normal loading. • Understand potential for noble gas release and factor monitoring into licensing (Part 20/50).
19	Repository regulation will not be implemented due to uncertainty (not available: STAD) (e.g. Part 63)	• Accept.

ID	Risk Description	Risk Handling
20	Public persuasion interfaces with shipping	• Enforce, circulate education (communication plan). • Meet or exceed new requirements. • Talk to each other. • Subgrade pool. • Provide proof of principle. • Provide incentives, more local emergency services, etc.
21	Shipping regulation change	• Work with regulators to meet their needs while ensuring impacts to STAD strategy are minimized. • Exercise public comment period.
22	Changes are required (i.e. does not address consolidation)	• Identify if not addressed. • Work with regulators to amend. • Work with regulators to meet their needs while ensuring impacts to STAD strategy are minimized. • Exercise public comment period.
23	NRC change regulation (e.g. Part 20, 71, 72, 73, etc.)	• Work with regulators to meet their needs while ensuring impacts to STAD strategy are minimized. • Exercise public comment period.
24	Technical uncertainty of materials (STAD) in intimate contact with fuel	• Prototype. • Testing. • Test various fuel assemblies (types damaged). • Ensure “robustness” in design. • Use 3rd generation technology. • Investigate proving at a commercial plant. • Develop a comprehensive technology development plan including off normal loading.
25	Assumptions on pricing are not valid in 20-30 years and option is considered too costly	• Implement early. • Ensure reserves.
26	Materials of construction for STADs are not available	• Implement early. • Ensure reserves.

Table 6-2. Option 4 Opportunities

Opportunity
• Consent basis is improved by additional work for local labor (consolidation, recycling, etc.).
• R&D facility for risk mitigation can be something to bring expertise and then be a center for research with excellent teaming opportunities.
• DOE lab programs will be involved in R&D.
• Universities offer partnering opportunities.
• Investigate other international facilities, which may consolidate fuel and obtain data if possible.
• Investigate manufacturing processes (e.g., factory for STADs).
• Investigate opportunities for recycling/reuse of equipment (containers/spacers, etc.).
• Develop remote handling equipment, both at CSF and repository (compatibility).
• R&D to identify fission gas control.
• Optimize inter-modal transportation to reduce cost (e.g., barge, heavy haul, and rail).

6.6 Discussion

After the risk assessment was performed, the Team concluded that the consolidated options in general, while showing a great potential for savings and dose reduction, presented a solution with many inherent uncertainties when compared to the unconsolidated options. After discussion, the Team determined that any option involving consolidation would not be recommended at this stage due to these numerous uncertainties.

The Team then performed the SE Evaluation with only the unconsolidated options to assess if a point solution could be achieved with an unconsolidated STAD.

Figures 6-12 through 6-14 illustrate the results of those evaluations.

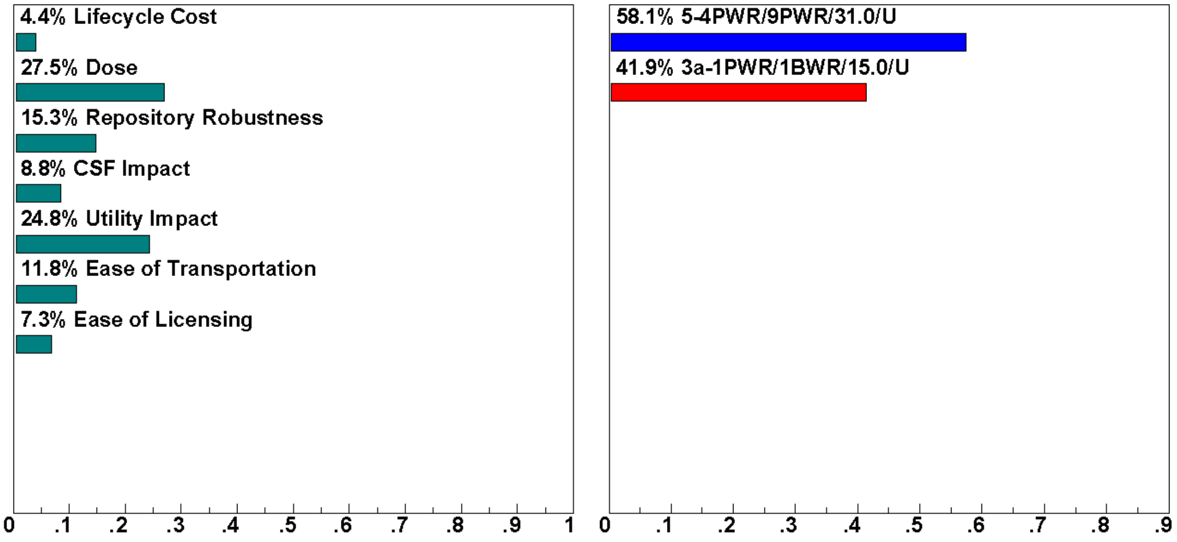


Figure 6-12. Evaluation 2 (Unconsolidated STADs only) Synthesized Results

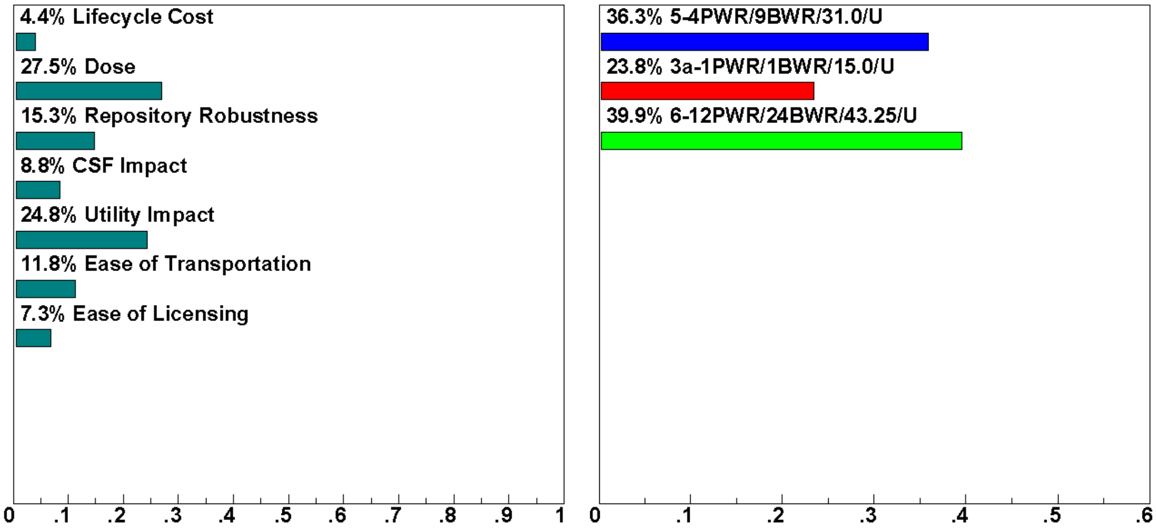


Figure 6-13. Evaluation 3 (Unconsolidated STADs only) Synthesized Results

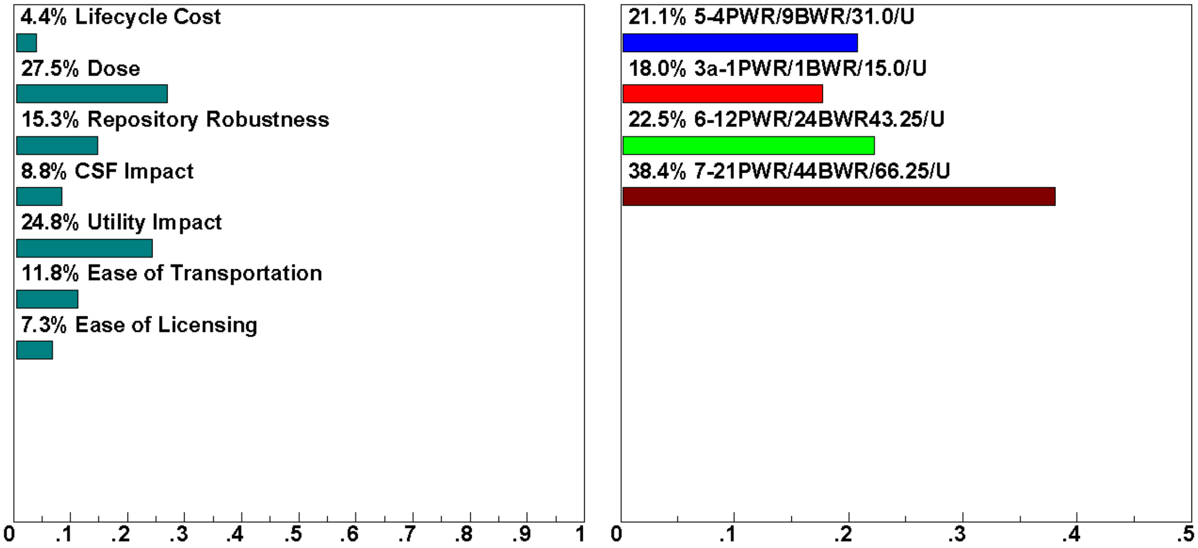


Figure 6-14. Evaluation 4 (Unconsolidated STADs only) Synthesized Results

The results from performing evaluations 2 through 4 with only unconsolidated options demonstrate that when considering only unconsolidated STADs, the larger the STAD the more desirable it is.

6.7 Recommendation

The Team identified the options and their associated compatibility with repository types as shown in Table 6-3.

Table 6-3. Options and Repository Types

Repository Type	Compatible Option
Borehole	2, 3, 3a, 4
Salt	2, 3, 3a, 4, 5, 6
Un-backfilled (Clay, Shale)	2, 3, 3a, 4, 5
Backfilled (Clay, Shale, Crystalline)	2, 3, 3a, 4, 5
Un-backfilled (Crystalline, Volcanic)	2, 3, 3a, 4, 5, 6, 7, 8

Option 4 showed great promise, however, at this time it could not be recommended due to the significant number of issues and uncertainties to be resolved.

Option 3a (small-size STAD) will meet all repository requirements and ranks higher among the small size unconsolidated STAD options. Option 5 (medium size STAD) will not meet the size requirements for a borehole repository; however, unlike Option 6 (other medium size STAD), meets the requirements of all other repository types.

Option 7 (large size STAD) will meet the repository requirements for un-backfilled crystalline and volcanic repositories and is the highest ranking option when considering only those.

Based on the results of the evaluation, risk assessment, and re-evaluations, the Team recommends the start of conceptual design on Options 3a, 5, and 7, while pursuing a CSF design that would allow for research on fuel consolidation.

The capital expenditure on pursuing both designs will be relatively small and result in a final design that is closer to the time a repository type may be selected. Transfer of UNF to the CSF in standard containers would alleviate the issues with stranded UNF and also allow research and development on fuel consolidation to take place.

If the result of this R&D determines consolidation to be viable and of benefit, a decision could be made to pursue the whole or partial deployment of the technology on a production scale at the CSF.

These recommendations are discussed in further detail within Section 7.0

7.0 STAD LOADING STRATEGIES

This section describes the strategies associated with loading the selected STAD options at reactor sites, the CSF, and the placement of the STAD into the geological repository, as well as strategies that apply in general. For the purposes of this section, loading is defined as placement of UNF into the STAD. The actual process of loading the STADs at reactor sites and at the CSF is discussed in Section 7.2, Operations. Appendix C includes an evaluation on the impact of use and loading of the STADs on reactor sites and at the CSF, and Appendix E contains supporting white papers associated with typical loading at a reactor site and a time and motion study.

This section also provides key information that should be taken into account during design, fabrication, and delivery of STAD options and delivery of the equipment associated with loading the STAD including:

- Key Dates
- Pilot CSF 2021
- Demonstration CSF 2025
- Site Selection for geological repository 2026
- Final licensing and design of STAD 2026
- Geological repository opens 2048

7.1 Proposed Timeline for the STAD Concept for UNF Management

Final Selection of STAD Design

Adopting the STAD concept for UNF disposal would allow for an optimum design of packaging for geological disposal. The final size of the STAD will, however, be a function of the geological repository chosen. For example, deep borehole disposal will tend to a smaller package design to fit into the disposal shaft whereas a salt repository will be limited by weight and to a lesser extent heat load allowing for a larger STAD concept to be considered. Therefore the final selection of the STAD design cannot be made until such time as the siting for the geological repository has been made. Based on the Yucca Mountain licensing schedule the repository type would be selected in 2026 assuming (1) a repository is operational by 2048, (2) a similar model as Yucca Mountain is chosen for site selection, and (3) siting selection work is started in 2016.

Reactors and Quantity of UNF

For the purpose of this study, it is assumed that the existing reactor fleet will operate to a lifetime of 60 to 80 years and only the reactors currently planned or under construction will be added to the fleet. The volume of UNF discharged each year was estimated as a ratio of 2000/104 multiplied by the number of operational reactors.

CSF Size, Timeline, and Shipments

Based on recent DOE announcements and assuming that work on the pilot CSF started in 2013, a pilot plant would be operational in 2021, and a demonstration CSF between 50,000 to 70,000-

tUNF facility would be operational in 2025. For the purpose of this study we have assumed UNF shipments would gradually ramp up to reach 3,000 UNF a year from the reactor sites to the CSF. It can be seen from Figure 1-2 that the CSF would contain close to 70,000 tUNF before the geological repository is open. Once 70,000 tUNF is transferred to the CSF there will still be 58,000 tUNF at the reactor sites.

7.2 General STAD Loading Strategies

- The SE evaluation considered the optimum design and use of 8 STAD designs against each of five geological repository types that are under consideration in the U.S. Our evaluation selected three design options for the STAD as “bounding” cases for a future STAD concept to be used in a future U.S. repository. A small capacity (Option 3a – 1 PWR/2 BWR fuel assembly capacity), a medium capacity (Option 5 – 4 PWR/9 BWR fuel assembly capacity) and a large capacity (Option 7 – 21 PWR/44 BWR fuel assembly capacity) unconsolidated UNF STAD design option should be carried through the conceptual and preliminary design stages. The options will be re-evaluated before the preliminary design stage to ensure that the chosen options are still optimal based on final geological repository status, changes in dry storage regulations, and emergent UNF research.

- Final design of the STAD will not be performed until the final geological repository has been selected and repository acceptance criteria have been finalized, approximately 2026.

- It is important to remember that in the nuclear industry the timeline for building or operating major facilities or projects can easily take decades, therefore, any proposal for handling, unloading, and loading the UNF from the current storage canisters into a STAD must be flexible to accommodate future backend issues such as the final geological repository and lessons learned in moving and repackaging the first of the Part 72 Dry Cask Storage System (DCSS) canisters. It is important to remember that as time progresses and more UNF is placed into dry storage, it is entirely feasible and likely that STAD operations will occur both at the reactor sites and the CSF. Therefore, for the purpose of this study, we considered three broad time frames for handling UNF.

    - Period 1: Current procedure of loading UNF into Part 72-licensed DCSS while utilities wait for STADs to be designed, built, and licensed and the CSF to be built, including the scenario that the STAD selected is similar in size to current DCSS.

    - Period 2: The CSF begins operations. UNF is moved to the CSF in Part 72-licensed DCSS where it is placed into temporary storage until the UNF can be transferred into STADs.

    - Period 3: The STAD is generally available for use at the reactor sites and at the CSF. Once the STAD is available, reactor sites package UNF into the STAD. Also, the CSF begins the process of transferring the UNF from the Part 72 DCSS in temporary storage into STADs. Transfer of UNF from Part 72 DCSS to STADs at reactor sites is not recommended.

- Use the R&D Facility at the CSF, including the Wet Pool, to develop and optimize STAD-loading methods to be implemented at reactor sites. The Option 3a, 5, and 7 preliminary designs will be used as part of this future R&D program.

- Use the R&D Facility at the CSF, including the Wet Pool, to develop and optimize methods for transfer of UNF from 10 CFR Part 72-licensed DCSs to STADs. Use the R&D Facility at the CSF, including the Wet Pool, to further evaluate the feasibility of fuel rod consolidation and to investigate production methods for rod consolidation especially if a smaller design of STAD is chosen for deep borehole disposal. This might be more relevant to the newer fuel designs that are to a certain extent designed to be dismantled.

7.3 STAD Loading Strategies at Reactor Sites

- In the U.S., at this time there are currently 104 operational reactors operated by numerous utilizes. It is not possible to make blanket statements that all the utilities will do this or will not do that. For the purpose of this study, we have incorporated comments from our utility partners and tried to identify a path forward for using the STAD that is cognizant of the utility’s main requirement to produce electricity.

- The final design, licensing, fabrication, and delivery of STADs will not commence until after final geological repository acceptance criteria have been finalized and accepted by regulators, 2026. Until STADs become available, it must be expected that UNF will be transferred to dry storage at reactor sites using current methods and Part 72-licensed DSCs, unless DOE decides to take a risk on the final STAD design, at which point, we can move forward at a faster rate.

- UNF could be transferred directly from wet storage to a larger design of STADs once they are available for use at operational reactor sites.

- Once reactor shuts down there will be a period of approximately five to seven years when the utility will work to empty the fuel pool and move the fuel to dry storage. Emptying the pool will occur relatively quickly after the reactor shuts down due to the large costs associated with security of the wet pools.

- Transfer of UNF from loaded Part 72 DSCs could be performed at reactor sites when the reactor enters the D&D phase or if required for transportation needs (e.g. the Part 72 DCSS is not licensed for transport).

- Dry transfer of UNF from 10 CFR Part 72-licensed DSCs could be considered for some of the 104 operational reactors where siting of a dedicated dry transfer facility could be used for a regional or state approach to managing UNF where the quantity of UNF available for repackaging warrants the expense of building a dedicated facility.

- The operations associated with transfer of UNF from Part 72 DSCs to STADs would initially best be performed at the CSF.

This strategy provides a number of benefits related to loading of UNF for dry storage:

- Final STAD design selection will not occur until 2026.
- In the near term, the reactor site will continue to use a Part 72 DSCs that best suits the needs of the site including compatibility with site facilities and equipment.
- UNF already in dry storage at reactor sites can be shipped as soon as the CSF becomes operational.
- Re-packaging at a single site (i.e. the CSF) allows for development of a dedicated, highly trained crew and associated equipment and tools that can perform the required operations most efficiently.
- Lessons learned from operation at the CSF can then be transferred back to operations at the reactor site.
- Typical current Part 72-licensed DCSSs have greater capacities than the chosen STAD options. Therefore, a reactor site may choose to continue use of their particular Part 72 DCSS thereby resulting in a smaller storage site footprint and fewer loading operations compared with the STAD, benefiting ALARA and financial considerations.
- Use of the reactor pool once the reactor shuts down and enters the D&D phase should be considered a viable option.

7.4 STAD Loading Strategies at the CSF

Based on the assumptions used in the study, UNF will initially be received at the CSF at a rate of 3,000 tUNF per year in Part 72 DSCs. Assuming pilot plant operation in 2021 and large CSF in 2025, UNF will be stored at the CSF until the STADs become available in 2026. It is estimated that approximately 6,500 tUNF will be at the site by 2026. Once STADs are available it is anticipated that UNF will continue to arrive in Part 72 DSCs and later also in STADs. However, it is possible that STADs could be transferred from the reactor site directly to the repository if the repository is open. The Team thought that loading 3,500 tUNF a year on STADs at the CSF would consume the manufacturing capability to produce STADs for the initial time period considered.

To transfer UNF received in Part 72 DSCs to STADs, two options were considered at the CSF—a wet option using the pool and a dry option using dedicated transfer cells. These options are discussed in more detail the sections below. The following strategies are recommended for the loading of STADs at the CSF:

- An extensive database of UNF received at the CSF should be developed. The database should, as a minimum, include information related to repository acceptance. This may include information such as material condition, burn up, initial enrichment, and heat load. The database may also be used for Special Nuclear Materials (SNM) accountability. Therefore, information such as fuel assembly make and serial number will be acquired. This data could also be used to determine the final loading of UNF into STADs to meet thermal heat requirements.

- Transfer of UNF from Part 72 DCSSs to STADs may not happen for a significant time period after the CSF has started to receive UNF from reactor sites. It is recommended that this time period be used to perform the R&D discussed in Section 7.1.
- The STAD-loading strategy at the CSF should consider accountability. The loading strategy will also need to consider UNF parameters such as burn up, initial enrichment, heat load, etc. with respect to repository and STAD requirements.

7.5 STAD Handling Strategies at the Final Geological Repository

For the purpose of this study the AREVA Team considered that loading of the STADs would occur at the reactor site or the CSF and not be replicated at the geological repository. There is, however, no reason to believe that the CSF could not be collocated at the geological repository site.

The Yucca Mountain geological repository assumed a placement rate of 3,500 tUNF per year. It is the AREVA Team's belief that the use, handling, and placement of a single design STAD will make operations at the geological repository safer, cheaper, and faster. Figures 7-1 and 7-2 compare loading rates into the geological repository assuming the Yucca Mountain rate of 3,500 tUNF per year and an increased rate of 5,000 tUNF per year. Based on this initial study, all the UNF in the U.S. could be placed in the geological repository approximately 15 years faster representing a significant savings on the operational costs of the geological repository and ensuring the large majority of UNF is placed in the repository before it loses its self-protection.

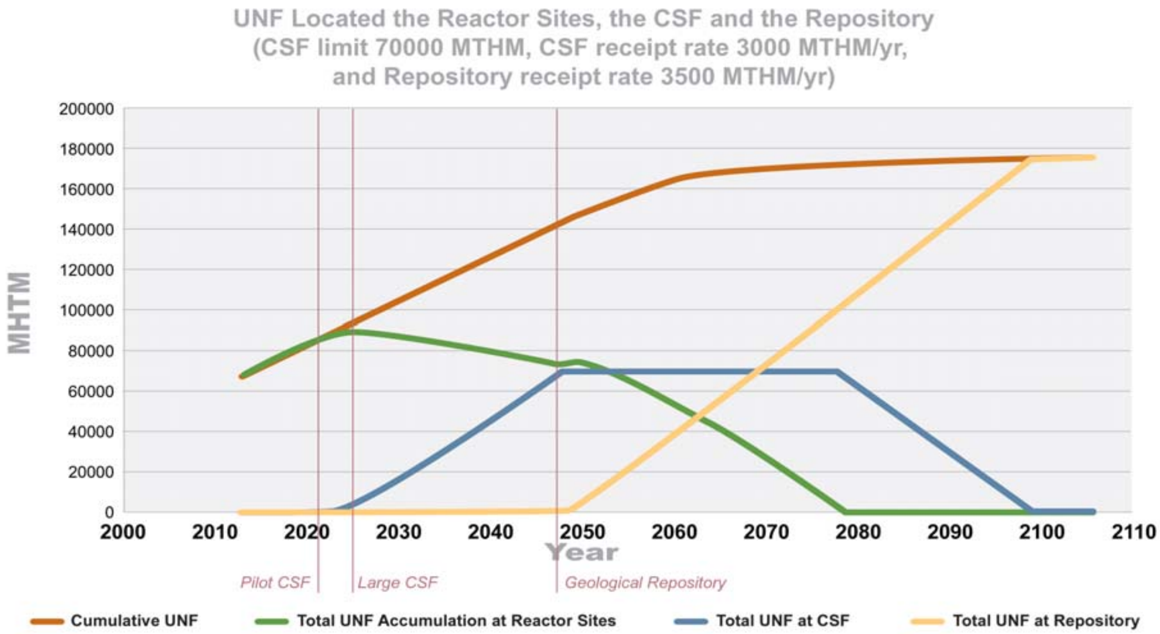


Figure 7-1. Timeline for Loading UNF into Repository Assuming 3,500 tUNF Placed Per Year

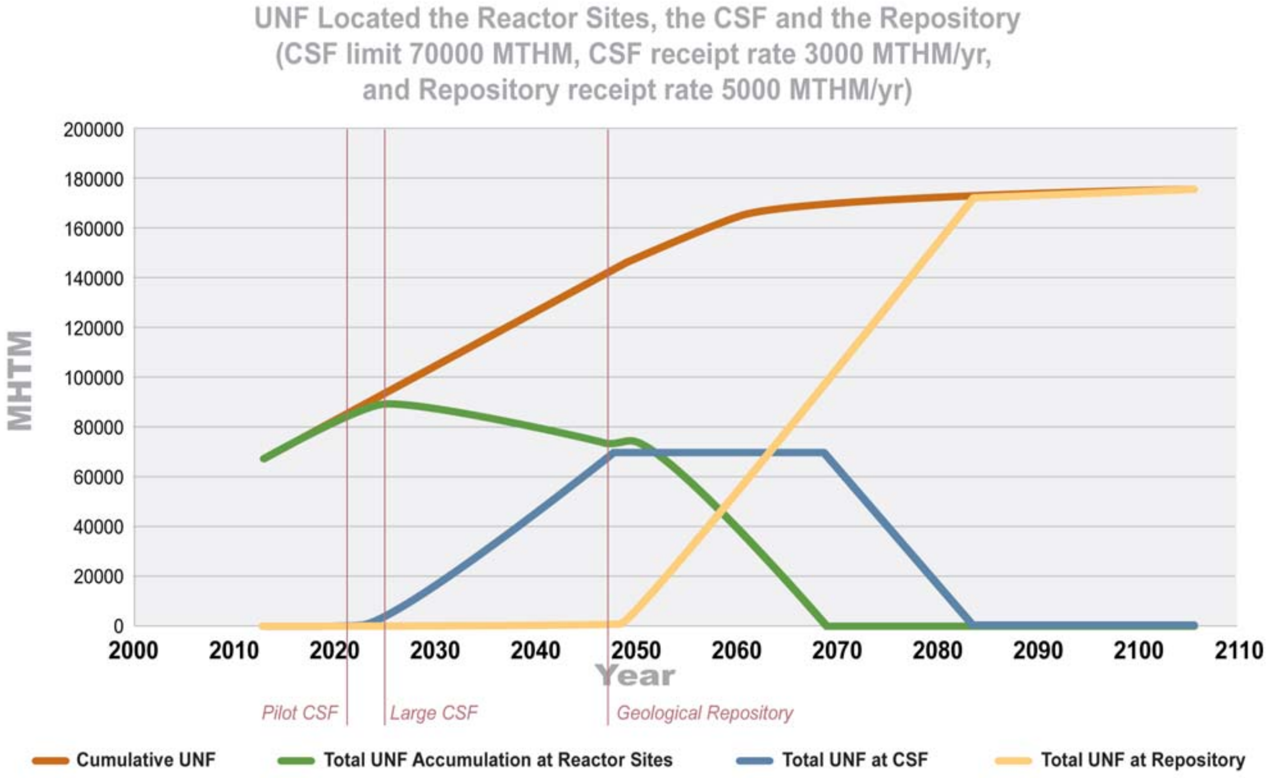


Figure 7-2. Timeline for Loading UNF into Repository Assuming 5,000 tUNF Placed Per Year Using STAD

7.6 STAD Size Advantages and Disadvantages

7.6.1 STAD Size Impact

In support of this report, AREVA has performed various studies including loading times for the different sized (small, medium, and large) STADs (see Appendix E) assuming that only one STAD and associated handling frame are being processed through the system at one time. The loading time study concluded that based on a single STAD in the process, on a per UNF assembly basis, loading larger capacity STADs takes less time. As an example, on a per assembly basis loading the Option 3a STAD (1 PWR/2 BWR assembly capacity) takes about five times longer than loading the Option 7 STAD (21 PWR/44 BWR assembly capacity) and about seven times longer than a Part 72 dry storage system.

Longer loading times will have the following impacts:

- Assuming similar loading crew makeups, increased loading times will increase personnel dose. Typical dry storage operations using a Part 72 dry storage system have doses of 500 – 600 mRem/cask. Assuming a 61-BWR capacity cask results in a dose of about 10 mRem per assembly. The dose impact of using an Option 3a STAD vs. a Part 72 system may be up to 40 mRem per fuel assembly assuming dose is directly related to loading time.

- Assuming similar loading crew makeups, increased loading times will increase the impact on personnel availability. Either additional personnel will be required to cover loading or other duties will be impacted. A typical reactor site loading campaign involves three to four Part 72 casks or 96 to 128 PWR assemblies. Assuming 128 PWR assemblies, loading the required number of Option 3a STADs will take about 2100 hours compared with 300 hours for the Part 72 system.

- Increased crew hours will result in an increase, on a per assembly basis, in cost of loading UNF into STADs. For comparison purposes, a per-crew-hour cost of $500 is used. A typical 4 cask/128 PWR assembly campaign using an Option 3a STAD would cost $700,000 more than a Part 72 system.

The storage or transportation configuration of the Option 3a STADs will be 12 STADs placed in a handling frame resulting in 12 PWR or 24 BWR assemblies per storage overpack or transportation cask. The configuration for the Option 5 STAD is 3 STADs in a handling frame resulting in 12 PWR or 27 BWR assemblies per storage overpack or transportation cask. One Option 7 STAD with 21 PWR or 44 BWR assemblies would be placed in a storage overpack or transportation cask.

The decreased number of assemblies in a storage overpack or transportation cask will have the following impacts:

- Storage
    - More storage overpacks will be required resulting in increased costs and onsite storage facility size.
    - Since there will be more trips between the loading area and storage area, the crew hours associated with transfer to storage will increase with associated cost and personnel impacts.
    - Personnel dose will be larger as a result of the increased number of operations. This impact should not be significant as dose during transfer to storage is minimal.
- Transportation
    - A decreased number of assemblies per transportation cask will require more trips from the initial facility to the CSF or repository. This will impact the overall logistics and may require additional transport equipment (casks, rail cars) or a reduction in the rate of transfer from a reactor site to the CSF or repository or from the CSF to the repository.
    - The additional number of transports will increase the dose to personnel directly associated with operations. This is not expected to be significant as dose during transport should be minimal.

7.6.2 STAD Size Advantages/Disadvantages

This section describes the advantages and disadvantages related to using each of the three recommended STAD options. The advantages and disadvantages are relatively immune to time of implementation except in the following cases: (1) the reactor site has shut down and UNF remains in the site storage pool; (2) the UNF will be placed into a STAD and shipped directly to the CSF or the final repository. Both cases are discussed in Section 7.6.3, STAD Impact Mitigation Strategy below.

7.6.2.1 STAD Option 3a

- Advantages
    - This STAD can be used for all projected repository types including the deep bore hole type.
    - Its small size and relative simplicity may result in decreased costs and increased production.
    - The use of this STAD should not be restricted by space or crane capacity issues.
    - The reduced capacity of the STAD itself and of its associated handling frame should allow it to handle higher heat load and/or less cooled UNF for storage and transportation.
- Disadvantages
    - As the smallest capacity STAD, Option 3a has the highest per assembly loading time, personnel dose, and procurement cost of the STAD options.
    - Use of this STAD requires increased numbers of storage overpacks and storage facility size compared with other STAD options and Part 72 systems.
    - Use of this STAD will require an increase in transportation equipment or a reduction in UNF transfer rate compared with other STAD options and Part 72 systems.

7.6.2.2 STAD Option 5

- Advantages
    - This STAD can be used for all projected repository types except the deep bore hole type.
    - Its smaller size may result in decreased costs and increased production compared to the Option 7 STAD and Part 72 systems.
    - The use of this STAD should not be restricted by space or crane capacity issues.
    - The reduced capacity of the STAD itself and of its associated handling frame should allow it to handle higher heat load and/or less cooled UNF for storage and transportation.

- Option 5 has a lower per assembly loading time, personnel dose, and procurement cost compared with Option 3a.

- Disadvantages
  - Option 5 has higher per assembly loading time, personnel dose, and procurement cost compared with STAD Option 7 and Part 72 systems.
  - Use of this STAD requires increased numbers of storage overpacks and storage facility size compared with STAD Option 7 and Part 72 systems. There is a slight decrease compared to STAD Option 3a because of its increased BWR assembly capacity (27 vs. 24).
  - Use of this STAD will require an increase in transportation equipment or a reduction in UNF transfer rate compared with STAD Option 7 and Part 72 systems. There is a slight decrease compared to STAD Option 3a because of its increased BWR assembly capacity (27 vs. 24).

7.6.2.3 STAD Option 7

- Advantages
  - This STAD can be used at any facility that currently uses Part 72 systems.
  - The similarity between this STAD and Part 72 systems will allow use with potentially only minor modifications of the procedures, processes, and equipment used for Part 72 systems.
  - Compared with Part 72 systems, the reduced capacity of the STAD should allow it to handle higher heat load and/or less cooled UNF for storage and transportation.
  - Option 7 has the lowest cost, dose, and personnel impacts of the three STAD options.

- Disadvantages
  - Option 7 is compatible with a limited number of repository types.
  - Option 7 has higher per assembly loading time, personnel dose, and procurement cost compared with Part 72 systems.
  - Use of this STAD requires an increase of about 50 percent in the number of storage overpacks and storage facility size compared with current Part 72 systems. There is a considerable decrease compared to STAD Options 3a and 5 because of its increased capacity (21/44 vs. 12/27 vs. 12/24).
  - Use of this STAD will require an increase in transportation equipment or a reduction in UNF transfer rate compared with Part 72 systems. There is a decrease compared to STAD Options 3a and 5 because of its increased assembly capacity.

7.6.3 STAD IMPACT MITIGATION STRATEGY

The time and motion study discussed in section 7.6 was conducted based upon today's current industry practice for loading Part 72 DCSS based on typical reactor operations. Please note each utility is slightly different and the study was prototypical in nature to identify where it would be possible to reduce the time for loading while maintaining the high safety requirements of an operational reactor and keep radiation exposure to a minimum. These results are presented in Appendix E.

It should be noted that for most of the utilities we researched, space constraints and the design of the SFP building were the limiting factor for increasing the through-put of the preparation, loading, closing, and drying process. These steps are sequenced in a limited space with one crane and hence, one place in the SFP to place a cask for loading and one place to prepare for loading, decon, drying, inerting, and welding of the cask (decon pit). Any operation that lifted a loaded STAD over another STAD that was being loaded was deemed to be unsafe and unworkable.

Table 7-1 lists the sequence of activities (coarse) and their location.

Table 7-1. Sequence of Activities

Step	Activity	Equipment	Location at Reactor Site
1	Upending of transportation or transfer cask from conveyance	Overhead crane Rigging (yolk) Transportation/transfer cask Conveyance (railcar/trailer) Upending cradle	Receiving area of SFP building
2	Lifting and transfer of transportation or transfer cask from conveyance to decon pit	Overhead crane Rigging (yolk) Transportation/transfer cask Conveyance (railcar/trailer) Upending cradle	Receiving area of SFP building Decon pit of SFP building
3	Removal of transportation or transfer cask lid (bolted)	Overhead crane Rigging (straps) Transportation/transfer cask Transportation/transfer cask lid	Decon pit of SFP building (lid may be placed in receiving area)
4	Upending of STAD from conveyance	Overhead crane Rigging (sling) STAD Conveyance (railcar/trailer) Upending cradle	Receiving area of SFP building
5	Lifting and transfer of STAD from conveyance into transportation/ transfer cask	Overhead crane Rigging (sling) STAD Conveyance (railcar/trailer) Upending cradle	Receiving area of SFP building Decon pit of SFP building
6	Addition of demineralized water to annulus between cask and STAD and to STAD and placement of rubber seal at top	Transportation/transfer cask STAD Rubber seal	Decon pit of SFP building

Step	Activity	Equipment	Location at Reactor Site
	of annulus (to minimize contamination of STAD surfaces)		
7	Lifting and transfer of cask with STAD into SFP	Overhead crane Rigging (yolk) Transportation/transfer cask STAD Rubber seal	Decon pit of SFP building Cask loading pit in SFP
8	Move UNF into STAD (verify correct UNF moved into STAD several times)	SFP bridge crane Transportation/transfer Cask STAD Rubber seal	SFP Cask loading pit in SFP
9	Place shield plug with inner lid on STAD	Overhead crane Rigging (yolk and metal straps) Transportation/transfer cask STAD STAD shield plug with inner lid Rubber seal	Cask loading pit in SFP
10	Lift loaded STAD in cask above SFP and decon outside of cask	Overhead crane Rigging (yolk and metal straps) Transportation/transfer cask STAD with shield plug and inner lid Rubber seal	Above cask loading pit in SFP
11	Move loaded STAD in cask to decon pit	Overhead crane Rigging (yolk and metal straps) Transportation/transfer cask STAD with shield plug and inner lid Rubber seal	Cask loading pit in SFP Decon pit of SFP building
12	Disconnect rigging from STAD inner lid and transportation/ transfer cask and decon inner lid of STAD	Overhead crane Rigging (yolk and metal straps) Transportation/transfer cask STAD with shield plug and inner lid Rubber seal	Decon pit of SFP building
13	Remove rubber seal and drain annulus (check for contamination)	Transportation/transfer cask STAD with shield plug and inner lid Rubber seal	Decon pit of SFP building
14	Dry and survey surfaces and partially drain STAD	Transportation/transfer cask STAD with shield plug and inner lid Drain portion of vacuum drying system	Decon pit of SFP building
15	Place and fix welding equipment to top of inner lid	Overhead crane Rigging (metal straps) Transportation/transfer cask STAD with shield plug and inner lid Welder	Decon pit of SFP building
16	Weld inner lid of STAD (inspections)	Transportation/transfer cask STAD with shield plug and inner lid Welder	Decon pit of SFP building
17	Remove welding equipment	Overhead crane Rigging (metal straps) Transportation/transfer cask STAD with shield plug and inner lid	Decon pit of SFP building

Step	Activity	Equipment	Location at Reactor Site
		Welder	
18	Drain, vacuum dry, and inert STAD	Transportation/transfer cask STAD with shield plug and inner lid Vacuum drying system	Decon pit of SFP building
19	Weld plates (“silver dollars”) over drain and vacuum ports	Transportation/transfer cask STAD with shield plug and inner lid	Decon pit of SFP building
20	Place outer lid on STAD	Overhead crane Rigging (metal straps) Transportation/transfer cask STAD with shield plug and inner lid STAD outer lid	Decon pit of SFP building
21	Place and fix welding equipment to top of outer lid	Overhead crane Rigging (metal straps) Transportation/transfer cask STAD with shield plug, inner and outer lids Welder	Decon pit of SFP building
22	Weld outer lid of STAD (inspections)	Transportation/transfer cask STAD with shield plug, inner and outer lids Welder	Decon pit of SFP building
23	Remove welding equipment	Overhead Crane Rigging (metal straps) Transportation/Transfer Cask STAD with shield plug, inner and outer lids Welder	Decon pit of SFP Building
24	Place cask lid on transportation/transfer cask	Overhead crane Rigging (metal straps) Transportation/transfer cask STAD with shield plug, inner and outer lids Cask lid	Decon pit of SFP building
25	Bolt cask lid	Transportation/transfer cask containing loaded STAD	Decon pit of SFP building
26	Lifting and transfer of transportation or transfer cask with loaded STAD from decon pit to conveyance	Overhead crane Rigging (yolk) Transportation/transfer cask containing loaded STAD Conveyance (railcar/trailer) Downending cradle	Receiving area of SFP building Decon pit of SFP building
27	Downending of transportation or transfer cask with loaded STAD onto conveyance	Overhead crane Rigging (yolk) Transportation/transfer cask containing loaded STAD Conveyance (railcar/trailer) Downending cradle	Receiving area of SFP building

Based on the above activities and the fact that space in the area around the SFP is very limited for moving and setting down the heavy cask system (really limited to cask loading pit in the

SFP, decon pit of the SFP building, and the receiving area of the SFP building), there really is no option to bring in a second cask/STAD system. If the 2nd cask/STAD system were placed in the decon pit while the first cask/STAD system were being loaded, then the second system would have to be moved out of the building to the receiving area when the first system were loaded and ready to be welded shut. There may be a possibility that the second system could then be brought into the facility and placed into the SFP to be loaded, but the following would have to be considered: (1) we cannot move the empty second system over the loaded first system; (2) the viability of allowing for the door to the receiving area to be opened to allow the second cask into the facility while the first cask is being prepared or undergoing welding activities; (3) the need for the overhead crane to complete the buttoning up procedures for the first cask versus the moving of the second cask; (4) the duration the second cask would have to reside in the SFP while the first cask is being buttoned up; (5) the contingency for the first cask having to be moved back into the SFP; (6) the potential hazards (including exposure) to personnel and to the cask systems themselves and their supporting equipment as a result of moving two casks in these tight spaces; and (7) the potential for mixing equipment (e.g., rigging) that could lead to safety issues.

The alternative is to redesign the SFP building at the operational reactors to allow for increased space and flexibility in the management of the STADs.

8.0 STAD OPTIONS

This section of the report describes the STAD configurations (options) that evaluated the highest in the SE analysis the AREVA Team performed. For each option we describe the design concept, the operations for STAD options at the reactor site and the CSF, and the D&D of equipment used in handling, storing, and transporting the STADs.

8.1 Design Concept

The final STAD selection will be a function of the final geological repository selected. Unfortunately site selection is not anticipated to occur until 2026 at the earliest. Therefore, based on the results of the systems evaluation, risk assessment, and re-evaluations, the AREVA Team recommends the start of conceptual design on the three STAD options proposed (a small, medium, and large) be carried forward at this time. These options bound the envelope of the STAD sizes versus geological repository options. Adjustment to the final design can be made as a down selection so that final selection can be made on the U.S. geological repository.

8.1.1 STAD Option 3a

Option 3a is the smallest of the STADs considered containing only 1 PWR or 2 BWR UNF assemblies. The design of the Option 3a STAD makes it compatible with the following geometry types: crystalline rock (enclosed), generic salt, clay/shale (enclosed), shale un-backfilled (open), sedimentary (open), and hard rock (enclosed). Further, its relatively small outside diameter of 15 inches will allow use in a deep borehole-type repository.

Table 8-1 illustrates the design parameters for the Option 3a STAD. Figures 8-1 (PWR) and 8-2 (BWR) show loaded configuration.

Table 8-1. STAD Option 3a Design Parameters

Parameter	Value
UNF Assembly Capacity	
• PWR	1 intact assembly
• BWR	2 intact assemblies
Canister OD (inches)	15.0
Canister Inside Diameter (ID) (inches)	14.5
Canister wall thickness (inches)	0.25
Canister length* (inches)	198
Cell size, PWR/BWR (inches x inches)	8.9 x 8.9/6.0 x 6.0
Canister Material	Stainless steel

*Canister length may be increased to accommodate handling frame

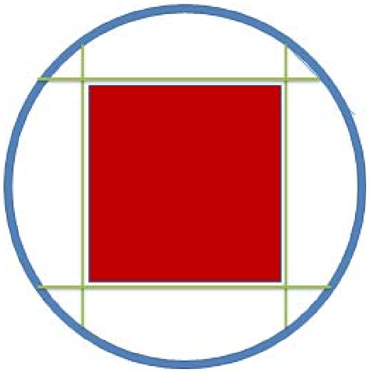


Figure 8-1. STAD Option 3a Loaded Configuration – PWR

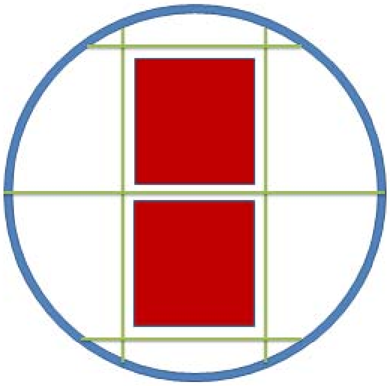


Figure 8-2. STAD Option 3a Loaded Configuration – BWR

Since the STAD will potentially be used in a number of varying environments, stainless steel is recommended for the canister material allowing for its compatibility with typical reactor site UNF pool chemistry, corrosion resistance, and satisfactory experience at reactor sites in use for UNF DSCs, and potential to store for a long period of time. The Core Team recognizes that the material requirements for the canister may change depending on repository requirements. This may be accommodated by providing a canister overpack of the required material and thickness rather than using a more exotic material for the canister itself. Alternatively, deep borehole disposal may require consideration of alternative materials.

The stainless steel STAD canister has a welded lid with provisions for inserting and leak testing, and a built-in lifting feature. The lid includes biological shielding, as necessary, if the closure weld and its examination were not performed remotely. This configuration is essentially the same as used for 10 CFR Part 72-licensed DCSSs currently in use at reactor sites.

Given the small diameter, a configuration with a threaded lid with metal gaskets/O-rings and/or a small seal weld could be used in place of the welded lid. The threaded configuration could have operational benefits including reducing dose; however, this type of configuration is in need of further development before use.

For storage at reactor sites, at the CSF, and for transportation purposes, 12 of the Option 3a STAD canisters will be packaged together using a handling frame and canister overpack described in Section 8.1.2. This will reduce storage and transportation operations and costs. The 12 STAD configuration does not exceed the existing reactor site weight and handling limits or transportation weight and size limits.

8.1.2 STAD Option 3a Handling Frame and Canister Overpack

To minimize handling operations and dose during storage and transportation, the Option 3a STADs are placed into a 12-cell handling frame for storing and transporting. In turn, the handling frame is integrated into a cylindrical overpack. A loaded handling frame/overpack may be stored and transported in storage and transport overpacks that are similar in size and weight as those designed and licensed today.

Conceptually, the handling frame is a grid structure that contains individual cells for the STADs and is designed as an integral part of the storage, transport and, possibly, disposal overpacks . The handling frame would have drain holes and a bolted lid that does not provide containment or confinement, but is designed for structural considerations. It would have a lifting feature for remotely lifting the 12 canisters contained within. The handling frame provides the internal structure to support the STADs during transportation and meet the structural requirements imposed by the Hypothetical Accident Conditions of 10 CFR Part 71. Internal aluminum plates may be needed between the canisters to transfer decay heat to the surface, thus maintaining peak cladding temperatures below the normal condition storage temperature limit of 752 degrees Fahrenheit. Poison plates may also be required during the transportation mode to meet sub criticality criteria under the assumptions of fresh fuel and optimum moderation. Figure 8-3 depicts the configuration of the 12 STADs in the handling frame and Figure 8-4 shows a similar configuration that is used to transport vitrified high-level waste canisters from La Hague across the globe to return waste to the point of origin.

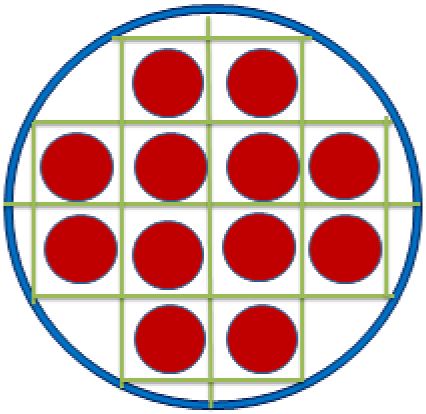


Figure 8-3. 12 STAD Handling Frame and Overpack

Figure 8-4. 12 High Level Waste Overpack for Transportation

8.1.3 STAD Option 3a Transportation Considerations

Based on the established DOE limits for rail transport[4], a practical limit on the loaded weight of the transport cask without impact limiters is approximately 125 tons. This weight limit derives from the maximum impact limiter diameter dimension of 126 inches, which is a U.S. rail infrastructure dimensional limit, and CFR Part 71 impact requirement for nuclear materials transportation.

---

[4] Transportation, Aging, and Disposal Canister System Performance Specification, Revision 1/ICN 1, DOE/RW-0585, US Department of Energy, Office of Civilian Waste Management, March, 2008.

The Transnuclear (TN) TAD Canister System[5] met these criteria having a shipping cask with a capacity of 21 PWR or 44 PWR fuel assemblies in a single canister. From this previous study, the limit on the inner diameter of the transport cask is about 68 inches. The diameter of a handling frame with overpack capable of holding 12 Option 3a canisters is about 62 inches without allowance for any internal structure, thermal conductors, or poison materials. Therefore, based on the TN TAD Canister System experience, the 12-canister configuration should result in a transportable system.

8.1.4 STAD Option 5

Option 5 is considered a medium size alternative of the STAD options developed. The Option 5 STAD has a capacity of 4 PWR or 9 BWR UNF assemblies. The design of the Option 5 STAD makes it compatible with the following final repository types: crystalline rock (enclosed), generic salt, clay/shale (enclosed), shale un-backfilled (open), sedimentary (open), and hard rock (enclosed). Its outside diameter of 31 inches would not allow use in a postulated deep borehole-type repository.

Table 8-2 illustrates the design parameters for the Option 5 STAD. Figures 8-5 (PWR) and 8-6 (BWR) show loaded configurations.

Table 8-2. STAD Option 5 Design Parameters

Parameter	Value
UNF Assembly Capacity	
• PWR	4 intact assemblies
• BWR	9 intact assemblies
Canister OD (inches)	31.0
Canister Inside Diameter (ID) (inches)	30.5
Canister wall thickness (inches)	0.5
Canister length* (inches)	198
Cell size, PWR/BWR (inches x inches)	8.9 x 8.9/6.0 x 6.0
Canister Material	Stainless steel

*Canister length may be increased to accommodate handling frame

---

[5] TN TAD Canister System Proof of Concept Design Report, Document No. 30552-0101 Rev. B, Transnuclear, Inc., Columbia, MD, March 21, 2007.

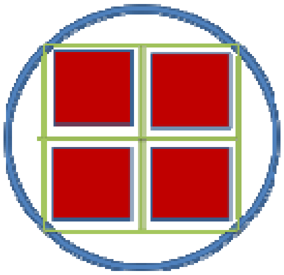


Figure 8-5. STAD Option 5 Loaded Configuration – PWR

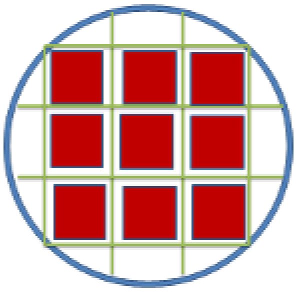


Figure 8-6. STAD Option 5 Loaded Configuration – BWR

Since the STAD will potentially be used in a number of varying environments, stainless steel is recommended for the canister material allowing for its compatibility with typical reactor site UNF pool chemistry, corrosion resistance, and satisfactory experience at reactor sites in use for UNF DSCs, as well as potential to store for a long period of time. The AREVA Team recognized that the material requirements for the canister may change depending on repository requirements. This can be accommodated by providing a canister overpack of the required material and thickness rather than using a more exotic material for the canister itself.

The stainless steel STAD canister has dual welded lids with provisions for inerting and leak testing, and a built-in lifting feature. The inner lid includes biological shielding, as necessary. This configuration is essentially the same as used for 10 CFR Part 72-licensed DCSSs currently in use at reactor sites. An interior grid structure will be provided. The grid may use high conductivity materials and neutron poisons for certain fuels depending on cooling time, enrichment, and burnup.

For storage at reactor sites, at the CSF, and for transportation purposes, three of the Option 5 STAD canisters will be packaged together using a handling frame and canister overpack described in Section 8.1.5. This will reduce storage and transportation operations and costs. The three-STAD configuration does not exceed the existing reactor site weight and handling limits or transportation weight and size limits. The STAD Option's geometry and weight configured in its handling frame and overpack will allow handling and storage using equipment that is similar to that in use for current Part 72 DCSSs.

8.1.5 STAD Option 5 Handling Frame and Canister Overpack

To minimize handling operations and dose during storage and transportation, the Option 5 STADs are placed into a three-cell handling frame for storing and transporting. In turn, the handling frame is integrated into a cylindrical overpack. A loaded handling frame/overpack may be stored and transported in storage and transport overpacks that are similar in size and weight as those designed and licensed under 10 CFR Parts 71 and 72 today.

Conceptually, the handling frame is a grid structure that contains individual cells for the STADs and could be designed as an integral part of the cylindrical overpack. The overpack will have drain holes and a bolted lid that does not provide containment or confinement, but is designed for structural considerations. It would have a lifting feature for remotely lifting the three canisters contained within. The handling frame provides the internal structure to support the STADs during transportation and meet the structural requirements imposed by the Hypothetical Accident Conditions of 10 CFR Part 71. Internal aluminum plates may be needed between the canisters to transfer decay heat to the surface, thus maintaining peak cladding temperatures below the normal condition storage temperature limit of 752 degrees Fahrenheit. Poison plates may also be required during the transportation mode to meet sub criticality criteria under the assumptions of fresh fuel and optimum moderation. Figure 8-7 depicts the configuration of the three STADs in the handling frame. Refer to Figure 8-4 for a similar configuration that is used to transport vitrified high-level waste canisters from La Hague across the globe to return waste to the point of origin.

Figure 8-7. Three STAD Handling Frame and Overpack

8.1.6 STAD Option 5 Transportation Considerations

Based on the established DOE limits for rail transport[6], a practical limit on the loaded weight of the transport cask without impact limiters is approximately 125 tons. This weight limit derives from the maximum impact limiter diameter dimension of 126 inches, which is a U.S. rail infrastructure dimensional limit, and 10 CFR Part 71 impact requirement for nuclear materials transportation.

The Transnuclear TAD Canister System[7] met these criteria having a shipping cask with a capacity of 21 PWR or 44 PWR fuel assemblies in a single canister. From this previous study, the limit on the inner diameter of the transport cask is about 68 inches. The diameter of a handling frame with overpack capable of holding three Option 5 canisters is about 68 inches without allowance for any internal structure, thermal conductors, or poison materials. Therefore, based on the Transnuclear TAD Canister System experience, the three-canister configuration should result in a transportable system.

8.1.7 STAD Option 7

The STAD Option 7 will have a capacity of 21 PWR UNF assemblies or 42 BWR UNF assemblies and will be suitable for disposal in a geological repository that is capable of handling a higher canister heat load. The Option 7 STAD incorporated lessons learned from the earlier TAD design conducted by AREVA.

Design parameters for the Option 7 STAD canister are provided in Table 8-3 below. The STAD PWR and BWR configurations are shown in Figures 8-8 and 8-9, respectively.

Table 8-3. STAD Option 7 Design Parameters

Parameter	Value
UNF Assembly Capacity	
• PWR	21 intact assembly
• BWR	44 intact assemblies
Canister OD (inches)	66.25
Canister ID (inches)	64.75
Canister wall thickness (inches)	0.75
Canister length (inches)	198
Cell size, PWR/BWR (inches x inches)	8.9 x 8.9/6.0 x 6.0
Canister Material	Stainless steel

---

[6] Transportation, Aging, and Disposal Canister System Performance Specification, Revision 1/ICN 1, DOE/RW-0585, US Department of Energy, Office of Civilian Waste Management, March, 2008.

[7] TN TAD Canister System Proof of Concept Design Report, Document No. 30552-0101 Rev. B, Transnuclear, Inc., Columbia, MD, March 21, 2007.

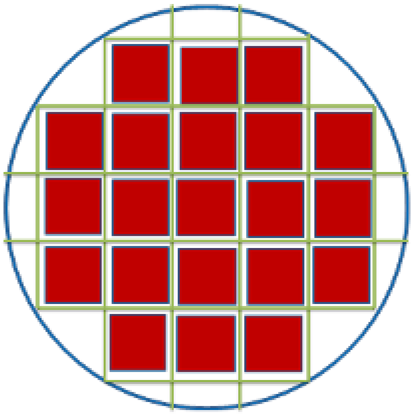


Figure 8-8. STAD Option 7 Loaded Configuration – PWR

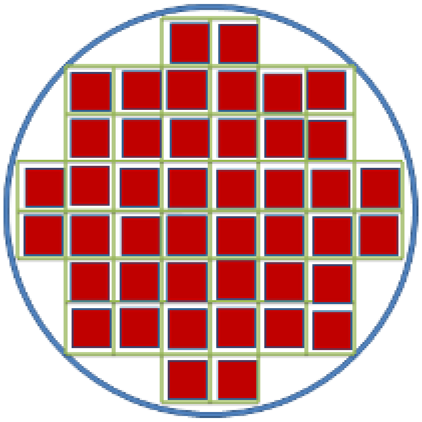


Figure 8-9. STAD Option 7 Loaded Configuration – BWR

As with STAD Option 3a, stainless steel was selected for the canister material based on its compatibility with typical reactor site SFP chemistry, corrosion resistance, and satisfactory experience at reactor sites in use for UNF DSCs. We recognize that the material requirements for the canister may change depending on repository requirements. This may be accommodated by providing a canister overpack of the required material and thickness rather than using a more exotic material for the canister itself.

An interior grid structure will be provided. The grid may use high conductivity materials and neutron poisons for certain fuels depending upon cooling time, enrichment, and burnup.

This STAD Option's geometry and weight will allow it to be handled and stored using equipment that is similar to that in use for current Part 72 DCSSs.

8.1.8 STAD Option 7 Transportation Considerations

One transportation cask per canister (21 PWR or 44 BWR UFA) would be used for transport. This size cask would meet the size and weight limitations for rail, barge, and heavy haul truck shipments. Design of the canister basket including its structure, handling features, and any need for poison and thermal conductors can be based on the work done for current Part 72 DSCs. If required, the canisters would be stored at utility sites until sufficiently cooled to meet transport thermal and dose limits.

Based on the TN study at footnote reference five above, a 21/44 STAD canister system can be designed and licensed to meet the requirements of 10 CFR Part 71 and 72.

8.2 STAD Operations

This section describes the proposed operations at the reactor sites and at the CSF associated with the use of STAD canisters based on industrial experience from the AREVA Team as of spring 2013. We describe, in more detail, the steps associated with the canister-loading process and are consistent with the loading strategy discussed in Section 7.0.

8.2.1 Reactor Site STAD Operations

For loading the STADs at the reactor site, there are two possibilities: load fuel directly from the SFP into the STADs or build a dedicated dry loading facility to load UNF into the STADs. Until such time as a new geological repository is selected and STADs are licensed, fabricated, delivered, and ready for use in 2026, there is no option for UNF at reactor sites other than to continue to be packaged in licensed, 10 CFR Part 72[8] DCSSs similar to those currently in use at the majority of U.S. commercial power reactor sites. Therefore, for this initial time period, there are no operations projected for reactor sites that are specifically related to operations for the recommended STAD options.

Once the CSF starts operations in 2025, the packaged UNF will be shipped at a rate of 3,000 tUNF/year from the reactor site to the CSF for temporary storage and eventual transfer to STADs.

The final licensing of the STAD is linked to the selection of the geological repository in 2026. Therefore, a significant quantity of UNF would be available at the CSF for loading into STADs ready for shipment to the repository. Loading of STADs at the reactor site will not be a rate-limiting factor unless DOE decides not to build and operate a CSF. For STAD operations at the reactor site, it must be anticipated that the majority of the operational reactors would show a great deal of resistance to loading a smaller STAD from the SFP during normal site operations due to the extra handling and exposure of the workforce. This is discussed in more details in section 7.6. A better option may be to consider waiting until the reactor closes down, and then, while the pool is still available, loading the UNF into STADs with the option to move any larger canisters still at the reactor site back into the pool, and then load into the STADs. Talking with our utility advisors during the first five to seven years following the reactor shut down, there

---

[8] Title 10 Code of Federal Regulations Part 72, Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste.

will be a push by the utilities to empty the UNF from the reactor and the pool and move this to dry storage to reduce costs associated with safeguarding the fuel in the pools.

There is also an option to develop a dry transfer system and load directly from the site UNF ISFSI into STADs bypassing the pool and the CSF completely. It would not be economical to build a dry unloading facility at each of the operational reactor sites, but some thought should be given to moving and consolidating fuel at one reactor site in a particular state or consolidating the fuel within a given region at a reactor site. This would then essentially move the CSF from a central location and place the operations at a number of regional reactor sites.

Analysis of Loading at the Reactor Site

Dry Transfer Systems at Reactor Sites

- One of the options considered was the deployment of a dry transfer system at the reactor site to transfer fuel from large canisters into smaller STADs. Deploying a dry transfer system at all of the reactor sites would be financially unrealistic.

- Cost of designing, building, and operating more than 100 systems.

- Licensing amendment costs for more than 100 reactors.

- Duplicating training, services, and waste generation from more than 100 systems.

- The option does exist and may be beneficial to consider developing a dry transfer system for areas of the country where fuel from reactor sites can be consolidated at one reactor site or where fuel from reactors in neighboring states could be moved to the facility and repackaged before moving directly to the repository, southeast or northeast U.S., as shown in Figure 8-10. Moving fuel across state lines would be politically challenging until such time as a clear disposal path was available to move the packaged fuel to the geological repository.

Figure 8-10. Reactor Sites in the U.S.

Dry Transfer Facility Conceptual Description

The purpose of the dry transfer facility is to provide for the movement of UNF from Part 72-licensed DSCs to STADs at the reactor site. This facility description is based in part on operational experience from AREVA planned or operating plants.

The conceptual dry transfer facility provides the structures, equipment, and services necessary to transfer UNF assemblies from Part 72-DSCs stored at the reactor site into STAD canisters. The STAD canister would then be prepared for shipment to the final geological repository.

The facility will include:

1. A cell for unloading the UNF from a DSC and loading it into a STAD; and
2. An area for preparing the STAD for storage or transport.

Similar to the dry unloading facility at LaHague, the unloading/loading cell, Figure 8-11 will feature a cask connecting system, UNF assembly inspection and repair pits, a UNF assembly handling crane, and an area for post unloading operations.

The DSC will be received at the facility and positioned on a “go-between” rotating plate. The necessary inspection, radiation monitoring and contamination monitoring will be performed in the receiving area. The DSC will then be moved to a preparation area where the outer lid will be removed and the inner (shield) lid weld cut to allow for removal of the lid. Installation of the devices for the connection operations with the unloading cell will also be performed at this time.

A bridge crane rated for the combined weight of the loaded DSC will be used to raise the DSC onto a self-propelled dolly for transport to the unloading/loading cell.

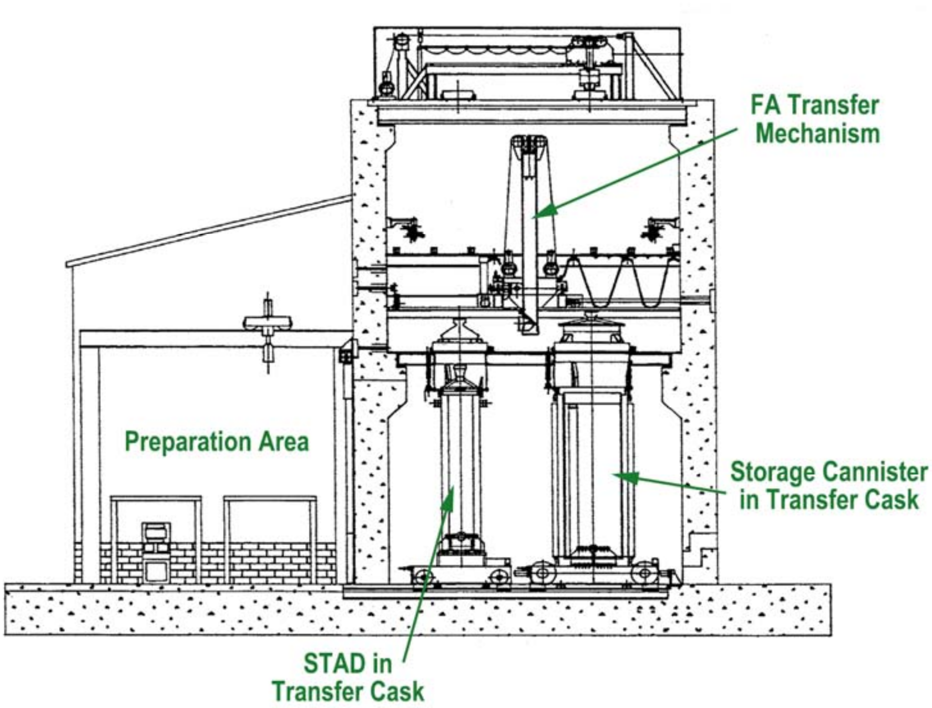


Figure 8-11. Permanent Repackaging Facility Located at a Reactor Site

The DSC are then moved into the unloading bay located below the below the unloading cell. The connection between the transfer cask and the unloading cell is made by a connecting device, which guarantees the necessary containment while limiting the surface contamination.

Once the DSC is in the connecting position, the DSC cover/shield plug is removed by a gripper and stored inside the cell. After the DSC is opened, the UNF assemblies are removed from the DSC and inserted one by one into a STAD canister already located in the cell using a remotely controlled handling crane. The integrity of each assembly can be checked at this time before transfer to a STAD. Pits are provided within the cell for UNF assembly inspection and repair if required.

The STAD will also be placed within a frame/transport cask while in the cell. The STAD may be placed in either a transfer cask for storage or a transportation cask for direct transport to the repository.

When the DSC unloading/STAD loading operations have been completed, the DSC will be moved to a decontamination facility at the CSF and the STAD will be moved to an area within the facility for inerting and sealing prior to transfer to storage or transport.

The TO facility features several items of advanced equipment design that should be considered for a CSF dry transfer facility. These include:

- A connecting device that allows opening of the DSC without any contamination of the external surface of the DSC or transfer cask.

- A remotely operated, seismically designed, fully stainless-steel-lined UNF handling crane.
- A monitoring robot to verify the absence of contamination from the transfer and/or shipping casks.
- A self-positioning UNF assembly-unloading robot.
- A computerized spent fuel transfer system.

Mobile Hot Cell

Recently AREVA has developed three “mobile” hot cells (Figure 8-12) that have been designed, manufactured, and deployed to manage and repackage high-level waste (HLW) at facilities in Europe. These systems, if properly designed, could be the basis of a semi-permanent system designed for repackaging UNF from large canisters into STADs.

Figure 8-12. Example of Mobile Hot Cell Used to Repackage HLW in Europe

AREVA would not propose to deploy these systems at every site, but the development of such a system could be beneficial in handling problem fuels or casks that may be encountered as we move 180,000 tUNF from storage at reactor sites to the geological repository.

8.2.1.1 STAD Option 3a Reactor Site Operations

The preparation and storage of an Option 3a STAD canister will generally proceed in the same manner as current Part 72-licensed DSCs with one exception. Whereas Part 72 systems do not combine individual canisters into packages, Option 3a will package 12 individual canisters into a handling frame and canister overpack. The handling frame and canister overpack operations are described in Section 8.1.

The major impacts of loading STAD Option 3a canisters at reactor sites compared with loading typical Part 72 DSCs are: (1) the increase in quantity of canister loadings resulting from the reduction in capacity of the STAD compared with a Part 72 DSC, and (2) the operations associated with placing the STAD canisters into the handling frame/overpack.

STAD Option 5 Reactor Site Operations

Option 5 STAD canisters will be loaded, prepared, and stored using the same general processes that are used for current Part 72-licensed DSCs. The major impact to the reactor site is the increase in the quantity of canister loadings resulting from the reduction in capacity of the STAD Option 5 canister compared with current Part-72 DSCs. It should be noted that for some utilities there may be no issue with this operation in the existing SFP, but others should be expected to push back against this smaller canister design.

8.2.1.2 STAD Option 7 Reactor Site Operations

Option 7 STAD canisters will be loaded, prepared, and stored using the same general processes that are used for current Part 72-licensed DSCs. The major impact to the reactor site is the increase in the quantity of canister loadings resulting from the reduction in capacity of the STAD Option 7 canister compared with current Part 72 DSC. It should be noted that for some utilities there may be no issue with this operation in the existing SFP, but others should be expected to push back against this smaller canister design.

8.2.2 Consolidated Storage Facility Site Operations

8.2.2.1 Receipt of UNF from Reactor Sites

This section provides a high-level outline of the operations at the CSF associated with receipt of UNF from reactor sites. These operations are applicable to both UNF that is packaged in Part 72 DCSSs and UNF packaged in STADs. This information is obtained in part from the AREVA Federal Services Report RPT-3008097-000[9].

---

[9] AREVA Federal Services Report RPT -3008097-000, titled **“**Task Order 11 – Development of Consolidated Fuel Storage Facility Concepts.”

- Shipping Cask Arrives at CSF – Outside the Entry Gate, the shipping cask and its transporter (rail car) are uncoupled from the main-line locomotive, picked up by a facility pony engine, and brought into the CSF similar to Figure 8-13. Security and Radiation Protection (RP) review shipping papers and perform an initial security and RP inspection of the vehicle and contents. The shipping cask is then moved into the CSF Protected Area (PA).

Figure 8-13. Rail Car of UNF Arriving at the Unloading Facility in France

- DSC/STAD Inspection – The rail car is moved to the Transportation Cask Queuing Area. The DSC/STAD is inspected for excess radiation and, to the extent possible, shipping damage. The rail car is then moved to the Cask Handling Facility (CHF).

- DSCs/STADs found to be in an off-normal condition are moved from the CHF to the Off-Normal Handling Area while on the rail car and within its shipping cask. DSCs/STADs suspected to contain UNF potentially damaged during shipping are also moved to the Off-Normal Handling Area, also while on the rail car and within its shipping cask.

- The off-normal conditions are assessed and the DSC/STAD is either moved to the Pad Storage Area for storage or to the CHF Wet Pool for mitigation. The process for transferring those DSCs/STADs with off-normal conditions to the Pad Storage Area follows the sequence below for normal DSC/STADs starting with “Shipping Cask Removal from Rail Car.” The process for movement of off-normal DSCs/STADs to the Wet Pool for mitigation is discussed in a separate paragraph below.

- Shipping Cask Removal from Rail Car – The onsite pony engine moves the rail car to the CHF. The rail car is positioned under the overhead Cask Handling Crane (CHC).

- For DSCs/STADs utilizing vertically oriented storage modules, the CHC is used to lift the shipping cask from the rail car, stack the cask on top of a Vertical Storage Module (VSM), and transfer the DSC/STAD from the shipping cask to the VSM. Note that some vertical systems may require the DSC to be moved from the shipping cask to a transfer cask. The DSC is then moved from the transfer cask to the VSM.

- For DSCs/STADs utilizing horizontally oriented storage modules, the CHC is used to lift the shipping cask from the rail car directly onto the onsite transfer trailer.

- Loaded VSM Movement to Pad Storage Area, Vertical DCSS – The loaded VSM is moved from beneath the CHC using the Low Profile Rail Sled. The onsite Vertical DCSS transporter straddles the loaded VSM and lifts it off the Low Profile Rail Sled. The transporter then moves to the Pad Storage Area.

- Loaded VSM Movement to Designated Storage Pad Location, Vertical DCSS – The onsite transporter with loaded VSM is driven directly onto the storage pad to the designated storage location. The VSM is lowered into position on the pad, and the transporter is disconnected and driven off.

- DSC/STAD Transfer to Storage Module, Horizontal DCSS – The onsite transfer trailer is backed up to the Horizontal Storage Module (HSM) and the shipping cask is aligned with the HSM opening. The shipping cask is opened and a hydraulic ram is used to insert the DSC/STAD into the HSM. The shipping cask is moved away from the HSM and the HSM door installed in the opening.

- Shipping Cask and Rail Car Refurbishment – Once the shipping cask is available, it is placed on its delivery rail car using the CHC. The rail car and shipping cask are then moved to the Cask Turnaround Facility (Figure 8-14) for refurbishment and repair if required. After needed refurbishment and repair, the cask/rail car is released and leaves the site.

Figure 8-14. Cask Turn Around Facility in France

The following steps describe handling DSCs/STADs with off-normal conditions:

- DSC/STAD Movement to Off-Normal Handling Area – DSCs are moved from the Transportation Cask Queuing Area to the CHF. The shipping cask is lifted off the rail car by the CHC and placed onto an onsite transfer trailer. The trailer is driven to the Off-Normal Handling Area and placed onto temporary cask storage supports (cradles) using a mobile crane.

- Inspection and Evaluation – In the Off-Normal Handling Area additional inspections and evaluations are performed to determine if the package can be directly stored or if mitigation is required.

- Movement to Pad Storage Area – If the inspections and evaluations performed for the off-normal package conclude that mitigation is not required, the DSC/STAD is returned to the CHF and then moved to the Pad Storage Area as described above.

- Movement to Wet Pool – The shipping cask with off-normal DSC/STAD/UNF is moved to the Wet Pool Facility, washed down, upended, and lifted with the Wet Pool CHC and then placed in the Cask Preparation Area. The shipping cask lid is opened to allow access to the DSC/STAD top cover. The top cover plates are then removed, and the DSC/STAD and shipping cask are placed in the Wet Pool.

- Prior to placing the DSC/STAD into the Wet Pool, the Wet Pool chemistry will be adjusted as required for compatibility with the UNF.

- Prior to opening, the DSC/STAD gas content is sampled for the presence of fission gases. Filtration systems can then be started and used to prevent a release. This will also provide some indication of the condition of the fuel clad.

- In some cases, the shipping cask may not be designed for immersion into the Wet Pool. If this is the case, the DSC/STAD will be moved to a transfer cask prior to placement in the pool. If the shipping cask is immersed, extensive leach-time may be required for decontamination. A bagging process may be used to help mitigate leaching effects.

- All UNF is then removed from the DSC/STAD and inspected and repaired if required. The UNF is placed into a new DSC or STAD, the DSC/STAD prepared for storage, and moved to a storage module. Depending on STAD availability, UNF that was packaged in a DSC could be packaged into a STAD rather than a new DSC.

8.2.2.2 Temporary Storage after Receipt of UNF from Reactor Sites Packaged in Part 72 DCSS

This phase of operations is only applicable to UNF received in Part 72 DCSSs. The phase starts with the receipt of the first shipment of UNF packaged in a Part 72 DCSS and continues until all Part 72 DCSS-packaged UNF is received. During this phase, DSCs are placed into storage modules that are licensed for use with the particular DSC and included in the CSF license.

Operations during temporary storage include monitoring and aging management. Monitoring ensures that DCSS/CSF technical specification thermal conditions during storage are met. This can be performed in several ways:

- Perform a periodic visual surveillance of the storage module air inlets and outlets to verify that no debris is obstructing the vents.
- Perform a temperature measurement in accordance with DCSS technical specification requirements.
- Or perform a combination of both of the above.

Storage module temperature measurements are accomplished by placing thermocouples/Resistance Temperature Detectors (RTDs) as required by the particular storage module design and in accordance with DCSS licensing documents as implemented by the CSF site license. The thermocouple/RTD signals will be processed and delivered to the CSF Monitoring Station.

An aging management and inspection/monitoring program are required. The program may include inspection/monitoring of the aging and conditions of the UNF, DSCs, and storage modules.

8.2.2.3 Movement of UNF Packaged in Part 72 DCSS from Temporary Storage to Repackaging Facility

There are two options for the unloading of the 10 CFR Part 72-licenses DSCs at the CSF: a wet operation in a dedicated pool and a specially designed dry facility. AREVA has operated both types of facilities at the La Hague reprocessing plant in France and has adopted the dry transfer system. The main comparisons between the wet and dry systems are contrasted in Table 8-4.

Table 8-4. Contrast of AREVA Wet and Dry Unloading Experience

	Wet System	Dry System
Maximum Casks Unloaded per Year	240	200
Number of Operators per Shift	10	8
Average Personnel Dose mSv/year	1.25	0.45
Fuel Assembly Unloading Dose Rate mSv/year	0.8	0
Volume of Liquid Effluents per Cask m^3	30	10
Activity of Liquid Effluents gBq/m^3	1.85	1.85
LLW Solid Waste per Cask m^3	1.2	0.6

It should be noted that AREVA still maintains the ability to off load fuel wet for off-spec conditions including failed fuel or fuel that requires special handling. For the concept CSF it would be proposed to use both dry and wet unloading.

These operations include removal of DSCs from their storage module and movement of the DSCs from the CSF Pad Storage Area to the CSF Wet Pool or the dedicated dry repackaging facility.

Vertical DCSS

- Movement from Pad Storage Area – The onsite transporter is driven directly onto the storage pad to the designated storage module. The transporter is connected to the VSM and then driven to the Wet Pool CHC. At the CHC, the VSM is lowered onto the Low Profile Rail Sled. The VSM lid is removed and the transfer adapter is placed on top of the VSM. Seismic supports may be installed at this point.

- Transfer of DSC to Transfer Cask – The CHC will lift the Transfer Cask and move over the VSM. The Transfer Cask will be set on the VSM and its doors opened using the transfer adapter. Rigging will be attached to the DSC, which will be raised by the CHC. Once the DSC is in the Transfer Cask, the cask doors are closed, the DSC rested on the doors, the rigging removed, and the Transfer Cask moved to the Wet Pool Cask Preparation Area or the dry repackaging facility.

Horizontal DCSS

- Transfer of DSC to Transfer Cask – This operation takes place at the designated HSM. The onsite transfer trailer with empty, open transfer cask is backed up to the HSM and aligned with the HSM opening. The HSM shield door is then removed. The transfer trailer's mounted hydraulic ram is attached to the DSC and used to move the DSC from the HSM into the Transfer Cask. The Transfer Cask is then closed.

- Movement to Wet Pool – The loaded transfer trailer is moved to the Wet Pool CHC. The transfer cask is upended and removed from the transfer trailer by the CHC, which then moves it to the Wet Pool Cask Preparation Area or the dry repackaging facility.

8.2.2.4 CSF Wet Unloading

In the Wet Pool, the DSC is opened; the UNF is removed from the DSC, and then placed into a STAD canister. The STAD canister will then be prepared for storage and transferred from the Wet Pool to a storage module.

The STAD canister will remain within its storage module at the CSF Pad Storage Area until a final repository is available. At that time, depending on repository requirements and available facilities, the STAD may be shipped directly to the repository with no additional operations performed at the CSF, other than preparation for transport. If required, operations associated with repository acceptance requirements, such as placement of the STAD into an overpack, could be performed at the CSF prior to shipment.

At some point after the STAD is made available to reactor sites, the UNF received at the CSF will be packaged in the STAD. This UNF is transferred within the STAD from its transport cask into a storage module. The UNF will remain within the STAD/storage module until it is prepared for transport to the final geological repository.

Each of the above operations is discussed in more detail in the following sections.

8.2.2.5 STAD Packaging of UNF in Part 72 DCSS (Wet Pool Operations)

This phase starts when the operations for movement from temporary storage, described in Section 8.2.2.3, are completed. These operations would also be performed for UNF packaged in a Part 72 DCSS that is received at the CSF and moved directly to the Wet Pool Cask Preparation Area in preparation for transfer of the UNF to a STAD canister. At that point, the DSC will be prepared to allow removal of its UNF and the UNF will be packaged into a STAD. The loaded STAD is then prepared for interim storage at the CSF.

- Cask Preparation Area – The transfer cask lid is opened to allow access to the DSC top cover. The DSC top cover plates are then removed as described below.

- Note: The steps below are high level and generic in nature. The actual process used to remove covers, access the UNF, and remove it from a DSC are performed in accordance with the Licensing Basis documents for the facility and DSC. The process is described in detail in the AREVA White Paper in Appendix E of this report.

- Cut or drill a hole through the DSC top cover plate to expose the drain port on the inner top cover. Remove the drain port cover plate. As an option, the top cover may be removed first to avoid cutting holes.

- Repeat for the vent port. Obtain a sample of the DSC atmosphere. Confirm acceptable hydrogen concentration and check for presence of fission gas indicative of degraded fuel cladding.

- If degraded fuel is suspected, additional measures to minimize exposures to workers and radiological releases to the environment may be required.

- If required, connect the UNF cool down (helium flush) system and cool the UNF as required.

- Fill the DSC with water from the Wet Pool or equivalent source through the drain port with the vent port open.

- Using a suitable method, such as mechanical cutting, remove the weld of the outer top cover plate to the DSC shell and then remove the outer top cover plate.

- Remove the weld of the inner top cover/shield plug to the shell. Do not remove the inner top cover/shield plug at this time. Note that for some designs, provisions for lifting the inner cover (e.g. lifting attachments) may need to be implemented prior to placement in the pool or the inner cover may need to be removed.

- Move the transfer cask and DSC to the Wet Pool.

- Prior to movement into the pool, adjust pool chemistry as required for the specific UNF being transferred.

- Lower the transfer cask into the pool.

- Lift the inner top cover/shield plug from the DSC.

- Remove the UNF from the DSC and move it to a temporary storage rack or directly into a STAD. Once empty, the DSC is removed from the Wet Pool, decontaminated, and prepared for disposal or recycling.

- Load the STAD with UNF, move the STAD to the Cask Preparation Area, and prepare the STAD for interim storage.

- If multiple STADs are to be placed into a cask overpack, each STAD will be loaded with the designated consolidated UNF and then placed into the cask overpack, which is located in the Wet Pool. The loaded overpack will then be moved from the Wet Pool to the Cask Preparation Area. The multiple STADs and the overpack are then be prepared for interim storage.

8.2.2.6 Movement of STAD to Storage

The movement of the STAD (Option 7) or STAD with cask overpack (Option 5 and 3a) from the Wet Pool to the Pad Storage Area is the reverse of the process used to move the DSCs from the Pad Storage Area to the Wet Pool.

8.2.2.7 STAD Packaging of UNF in Part 72 DCSS (Dry Cell Operations)

Section 8.2.2.4 describes the transfer of UNF from Part 72 DCSSs to STADs using wet pool operations. The transfer could also be accomplished using a dry transfer facility as described in this section and shown schematically in Figure 8-15. The facility description is based in part on the current T(0) facility at AREVA's La Hague UNF recycling facility[10] Assuming an annual throughput of 3,500 tUNF (approximately 12,000 FAs per year) with a facility operating for 240 days a year on a three-shift system, it is estimated that four to six lines will be required.

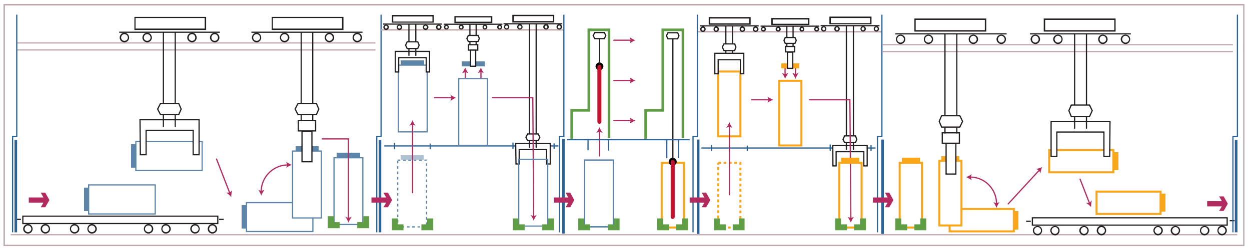


Figure 8-15. Schematic of Dry Transfer Facility

Dry Transfer Facility and Operations Description

The Dry Transfer Facility provides the structures, equipment, and services to receive, open, unload, and transfer UNF assemblies from Part 72 DCSSs stored or received at the CSF into STAD canisters. The STAD canister may then be placed into storage at the CSF or prepared for shipment to the final geological repository.

The facility will include:

- Receiving and shipping building
- DSC preparation area
- Cell for DSC opening
- Cell for DSC unloading and STAD loading
- STAD preparation area

---

[10] Saverot, Hacard, and Tucoulat, From Shipping Cask to Interim Storage: Spent Fuel Transfer Technologies at La Hague, WM Symposia 1993, Volume 1.

Similar to the T(0) dry unloading facility at La Hague, the unloading/loading cell will feature a cask connecting system, UNF assembly cooling pits, a UNF assembly handling crane, and an area for post unloading operations. The method for opening the DSC is described in the white paper in Appendix E of this report.

The DSC within a transfer cask will enter the receiving cell on a trolley that is positioned on a "go-between" rotating plate. This intermediate storage position increases the availability of the receiving area since a fully loaded DSC can be stored in this area while an unloaded DSC is in the process of being moved from the facility. The necessary inspection, radiation monitoring, and contamination monitoring will be performed in the receiving area.

A bridge crane rated for the combined weight of the loaded DSC and transfer cask will be used to raise the DSC onto a self-propelled dolly, as shown in Figure 8-16, for the following operations:

- Monitoring of the internal atmosphere of the DSC.
- Detection of damaged FAs. The T(0) facility uses a Kr 85 counting method in the cask internal cavity.
- Removal of the DSC covers.
- Installation of devices for connection operations with the unloading cell.

Figure 8-16. Dry Transport Canister Attached to Dry Unloading Cell

The DSC and transfer cask are then transferred into the unloading bay located below the unloading cell. A connecting device, which guarantees the necessary containment while limiting the surface contamination, makes the connection between the internal cavity of the DSC and the unloading cell. The connecting device and the DSC itself provide containment of the cell and of the DSC cavity.

Once the DSC is in the connecting position, a mechanical device is lowered from the cell and connected to the DSC. A gripper removes the DSC cover/shield plug and stores it inside the cell as shown in Figure 8-17. After the DSC is opened, the UNF assemblies are removed from the DSC and inserted into a STAD canister one by one with a remotely controlled handling crane (Figure 8-18). The integrity of each assembly can be checked at this time before transfer to a STAD already located in the cell. The STAD will be placed within a transfer cask for storage or a transportation cask for direct transport to the repository.

Figure 8-17. View Inside T(0) Dry Unloading Cell with Final Canister Plug Removed

When the DSC unloading/STAD loading operations have been completed, the DSC and transfer cask will be moved to a decontamination area and the STAD will be moved to an area within the facility for inerting and sealing prior to transfer to storage or transport.

The T(0) facility features several items of advanced equipment design that should be considered for a CSF dry transfer facility. These include:

- A connecting device that allows opening of the DSC without any contamination of the external surface of the DSC or transfer cask.

- A remotely operated, seismically designed, stainless-steel-lined UNF handling crane.

- A monitoring robot to verify the absence of contamination from the transfer and/or shipping casks.
- A self-positioning UNF assembly unloading robot.
- A computerized spent fuel transfer system.

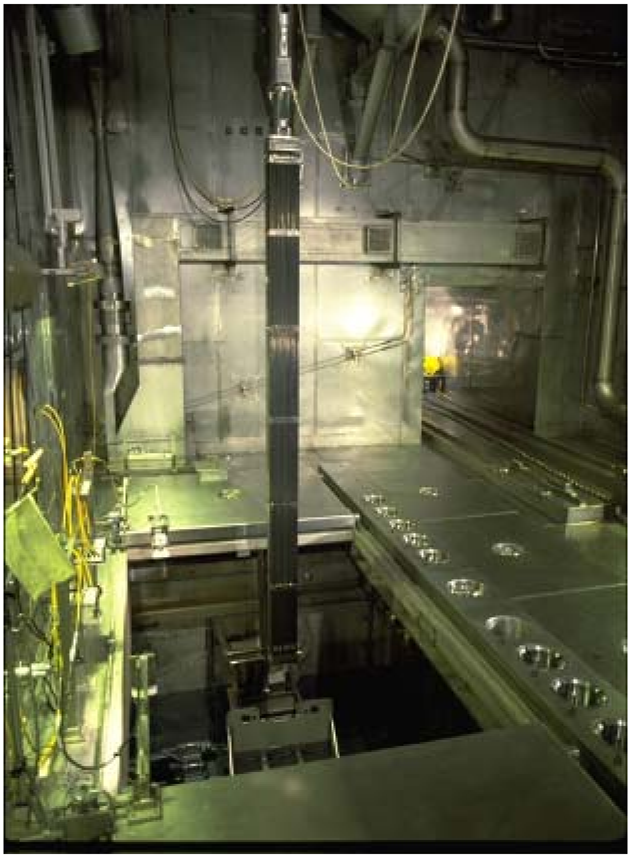


Figure 8-18. Repackaging the UNF from the Transport Canister into a New Configuration at the T(0) Facility

8.3 Decontamination and Decommissioning

This section describes the D&D of the STAD-associated equipment, fuel assembly skeletons, and other components that are typically included with UNF assemblies in storage. These components include burnable poison rod assemblies, thimble plugs, BWR flow channels, channel clips, etc.

8.3.1 STAD and UNF

STADs and their UNF contents will be emplaced in the repository. Therefore, no D&D of the STAD canisters of UNF-associated components is required.

8.3.2 Handling Frames and Canister Overpacks

The handling frames and canister overpacks will be used to store the STAD canisters at reactor sites and the CSF and transport them to the CSF and to the repository. Once the STADs are removed from the handling frames/overpacks, the frames and overpacks can be shipped back to the CSF for reuse. After final use, the frames and overpacks can be decontaminated as necessary and recycled, provided they do not contain activated materials. With proper design of the STAD system, contamination of the handling frames and overpacks should be minimal. If these components are activated, they will require disposal as low-level radioactive waste.

8.3.3 Storage and Transport Overpacks

Storage overpacks may contain activated and/or contaminated materials; however, it is likely that if the activated or contaminated materials are present, they will be minimal. The Team expects that the majority of the materials used for the storage overpacks can be recycled with minimal materials requiring disposal as low level radioactive waste.

Only a limited number of transport overpacks will be manufactured; therefore, they will be re-used a significant number of times. As with the storage overpacks, the transport overpacks may contain activated and/or contaminated materials; however, it is likely that if the activated or contaminated materials are present, they will be minimal. The Team expects that the majority of materials used for the transport overpacks can be recycled with minimal materials requiring disposal as low level radioactive waste.

Recommendation for Loading UNF

The preceding sections of this report describe the options, rational, and methods for loading STADs at the reactor site or a centralized CSF before shipment to a geological repository. Based on these trade studies and discussions with industry SMEs, the AREVA Team would propose the following rational for loading STADs.

Since the new geological repository will not be operational until 2048 and the site selection cannot be complete before 2026, then the STAD design cannot be licensed before 2026. There will be a significant quantity of fuel already packaged ready for shipment. We recommend shipping this fuel to a CSF and repackaging the fuel into STADs using a mixture of wet and dry unloading facilities. This will ensure a controlled steady shipment of STADs from one central point to the geological repository for final placement.

Assuming an operating life of 80 years, most of the reactors in the U.S. will shut down between 2050 and 2070. We therefore recommend that DOE conducts and develops automated options for loading fuel from the reactor pools into STADs. Once a reactor shuts down there will be a period of approximately five years where the reactor operator will move fuel from the core to the pool to dry storage. If STADs are available and a suitable loading system is developed, then deployment of the system and its operation at the reactor site may be seen as a benefit to the operator in loading high burnup fuel shortly after discharge into dry storage. Based on the projected shut down of the existing reactor fleet in the U.S. a significant quantity of fuel could be packaged and prepared, ready for shipment, allowing an increase in the amount of STADs shipped to the geological repository for placement.

A mobile system to repackage off-spec fuel in DSC maybe required, but is a low priority during the initial period of deployment of the STAD.

Sensitivity Analysis of Reactor Shut Down

For comparison purposes, a sensitivity analysis was conducted assuming that the existing reactor fleet did not apply for a license extension to go past 60 years of operation. This is shown in Figure 8-19 below and does not significantly affect the results highlighted in the study assuming that the reactors operated to 80 years. The movement of UNF to the CSF from the reactor sites should still be conducted in 2025 and the loading of the STADs at the shutdown reactor sites starting 2026 is still a desirable option. Depending upon the thermal limits of the repository, and hence the STAD loading, this option could potentially increase the number of STADs available for placement in the geological repository by utilizing both the CSF and the reactor sites to load STADs simultaneously.

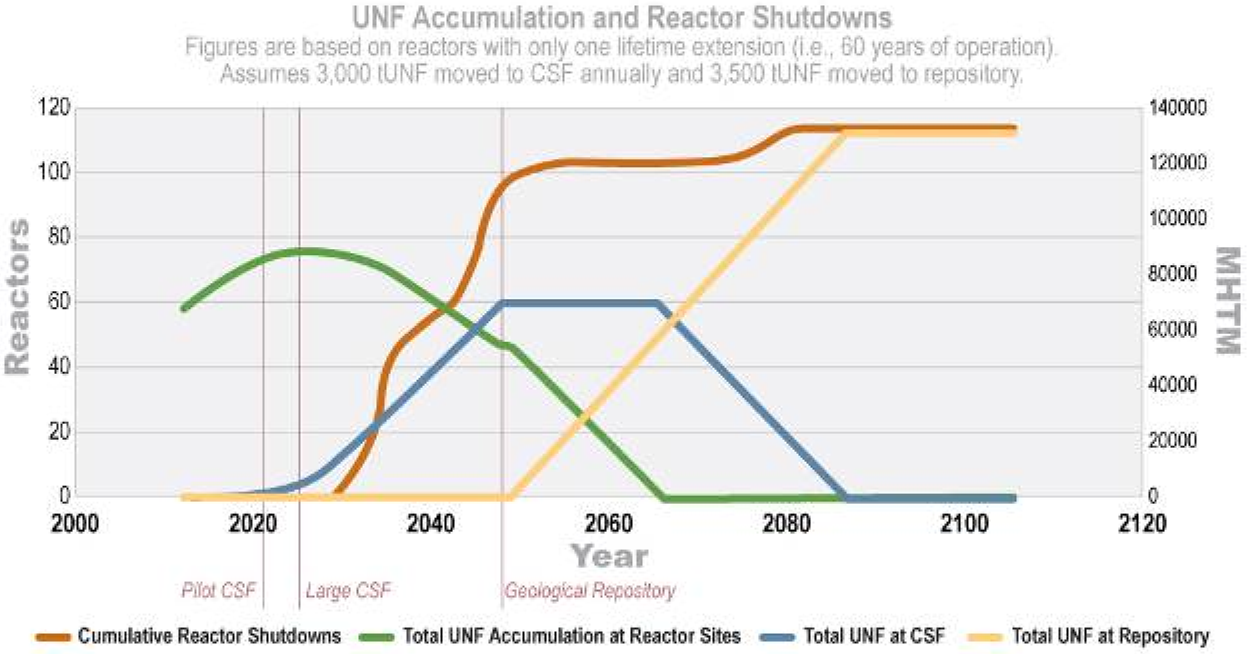


Figure 8-19. UNF Management Scenario Assuming Operational Reactors Operate for 60 Years

9.0 TRANSPORTATION

A key component of the system for final disposition of the nation’s UNF is the transportation system. The UNF will be placed in a STAD prior to its transport to the repository. This section of the report evaluates the transportation fleet and logistics required for delivery of UNF from the CSF to the repository at an annual average rate of 3,500-tUNF per year. All eight STAD options were considered for the transportation study. This section includes a description of the performance objectives and assumptions, a clear concept of transportations operations, and a detailed comparison of the STAD Options transportation requirements and costs.

9.1 Performance Objectives and Assumptions

The performance objective for the transportation fleet is to move UNF from the CSF to the repository starting when the repository is open in 2048.[11] The UNF is assumed to have been packaged into STADs during its storage period at the CSF and is ready for transport. The supply of loaded STADs will permit a constant delivery rate of 3,500 MTU per year of UNF from the CSF to the repository. Identification of the fleet development and operations cost is based on the following assumptions:

- For the purpose of the transport study a nominal size was chosen for the CSF of 50,000 to 70,000 tUNF.
- Transportation to the repository begins when the repository is open.
- Rate of transport is approximately 3,500 MTU per year.
- The repository can receive and return casks at the same rate at which the CSF ships them. The repository may need to have a higher capacity if it is also expected to receive STADs directly from reactors in this time frame.
- All transport will occur by commercial rail systems, except possibly for short branch lines owned by DOE connecting to the respective facilities.
- A regulatory body (NRC) will license the transportation casks in the same manner as currently employed (10 CFR 71) for transport of radioactive materials.
- Each STAD is closed and verified to be leak tight prior to shipment from the CSF. However, the cask is the containment boundary for purposes of transportation.

---

[11] AREVA Federal Services LLC, *Task Order 11 – Development of Consolidated Fuel Storage Facility Concepts Report*, RPT-3008097-000, February 12, 2013.

- Transportation of UNF starts at a security gate at the CSF boundary and ends at a security gate at the repository boundary. The AREVA Team assumed that both the CSF and repository are sized and configured to preclude shipping delays from either receipt or preparation of a train consist. A 14-day turnaround time is based on the following consecutive operations:

Table 9-1. Transportation Time Frame

Transport Activity	Days
Arrive at CSF and unhook empty cars from the consist	1
Make up loaded consist	1
Transit time to repository	5
Arrive at repository and unhook loaded cars from consist	1
Make up unloaded consist	1
Transit time to CSF	5

  - The number of possible repository deliveries per year, 17, is based on a year of 240 working days and a 14-day turnaround cycle.
  - Each consist will contain three cask cars. Each cask car includes one transport cask, one railcar, and one skid between the railcar and the cask.
  - Each consist will contain two buffer cars and one escort/security car.
  - The UNF is assumed to be comprised of 43 percent PWR and 57 percent BWR fuel types.
  - The blended (PWR/BWR) average MTU per fuel assembly is 0.29.
  - For STAD options that assume consolidated fuel, the capacity of the transportation system is increased by 10 percent over what it would otherwise be in order to accommodate the non-fuel components of the UNF left over from consolidation activities.
  - Non-UNF material, such as Greater-than-Class-C (GTCC) waste that is not a fuel assembly (FA) component, is not considered.

9.2 Concept of Operations

The basic components of the system used to transport the UNF from the CSF to the repository are the transportation casks, handling frames if required, rolling stock, and ancillary equipment. The use of heavy-haul tractor-trailers or barges and the associated intermodal transfers is not required for the transport from the CSF to the repository. Transportation operations are defined to be limited to the transport between the respective CSF and repository security gates. All operations which take place within the security gates at the CSF or the repository (such as preparation for transport, yarding the rolling stock, loading/unloading casks, etc.) are assumed to be within the scope of the respective facilities, and not in the scope of transportation operations. The transportation processing capacities of both facilities are assumed to be nominally matched to each other and capable of an annual average of 3,500 MTU.

9.2.1 Transportation Casks

The NRC will certify all casks used according to the requirements of 10 CFR 71. A single cask type suitable for transporting the UNF in STAD canisters will be designed, licensed, and fabricated for the transport campaign. We assume the cask will be designed with the largest practical size for unrestricted rail transport. Therefore, for the smaller STADs (i.e., those whose size permits the cask to carry more than one STAD), a handling frame will be utilized to interface between the STADs and the cask. Consequently, the same transportation cask will apply regardless of the STAD option eventually chosen. The UNF will be sealed in an optimally configured STAD of a single type for transport to the repository. Individual STADs are removed from storage at the CSF, placed in handling frames (for the small STAD options), and staged at the CSF until ready for transport. When an empty transportation cask arrives at the CSF, the STADs in the handling frame are transferred to the transportation cask. The transportation cask is then closed, leak tested, assembled with impact limiters, inspected, and loaded onto the railcar as a part of CSF site operations. At the repository, the casks will be accepted, opened, and unloaded as a part of repository operations. Decontamination and maintenance of the casks is not expected to be a significant effort and is not considered in this study.

The transport cask considered in this analysis assumes the same basic design as similar casks in current use, and has a cylindrical shape with flat ends. Each end will feature an energy-absorbing impact limiter. The structures of the cask provide all necessary shielding for transportation purposes. No reliance is placed on the STADs for either shielding or containment. The handling frames (for the smaller STADs) or the full-size STADs will provide criticality control. The cask will be lifted and mounted to the railcar skid using trunnions.

The handling of the cask, its configuration on the railcar, the railcar and skid designs, and the cycle or turnaround time to transport UNF to the repository will be independent of the STAD option chosen. Since the STADs will be contained in a handling frame (or not require a handling frame), there will be no differences among the options in loading or unloading the STADs from the cask. There would be some difference in cask gross weight, depending on the density of UNF in the cask (a function of STAD option), but any such difference is not expected to be material.

The transport system is estimated to be required when the repository is open. Given the rate of regulatory evolution over the prior 50 years, it is a safe assumption that the licensing of the STAD transportation cask will be subject to a number of new and currently unpredictable design requirements. However, since the same cask design can be used with any of the STAD options, there is no difference in licensing between the options.

9.2.2 Rolling Stock

Components of the rolling stock include standard locomotives and three dedicated and specially designed railcars: cask cars, buffer cars, and escort cars. A typical consist includes the engines, followed by a buffer car, three cask cars, a buffer car, and an escort car (in that order). Each cask railcar carries a skid and a single cask. Cask railcars are up to 100 feet long and designed to accept a cask and skid with a combined weight of up to 200 tons. The cask skid is positioned on the railcar, the cask is positioned on the skid, and the railcar is then positioned between the buffer cars in the middle of the train consist. Buffer cars act as a spacer between the cask railcars and the security escort car, as well as between the cask railcars and the locomotives.

The security escort car is used to transport security equipment and personnel. The buffer car does not interfere with the ability of security escort personnel to maintain visual contact with cask railcars.

The railcar, which transports the cask and skid, will be subject to the requirements of Association of American Railroads (AAR) Standard S-2043.[12] This specification is an industry standard and not a regulation; however its application is expected to be necessary. As currently written, it will be a significant challenge to design and certify a railcar in compliance with S-2043. However, the railcar development and procurement cost is a constant regardless of the STAD option selected with the only variable being the number of required railcars.

For cross-country shipments, commercial carriers provide locomotive service; however, the CSF may acquire locomotives through a purchase or lease of dedicated locomotives to ensure availability of power sources for the rail shipments. The CSF and repository rail yard will have switch engines or equivalent power sources to enable movement of railcars and assembly of train consists and supporting operations.

9.2.3 Ancillary Equipment

The casks are transported on removable skids that adapt the standard railcar structure to a transportation cask. Skids may also be designed to fit on facility transporters and be customized to accommodate the specific cask model used in the UNF transport campaign. If skids are not needed at the facilities, they could be designed to be an integral part of the railcars.

The transportation cask will require unique equipment for lifting, operating, and leak testing. Ancillary equipment encompasses all components used in cask handling operations to move the cask, operate the working mechanisms of the cask (such as lids, port covers, and removable trunnions), and complete the cask loading and unloading process. These components include lifting yokes, lifting slings, vacuum drying systems (for pool loading operations), helium leak test equipment, hoses and tubing, torque wrenches and other hand tools, and other equipment as required by the cask vendor to operate a specific cask system. These components are designed in conjunction with any new cask system and the design/procurement for the ancillary equipment

---

[12] Association of American Railroads (AAR) *Manual of Standards and Recommended Practices, Section C, Car Construction Fundamentals and Details, Standard S-2043, Performance Specification for Trains Used to Carry High Level Radioactive Material*, 2008.

is included with the CSF and repository costs. Thus, the only ancillary equipment considered for the transportation segment is the transport skids.

9.3 STAD Options Comparison

A comparative transport cost analysis for each STAD option was performed and is detailed in the following sections. A total of eight STAD canister design options were considered. The overall cost of transporting the first 50,000 MTU of UNF from the CSF to the repository was developed considering the capital cost of the transportation fleet and the operational costs for each option. Before considering how the cost of each option was calculated, the input cost elements have been addressed. All costs in this section are in 2013 dollars.

A standard train consist will include locomotives (quantity and type are not investigated in this report), followed by a buffer car, three cask cars with casks and skids, a second buffer car, and a trailing escort/security car. The quantity of three for the cask cars is somewhat arbitrary but is considered a practical number for this kind of transport. We assume the locomotives will be leased, and their cost is therefore variable. The cost of the locomotives, personnel, and use of track is assumed to be $0.25M for each round trip between the CSF and the repository. This is equal to the total variable cost per trip. State transit fees may be imposed in some cases but are not included in these estimates due to their unpredictable nature.

The hardware cost is estimated using data from DOE report DOE/RW-0591.[13] Table 3-7 of that report gives the estimated cost of a transportation cask for SNF as $4.5M. Table 3-8 of that report gives the cost of the corresponding cask car of $0.7M. The general rate of inflation between 2007 and 2013 is a factor of 1.12.[14] The current cask cost would therefore be:

$$1.12 \times 4.5 = \$5.04\text{M}$$

The current railcar cost would be:

$$1.12 \times 0.7 = \$0.78\text{M}$$

Since it is assumed that the quantity of casks and railcars is the same, the two values may be summed. With an amount of $0.2M estimated to cover the skid, the cost of the railcar, skid, and transportation cask unit will be $6.0M each in current dollars. Note that this estimate does not include the costs, which may result from meeting AAR S-2043 requirements as previously discussed.

---

[13] *Analysis of the Total System Lifecycle Cost of the Civilian Radioactive Waste Management Program, Fiscal Year 2007*, DOE/RW-0591.

[14] Rate obtained from http://data.bls.gov/cgi-bin/cpicalc.pl.

Table 3-8 of the DOE reference gives the cost of an escort car as $3.7M and that of a buffer car as $0.5M. Therefore, the cost of ancillary cars (two buffers and one escort) per consist, in current dollars, would be:

(2 × 0.5 + 3.7) × 1.12 = $5.26M

The costs of each consist, assuming three cask cars per consist, is therefore:

3 × $6.0M + $5.26M = $23.26M

The overall lifetime transport cost of each option is calculated by adding the hardware costs to the variable costs. The lifetime cost means the cost over the estimated first 25-year CSF-to-repository shipping campaign. STAD Option 3a will be used as an example to illustrate the calculations.

The capacity of the Option 3a STAD is either 1 PWR or 2 BWR UNF assemblies. A quantity of 12 Option 3a STADs can be placed in a single cask; therefore, the capacity of the transportation cask in this case would be 12 × 1 = 12 PWR or 12 × 2 = 24 BWR assemblies. Based on the assumed UNF inventory of 43 percent PWR and 57 percent BWR assemblies, the blended average capacity of the cask considering both types of fuel is:

Blended Avg. FAs per Cask: 0.43 × 12 + 0.57 × 24 = 18.84

Since the blended average inventory of heavy metal in each FA is 0.29 MTU (see Section 9.1), the average MTU per cask is:

Average MTU per Cask: 18.84 × 0.29 = 5.464 MTU per cask

To keep on schedule, the average shipment rate per year must be approximately 3,500 MTU. Therefore the number of cask loads that must be transported annually is:

Average Cask Loads Transported Annually: 3,500/5.464 = 640.6

If Option 3a was for consolidated UNF, the average cask loads transported annually would be increased by 10 percent to cover the non-fuel components of the UNF generated during consolidation activities. Since each consists has three cask cars, the number of round trips per year must be:

Number of Round Trips per Year: 640.6/3 = 213.5.0

Since each consist is assumed to be capable of 17 round trips per year (see Section 9.1), the total number of consists, with an additional consist added for margin, is:

Total Number of Consists in Inventory: 213.5/17 + 1 = 14

Since each consist is expected to cost $23.26M, the fixed hardware cost of STAD Option 3a (assuming that the initial inventory of hardware lasts the entire 25-year lifetime of the shipping campaign considered in this study) is:

Fixed Hardware Cost: 14 × 23.26 = $325.6M

The variable cost for all of the trips for 50,000 tUNF is:

Total Variable Cost: 214 × $0.25M × 14.3 Years = $765.1M

In this equation, the value of 214 represents the number of round trips a year, found as 122 above, and rounded upward (the actual number of trips is slightly larger than 122). Finally, the total lifetime cost is the sum of fixed hardware and variable costs, or:

Total Lifetime Cost of STAD Option 3a: 325.6 + 765.1 = $1,090.7M

The cost calculations for all of the STAD options are given in Table 9-2 and Table 9-3. As shown, the least expensive STAD option is Option 4, which is for consolidated UNF. The least expensive non-consolidated option is Option 7.

Table 9-2. Cask Transport Capacity of STAD Options

STAD Option	FAs per STAD		STADs per Cask	FAs per Cask		Blended Avg. FAs per Cask[1]	MTU per Cask[2]
	PWR	BWR		PWR	BWR		
2	2	4	12	24	48	37.68	10.93
3	1	1	12	12	12	12.00	3.48
3a	1	2	12	12	24	18.84	5.46
4	2	4	21	42	84	65.94	19.12
5	4	9	3	12	27	20.55	5.96
6	12	24	1	12	24	18.84	5.46
7	21	44	1	21	44	34.11	9.89
8	42	88	1	42	88	68.22	19.78

Notes:
1. Equal to 0.43 × (PWR FAs) + 0.57 × (BWR FAs)
2. Equal to (0.29 MTU per FA) × Blended Avg. FAs per Cask

Table 9-3. Transportation Costs of STAD Options

STAD Option	MTU per Cask[1]	Casks per Year[2]	Trips per Year[3]	Consist Inventory[4]	Fixed Hardware Cost, $M[5]	Variable Cost, $M[6]	Total Lifetime Cost,$M[7]
2	10.93	352.33	117.44	8	186.1	421.9	607.9
3	3.48	1005.75	335.25	21	488.5	1,201.2	1,689.7
3a	5.46	640.60	213.53	14	325.6	765.1	1,090.7
4	19.12	201.33	67.11	5	116.3	243.1	359.4
5	5.96	587.30	195.77	13	302.4	700.7	1,003.1
6	5.46	640.60	213.53	14	325.6	765.1	1,090.7
7	9.89	353.82	117.94	8	186.1	421.9	607.9
8	19.78	194.60	64.87	5	116.3	232.4	348.7

Notes:

3. Copied from Table 9-1 for continuity
4. Equal to 3,500 MTU per year/MTU per cask
5. Equal to Casks per Year/3 cars per consist
6. Equal to Trips per Year/17, rounded, plus one
7. Equal to Consist Inventory × $23.26M
8. Equal to Trips per Year × $0.25M per trip × 14.3 years to move 50,000 tUNF
9. Equal to the sum of Fixed Hardware Cost and Variable Cost

10.0 RESEARCH AND DEVELOPMENT RECOMMENDATIONS

In this section, R&D recommendations are provided to support or optimize the STAD options. These recommendations cover the activities needed to support loading and unloading (as applicable), transportation, storage, repository, and UNF consolidation as described in the various sections of this report. While the presented R&D activities are recommended, they are not necessarily necessary to design, license, and implement the identified STAD options unless otherwise designated in the text.

Activities required to license the identified STAD options are described in Section 11.0 and are not necessarily considered R&D activities; however, some of the R&D recommendations in this section could take advantage of potential activities associated with the licensing of the selected STAD options (e.g., testing of a scale model of the STAD). The potential benefits derived from some of these R&D recommendations should be considered in establishing planned licensing activities.

10.1 Loading R&D Activities

Loading strategies are discussed in Section 7.0 and cover the loading of the STAD option at: (a) SFPs at reactor sites; (b) the CSF for UNF, and (c) the final repository. If R&D were to provide significant improvements in the loading activities of the STAD options at the SFP, then the reactor sites may be more willing to load these STADs; hence, R&D activities will be identified in this section to address the issue of automation of (un)loading activities that could be utilized at SFPs and/or a CSF to support STAD loading at SFPs. In addition, R&D focusing on the retrievability of UNF and canister (e.g., STAD) is recommended if (un)loading activities do not occur within the next several decades. The final three R&D activities involve the optimization of vacuum drying canisters, the preparation for the (un)loading of outlier (less common) UNF assemblies into the selected STAD options, and the transfer of UNF currently in dry storage into the selected STAD options.

10.1.1 Retrievability of UNF and Canister

Prior to performing any unloading or loading activities involving UNF or canistered UNF, the UNF and canister (if applicable) must be verified to be retrievable. The NRC defines retrievability in 10 CFR 72.122(l) as "*Storage systems must be designed to allow ready retrieval of spent fuel or high-level radioactive waste for further processing or disposal.*" It further clarifies in 10 CFR 72.236(m) as "*To the extent practicable in the design of storage casks, consideration should be given to compatibility with removal of the stored spent fuel from a reactor site, transportation, and ultimate disposition by the Department of Energy.*" The NRC also noted in the Federal Register (51 FR 19108) in 1986, "*The spent fuel at an ISFSI must also be retrievable for transport to either the MRS or HLW repository whenever they become available.*" Additionally, the NRC's Division of Spent Fuel Storage and Transportation has provided Interim Staff Guidance (ISG) on fuel retrievability, which notes that:

> *"There are two aspects of ready retrieval: 1) the ability to transfer a sealed canister from the storage cask to either a) a transportation package without unloading the spent fuel or, b) a spent fuel pool or other facility for unloading and transfer, and 2) if it is not possible to demonstrate that the spent fuel condition is suitable for transportation, then*

> *there must be the ability to unload a storage cask and either repackage the fuel into a transportable configuration or to place the fuel in a different storage cask that is appropriate for future transportation”* [15]

Considering some of the UNF assembly and UNF canister issues (e.g., material properties associated with handling these items) identified by reports issued by the NRC[16], DOE[17], Nuclear Waste Technical Review Board (NWTRB)[18], and Electric Power Research Institute (EPRI)[19] and the advanced age of a significant portion of the UNF by the time these transfer activities may take place, R&D activities needed to ensure the retrievability of UNF and UNF canisters (if applicable) may have to be conducted to support the (un)loading of UNF into standardized canisters. Some parameters that need to be considered in the performance of this R&D include, but are not limited to:

- Fuel type
- Cladding type
- Hardware type
- The burnup of the UNF
- The duration UNF and canisters have been in dry storage
- The environment canister surfaces may have been exposed while in dry storage
- The impact of normal and abnormal transportation activities/events to UNF and canisters

---

[15] Nuclear Regulatory Commission, Division of Spent Fuel Storage and Transportation Interim Staff Guidance – 2, Revision 1, “Fuel Retrievability” (2010).

[16] Nuclear Regulatory Commission, “Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended Storage and Transportation of Spent Nuclear Fuel,” draft report for comment (May 2012).

[17] Hanson, Brady, H. Alsaed, C. Stockman, D. Enos, R. Meyer, and K. Sorenson (Department of Energy), “Used Fuel Disposition Campaign Gap Analysis to Support Extended Storage of Used Nuclear Fuel,” PNL-20509, FCRD-USED-2011-000136 Rev. 0 (2012).

[18] Nuclear Waste Technical Review Board, “Evaluation of the Technical Basis for Extended Dry Storage and Transportation of Used Nuclear Fuel” (2010).

[19] John Kessler (Electric Power Research Institute), “Extended Storage Collaboration Program (ESCP) Progress Report and Review of Gap Analyses,” Technical Report 1022914 (2011).

- Thermal impacts including potential thermal cycling between SFP storage, dry storage, and potential rewetting/requenching in a SFP or a pool at a CSF

- Stresses imposed by lifting operations (including those in a pool)

Clearly the number of potential parameters involved could require an extensive R&D effort; however, much of this could possibly be resolved for non-high burnup (<45 gigawatts/day (GWD)/MTU) UNF by examining some of the UNF assemblies and potentially canisters currently stored at: (1) Idaho National Laboratory (formerly at the Test Area North (TAN) facility) where dry storage of non-high burnup, commercial UNF has taken place for several decades, or (2) at the utilities. For high burnup UNF, a new R&D program potentially taking place at a facility dedicated to performing R&D activities needed to support interim and final disposition (e.g., disposal) activities (potentially a new facility co-located with the CSF) will likely be required to make this demonstration.

These R&D activities will be focused on verifying the retrievability of UNF and canisters to allow for:

(1) The unloading of UNF from canisters and/or casks in preparation for loading into the selected STAD options.

(2) The loading of UNF from SFPs into the selected STAD options.

(3) The unloading of canisters from storage and transportation casks in preparation for moving UNF into the selected STAD options.

(4) The unloading of the selected STAD options from transportation casks in preparation for moving the selected STAD options into interim storage, into the Engineered Barrier System (EBS) associated with disposal (if applicable), or into a recycling facility (if applicable).

Currently UNF and canisters are considered retrievable and hence, this R&D activity is considered longer-term and could be needed to support retrieval operations that occur several decades from now. However, if the UNF is considered to be potentially un-retrievable at an earlier time then this R&D activity could become a prompt issue because the approximate time the UNF could become un-retrievable would establish when the latest date the UNF would need to be loaded into a STAD and hence establish when a STAD option is required by. This could require a STAD option to be designed in advance of the selection of the final repository. Furthermore, if UNF becomes un-retrievable at an earlier time then the loading priority for the UNF into the selected STAD option could be impacted. Hence, both the timeline for the development of the selected STAD option and the hierarchy for the UNF loaded into the selected STAD option could be directly impacted if the UNF is established to be un-retrievable at a time earlier than the development of the STAD option associated with the selection of the final repository.

Furthermore, if certain parameters are demonstrated to adversely impact the retrievability of UNF (e.g., extended dry storage or transportation), then these could impact parameters associated with the loading of the selected STAD option. For example, if transportation of UNF can adversely impact the retrievability of the UNF, then the selected STAD option would likely have to be loaded at the reactor site prior to transportation to the CSF or repository. Similarly, if rewetting/quenching UNF after dry storage adversely impacts its retrievability, then a dry transfer system (e.g., hot cell) would likely have to be used to load the selected STAD option. These potential impacts to the retrievability of the UNF and their impact to the loading UNF activities associated with the selected STAD option suggest that this R&D activity should be of a more prompt nature.

The focus of this R&D activity on both the UNF and canister is considered consistent with existing regulatory positions and may evolve based on the NRC's recent "Request for Comment on Retrievability, Cladding Integrity, and Safe Handling of Spent Fuel at an Independent Spent Fuel Storage Installation and During Transportation" (Docket ID: NRC-2013-0004). It notes, "The NRC is assessing the current regulations and policy on retrievability to determine whether to maintain the current definition of retrievability or move towards canister-based retrievability." If the NRC moves to a canister-based retrievability requirement, then the focus of this R&D recommendation should change accordingly, as well as potentially the primary location of the STAD-loading activity (from the CSF to a reactor SFP).

10.1.2 Automation of Loading Activities for Selected STAD Options

Since there is a significant amount of UNF that could be loaded into a STAD option, and since many of the identified STAD options in this report are small compared to currently used commercial canisters, a significant amount of loading operations will be necessary. The cumulative dose to operators performing these loading operations of the selected STAD options could become a significant issue/burden. Therefore, an R&D activity focusing on automating, to the degree possible, the loading operation of the selected STAD options is recommended to reduce operator exposure to ALARA. In addition, this R&D activity can also examine the loading of the STAD options into a transportation cask, storage cask, and EBS (if applicable) for disposal, as well as the operations involving the handling and loading/unloading onto a conveyance of a cask containing the STAD options and the associated wastes produced from each of these activities.

This R&D activity would be best performed by a time-motion study of the various activities associated with the loading of the UNF into the selected STAD options and the subsequent handling and loading operations of the loaded STAD options. These time-motion studies would examine the cost-to-dose benefit of replacing human activities with automated systems involving the selected STAD options with the goal of making doses ALARA. These time-motion studies would have to consider the different types of UNF to be handled (e.g., PWR vs. BWR UNF) and the potential non-uniformity in UNF quality and material properties caused by differences in the design of the UNF and the water quality during cooling and storage. The studies should be supplemented with trade-off studies identifying differences in the quantity of potentially contaminated wastes produced from the proposed approaches.

In addition, if the loading of the UNF into the selected STAD options is to occur at the CSF, then there will also be an unloading activity at the CSF for which time-motion studies will need to be performed and optimized. Unfortunately, this time-motion study will be more difficult to perform as the transportation casks will not be standardized and the UNF could be transported in a canister or as bare UNF. Nevertheless, time-motion studies should be performed to ensure doses are ALARA and supplemental trade-off studies should be performed to identify differences in waste quantities between the proposed approaches.

Once time-motion studies have been performed, a demonstration of the (un)loading process is a key element of this R&D activity. Either a mock-up or an existing facility is required to demonstrate the (un)loading process with the automation intended to reduce operator exposure. The actual demonstration will depend on several factors including, but not limited to:

(1) Will the transfer be performed wet or dry (dry transfer would be completely automated)?

(2) The availability of the facility (e.g., SFPs at operating plants would likely not have sufficient available time to perform this demonstration unless the reactor were in an extended outage or were permanently shut down, but an SFP at a shutdown reactor or the General Electric Morris facility would likely be an ideal facility to perform this demonstration).

(3) The extent the equipment, which performs the automated actions, can be moved to and incorporated into the design and operation of the facility (applies mainly to activities at SFPs).

(4) The dose and waste impacts associated with maintaining and/or replacing the equipment performing the automated activities (i.e., doses associated with lifecycle activities of equipment designed to reduce operational dose activities must be considered as well as the cost of the waste produced from these activities).

Since the results from this R&D recommendation are likely to impact the design of new and/or existing facilities contemplated to perform STAD-loading activities, this R&D recommendation is considered to be a near-term activity that should be performed after selection of a STAD options.

10.1.3 Optimization of Vacuum-Drying Activities

One area where R&D activities can potentially improve extended storage and/or disposal performance and potentially reduce total operator exposure includes optimization of the vacuum-drying process prior to the sealing of a canister (including the selected STAD options). Vacuum drying is one of the more time consuming, labor intensive, and potentially imprecise activities associated with canister loading and often depends on the UNF being dried (e.g., UNF with low heat loads and UNF potentially damaged take significantly longer to dry, if even possible, than UNF with high heat loads).

By optimizing this process for the selected STAD options, the effectiveness of the activity can be improved overall, which potentially improves extended storage and disposal performance of the UNF. In addition, if the process and/or the design of the selected STAD options can be optimized in such a manner as to utilize automation, then the time to perform this activity and the exposure to operators could be reduced. Although existing vacuum-drying processes are adequate for the anticipated duration of interim storage of UNF, this R&D activity could benefit the long-term performance of the UNF and potentially the STAD; and since it has the potential to impact the design details of the selected STAD options, this R&D activity is recommended to occur as early as possible and likely prior to production of the selected STAD options.

10.1.4 Loading of Outlier UNF Assemblies

Due to the existence of uniquely sized UNF assemblies (e.g., South Texas Project's longer than typical fuel assemblies), the potential for additional unique UNF assemblies in the future (e.g., UNF from AP1000's, EPR™'s, and small modular reactors), and the existence of known damaged UNF assemblies, an R&D activity considering the unique (un)loading method of these UNF assemblies into the selected STAD options may be required. This R&D activity would need to consider the potential for development of specialized handling equipment to allow for the transfer of these UNF assemblies into the selected STAD options. In addition, inserts and/or other design modifications to allow for the placement and stabilization of these outlier UNF assemblies into the selected STAD options must be considered. A cost-benefit model may also need to be developed to understand if the costs incurred (e.g., due to generic design modification) to handle an outlier UNF assembly are reasonable or if alternative approaches taken to handle these outlier UNF assemblies are more cost effective.

This R&D activity is not necessarily a near-term need as outlier UNF assemblies can currently be handled safely and stored for the interim in existing commercial cask systems. However, if the selected STAD options is intended to be loaded with all the existing and potential UNF to be produced by U.S. reactors, then this R&D activity may become a nearer-term activity as some of the outlier UNF assemblies are likely to impact the design of the selected STAD options.

10.1.5 Investigation of Consolidation Activities

If consolidation of UNF assemblies is considered a viable option for the loading of a STAD, then there are several R&D recommendations that should occur to verify/demonstrate that the benefits of performing this activity (e.g., reduction in total number of canisters) merit the potential risks associated with consolidation (e.g., the increased operator exposure and expenses associated with the increased level of activity and increased potential for damaging the UNF). These R&D activities include the following:

- Optimizing and automating fuel rod consolidation activities to the extent possible, including maintenance activities on equipment used to perform automation to make operator exposure ALARA and to minimize waste production.
- Examining the impact to consolidation activities considering (noting that consolidation activities have occurred in the past):
  - The higher burnup of UNF compared to the UNF originally tested for consolidation
  - The older age of UNF compared to the UNF originally tested for consolidation
  - The newer fuel designs (especially modifications to grid spacer designs) compared to the UNF originally tested for consolidation
  - Some UNF will have been dry stored for extended periods of time

  - UNF will have been subjected to transportation activities if consolidation is to occur at a CSF (e.g., clad fretting)

- Examining the impacts and potential recovery from abnormal events during consolidation including, but not limited to:
  - Stuck fuel rods in a fuel assembly
  - Leaking through cladding (e.g., pin hole leak through, or tearing of, cladding)
  - Breaching of cladding such that fuel pellets or fuel segments drop to floor

- Optimizing the storage/disposal of the UNF assembly end pieces (e.g., (super-) compacting them and placing them into a STAD or establishing that they be placed into a LLW container).

- Demonstrating criticality safety for all consolidation activities and consolidated geometries for transportation and over storage and disposal time horizons (e.g., establish need for and extent of burnup credit, potentially time dependent moderator exclusion criteria, and required timeframes for maintaining geometric configurations).

- Demonstrating thermal safety for all consolidated geometries for transportation and over storage and disposal time horizons (e.g., establish if mixing of consolidated UNF with different burnups is required).

- Demonstrating adequacy of shielding for all consolidated geometries for transportation and over storage and disposal time horizons (e.g., establish if mixing of consolidated UNF with different burnups is required or if storage and transportation overpacks and EBS will provide necessary shielding for consolidated UNF).

- Examining the impacts to facilities performing rod consolidation (e.g., how does the increased amount of crud release impact SFP operation, occupational doses, and waste production and what are impacts of abnormal events?).

- Evaluating the pros and cons of performing rod consolidation at reactor SFPs, CSF SFP, or CSF process cell (dry activity).

These R&D activities involve demonstrating both the viability of performing rod consolidation at a large scale and the benefits of performing rod consolidation over the perceived risks and costs associated with taking this action. Hence, if rod consolidation was the selected option for a STAD, then some of the above R&D activities (e.g., demonstration of criticality, thermal, and radiation/shielding safety) would be expected to be promptly addressed.

10.1.6 Transfer of UNF from Dry Storage to Selected STAD Option

Due to a significant quantity of UNF already having been placed into dry storage, an R&D activity associated with the transfer of this UNF from the dry storage system into the selected STAD option needs to be considered. This R&D activity needs to also consider the possibility that, at the time a STAD option is selected, some of the UNF in storage may reside at reactors that have gone through D&D and therefore, do not have the option of going back to an SFP for unloading and loading activities. Hence, this R&D activity should consider the transfer of UNF from a dry storage system to a selected STAD option in one of the following facilities:

- SFP at a reactor (wet transfer only)
- CSF transfer facility (wet and/or dry transfer)
- Mobile hot cell (likely dry transfer only)

This activity would need to consider the approach to the opening of the DSC containing the UNF in either a dry or wet environment and in either a permanent installation or a mobile facility. The activity would need to establish the process to:

(a) Transfer the DSC from the storage overpack to one or more of the three transfer facilities identified previously.

(b) Open the DSC in a dry and/or wet environment.

(c) Unload the UNF from the DSC.

(d) Move and temporarily store (if applicable) the UNF in a dry and/or wet environment.

(e) Clean, remove, reuse, and/or dispose of the DSC.

(f) Load the UNF into the selected STAD option.

(g) Prepare the selected STAD option for closure (close, vacuum dry, seal, etc.).

(h) Move and load the selected STAD option into the storage or transportation overpack.

In addition, this R&D activity should consider performing time-motion studies similar to those discussed previously for the (un)loading of the selected STAD option, except it would consider the additional activities associated with the unloading of a DSC either prior to or concurrently with the loading of the selected STAD option. These time-motion studies would examine the cost-to-dose benefit of replacing human activities with automated systems involving the selected STAD option with the goal of making doses ALARA.

The studies would have to consider the different types of DSCs and UNF to be handled (e.g., PWR vs. BWR UNF) and the potential non-uniformity in UNF quality and material properties caused by differences in design of the UNF and the water quality during cooling and storage. They should be supplemented with: (1) trade-off studies identifying differences in the quantity of potentially contaminated waste produced from the various approaches, and (2) a cost-benefit model to understand the financial benefits and/or drawbacks of performing these transfers at each of the noted facilities.

The recommended time frame for this R&D activity depends on the priority of UNF being loaded into the selected STAD options. If UNF in dry storage is to be loaded first into the selected STAD options, then this activity should occur either promptly or in the near term (depending on the time frame the STAD is selected) as to (1) establish the optimal location(s) for this transfer to occur in and (2) optimize the unloading and loading activities while maintaining cumulative doses ALARA and minimizing waste production. If UNF in the SFPs is to be loaded first into the selected STAD options, then this R&D activity is likely a longer-term activity due to the significant quantity of UNF that currently exists in the SFPs. Ultimately, this R&D activity is dependent on the priority of transferring the UNF in dry storage from the DSCs to the selected STAD options, which itself is dependent on other priorities and factors (amongst them the retrievability of the canister and/or UNF, as discussed under another R&D activity).

10.2 Transportation R&D Activities

Transportation strategies are discussed in Section 9.0 and cover the transportation of UNF to the CSF and from the CSF to the disposal site. To identify potential transportation R&D activities, the transportation of UNF to the CSF and from the CSF to the disposal site were refined into the following cases:

- Shipment of canistered or bare UNF from utility site to CSF in transportation cask (option is recommended in this report to support the loading of the selected STAD options at the CSF).

- Shipment of UNF in selected STAD options from utility site to CSF (option was not recommended in this report).

- Shipment of canistered or bare UNF from utility site in transportation cask to intermediate STAD loading facility (e.g., General Electric Morris facility) to CSF, disposal site, or recycling facility (option was not considered elsewhere in this report, but a potential result of a recommended R&D activity).

- Shipment of STAD from CSF to disposal site(s) (option is recommended in this report) or recycling facility (option was not considered elsewhere in this report but is included here for completeness).

Based on these potential transportation activities, three primary transportation R&D recommendations have been identified:

(1) Development of a demonstration project to support the transportation of high burnup UNF.

(2) Examination of the impact of transportation to UNF that has been dry stored for an extended period of time.

(3) Development of a scale model of the selected STAD options to ensure constructability of the STAD and to allow for pre-operational testing (in addition to the testing requirements needed for the NRC licensing of the STAD).

10.2.1 Support of High Burnup UNF Transportation

As noted above, several studies[13-16] have identified potential gaps in data needed to support future storage and transportation activities involving UNF. Amongst the identified potential gaps, the transportation specifically of high burnup UNF has been identified as one area where potential gaps exist and data is needed to support future licensing activities. This recommended R&D activity involves performing a demonstration project for the safe transportation (and storage) of high burnup UNF by shipping some small quantity of high burnup UNF to a research facility (potentially co-located with the CSF) for examination and potential qualification prior to shipments of larger quantities of this UNF being shipped. This examination of the UNF would involve non-destructive analyses and, depending on the need to address the data gaps and the abilities of the research facility, some destructive analyses. Ideally, this small quantity of high burnup UNF would be composed of some UNF that has been stored in a pool and some UNF that has been dry stored (preferably from the same reactor) for a reasonable time frame to allow for contrasting the effects of wet versus dry storage of this UNF.

In the absence of this approach, the alternative is to ship some of this high burnup UNF to the CSF where it could be interim stored on an accelerated aging pad and tested and monitored accordingly. The drawback to this approach is that it requires the CSF to be licensed and built before the high burnup UNF testing can be initiated and therefore, would delay the receipt of this UNF type (the most prevalent of the currently discharged UNF).

This R&D activity is considered to be an immediate need to support the transportation of high burnup UNF to the CSF, the storage of high burnup UNF in the selected STAD options at the CSF, and the transportation of high burnup UNF in the selected STAD options to their final disposition (i.e., disposal or recycling). This R&D activity also supports the current storage of high burnup UNF at existing ISFSI, an area of concern as identified by the NRC [20]. The Nuclear Energy Institute presented an overview of this proposed R&D activity.[21]

10.2.2 Support of Transportation after Extended Storage

An R&D activity is recommended to investigate the impact of extended storage on UNF that will be transported to the CSF, an intermediate STAD-loading facility, a final disposal site(s), and/or a recycling facility. Extended storage can occur at an SFP, a utility owned ISFSI, a DOE-owned ISFSI (e.g., Fort St. Vrain), and the CSF in a STAD.

This R&D activity would focus on ensuring the credited UNF functions remain viable during transportation (e.g., maintain geometry) and after transportation (e.g., retrievability). The first step is to identify the credited functions (for transportation they are found in 10 CFR 71, but for post-transportation activities they will depend on the selected STAD options) and then establish

---

[20] Nuclear Regulatory Commission, Letter to Prairie Island Nuclear Generating Plant, “Subject: Acceptance Review of Renewal Application to Materials License No. SNM-2506 for Prairie Island Independent Spent Fuel Storage Installation – Supplemental Information Needed (TAC NO. L24592)” (2012) [see specifically “Material” Observation (O-1) under the “Request for Supplemental Information”].

[21] Nuclear Energy Institute, “Concept Plan for a High Burn-Up Fuel Storage and Transportation Confirmatory Data Project” (2012).

if there is an impact on these functions as a result of the extended wet and/or dry storage (the gap analyses[13-16] could provide some answers/insights).

For those functions that could potentially be impacted by extended storage, follow-up R&D activities would need to be formulated to ensure these functions remain viable. These follow-up R&D activities would likely take advantage of the demonstration project for transportation proposed in the previous section for high burnup UNF and on the activities necessary to support retrievability described under the loading R&D section.

There are multiple outcomes from this R&D activity including, but not limited to: identifying the priority of UNF to be transported and/or packaged into a STAD and identifying UNF that may not be able to be transported or transferred into a STAD without adding mitigating features. Due to the importance of some of these outcomes, this R&D activity should be considered a near-term activity.

10.2.3 Standardized Canister Testing for Transportation

Another R&D activity recommended to support transportation activities is to utilize the produced scale models of the selected STAD options, which will be built to support licensing activities (e.g., drop testing), STAD constructability, and transportation activities. Some of the risks identified for the various STAD options identified include the constructability of the STAD (e.g., fabrication of a square STAD), the cost of fabricating the STAD (too costly), the time to fabricate a STAD (too long and not enough fabricators), the availability of materials to fabricate a significant number of STADs, and the potential uncertainty of the impact to material properties in a STAD that are in contact with UNF. Hence, the production of a scale model (preferably a full-scale model) would allow for the addressing of most of these issues and no specific R&D activity would be necessary to resolve those issues.

However, to examine the impact on the material properties created by the potential interaction between the STAD materials and the UNF, an R&D activity is recommended that could utilize the scale model to establish what materials actually could come in contact with the UNF and then separate-effects tests can be performed to examine the impact to the material properties. In addition, the scale model could also allow for additional R&D activities (after having been utilized to demonstrate the meeting of licensing requirements) such as:

> (1) Establishing if the optimization of the loading operations discussed under Section 10.1 are effective (potentially loading the scale model at an existing SFP or wet ISFSI – but not shipping it).
>
> (2) Establishing acceleration forces experienced by UNF transported within the selected STAD options during transportation (utilizing mock fuel assemblies with accelerometers in the STAD–done prior to potentially contaminating the cask for activity (1)).
>
> (3) Identifying non-safety related structures internal to the selected STAD options that aid in the support of the unconsolidated or consolidated UNF.
>
> (4) Establishing the impact of beyond design base hazards to the STAD during transportation.

These R&D activities are not required for demonstrating the licensing of the selected STAD options and likely have no near-term need. However, since some of activities could impact the design of the scale model (e.g., recommending the building of a full scale model), they should be considered when establishing the design of the scale model.

10.3 Storage R&D Activities

The storage strategy for the selected STAD options is simply to store it at the CSF prior to shipping it to the disposal site or recycling facility. Any other storage-like activity would be identified as temporary storage, such as staging the STAD at CSF pads. Based on this storage scenario, three R&D activities were identified:

(1) Development of a demonstration project to support the storage of high burnup UNF in the selected STAD options.

(2) Demonstration of retrievability of UNF and/or the selected STAD options after extended storage.

(3) Examination of the impact to dry storage of UNF after UNF may have been:

(i) Wet stored
(ii) Dried and packaged into a canister for dry storage
(iii) Dry stored in a canister
(iv) Requenched/rewetted in a pool from dry storage
(v) Dried and (re)packaged into a canister or transportation cask for transport
(vi) Dry transported
(vii) Requenched/rewetted in a pool from transportation
(viii) Packaged into a STAD

10.3.1 Support of Extended Storage of High Burnup UNF

An R&D activity is necessary to support the extended storage of high burnup UNF in a STAD or other dry storage system. This R&D activity is a demonstration project that parallels the activities performed for lower burnup UNF at the Test Area North and Idaho Nuclear Engineering and Technology Center (INTEC) facilities at Idaho National Laboratory[22,23,24]. The

---

[22] Carlson, Al, C. Hoffman, S. Morton, J. Rivera, P. Winston, K. Shirai, S. Takahashi, and M. Tanaka, “Nondestructive Evaluation of the VSC-17 Cask,” INL/EXT-05-00968 (2006).

[23] Einziger, R.E., H.C. Tsai, M.C. Billone, and B.A. Hilton, “EPRI Examination of LWR Spent Fuel After 15 Years in Dry Storage.” Nuclear Technology Vol. 57, p. 65 (2003).

Nuclear Energy Institute provided an overview of this proposed R&D activity.[18] This R&D activity also follows the description provided in the previous "Support of High Burnup UNF Transportation" section and includes monitored dry interim storage and some non-destructive and potentially destructive analyses. The objective is to gain insights and data necessary to support NRC licensing of the extended storage of this high burnup UNF in a STAD or other canister.

This R&D activity is considered to be an immediate need to support the extended storage of high burnup UNF in the selected STAD options at the CSF and also supports the current storage of high burnup UNF at existing ISFSIs—an area of concern as identified by the NRC.[17]

10.3.2 R&D Needed to Support Retrievability

As noted in Section 10.1 on loading, R&D activities demonstrating the retrievability of UNF and canisters (including STADs) may be necessary to support NRC storage regulatory requirements. For storage, the R&D needs to focus on the retrievability of UNF not in STADs so they can be loaded into STADs and the retrievability of the STADs so they can be loaded into transportation casks if necessary and into the EBS designed for disposal. The R&D activities needed to support UNF transfer into a STAD are adequately covered in Section 10.1 and focus on the material properties at the time of handling.

The R&D activities needed to support the retrievability of the selected STAD option potentially include performing accelerated aging studies on a mock-up of the selected STAD options, followed by non-destructive and potentially destructive analyses to establish data necessary for the demonstration of retrievability (i.e., material properties important to handling as a function of age and cumulative radiation dose). Alternatively, R&D can be performed to establish mitigating approaches required after specified time frames when the selected STAD options may exhibit properties no longer suitable to ensuring retrievability (e.g., moving UNF into new STADs or repackaging STADs into an overpack or larger STAD).

Currently UNF and canisters are considered retrievable after storage, thus this R&D activity is considered a longer-term activity that could be needed to support retrieval operations that occur several decades from now. However, as noted in Section 10.1, this could also become a prompt R&D activity if the UNF could be considered un-retrievable at an earlier timeframe due to its impact on: (1) the development timeline of the selected STAD option, (2) the loading priority of the UNF; (3) the location where the selected STAD option could be loaded; and/or (4) the environment (wet or dry) under which the selected STAD option could be loaded under.

---

[24] Bare, W.C. and L.D. Torgerson, "Dry Cask Storage Characterization Project- Phase l: CASTOR V/21 Cask Opening And Examination," INEEL/EXT-01-00183, Rev. 1 (2001).

The focus of this activity on both the UNF and canister is considered consistent with existing regulatory positions and may evolve based on the NRC's recent "Request for Comment on Retrievability, Cladding Integrity and Safe Handling of Spent Fuel at an Independent Spent Fuel Storage Installation and During Transportation" (Docket ID: NRC-2013-0004), in which it notes "The NRC is assessing the current regulations and policy on retrievability to determine whether to maintain the current definition of retrievability or move towards canister-based retrievability." If the NRC moves to a canister-based retrievability requirement, then the focus of this R&D recommendation should change accordingly, as well as potentially the primary location of the STAD-loading activity (from the CSF to a reactor SFP).

10.3.3 Support of Storage after Transportation after Extended Storage (Wet or Dry)

R&D activities may also be required to address licensing nuances that result from activities that may not have been considered in the development of the original regulatory basis for 10 CFR 72. For example, the storage regulation likely did not consider interim storage of UNF after transportation of UNF from either extended storage in an SFP or an ISFSI, as UNF was originally intended to be transported from the SFP to a recycling or disposal facility. Under current conditions, UNF could be subject to:

- Extended storage in an SFP.
- Drying and packaging into a canister in preparation for dry storage.
- Extended storage in a canister in an ISFSI.
- Placement back into a pool (requenched/rewetted) from dry storage.
- Drying and (re)packaging into a canister in preparation for transportation.
- Transported from a utility to a CSF, recycling facility, or disposal facility.
- Placement back into a pool (requenched/rewetted) from transportation.
- Drying and packaging into a STAD in preparation for dry storage.
- Transported from a CSF to a recycling facility or disposal facility.

UNF can be handled/lifted, dried, transported, and stored multiple times over its lifetime, which the regulatory basis for 10 CFR 72 and 10 CFR 71 likely did not consider. In addition, UNF will have gone through multiple modes of cooling/heating (e.g., forced water convective cooling in SFPs at a nearly constant temperature, natural air cooling, and conduction in storage and transportation systems by variable temperatures, forced gas convective heating during vacuum drying, etc.) that have the potential to change material properties of the UNF and its cladding (e.g., hydride reorientation).

As a result, some additional R&D activities may be required to address these regulatory nuances such as: demonstration of retrievability of UNF and canister/STAD (to support multiple handling activities); the efficacy of the fuel cladding following exposure to variable thermal cycles and multiple transportation cycles (to support crediting of primary confinement boundary – especially with respect to fretting of the cladding); and the efficacy of the canister/STAD following exposure to variable thermal cycles and multiple transportation cycles (to support crediting of secondary confinement boundary).

These R&D activities, and identification thereof, require coordination with the NRC and will depend on the scenario that the UNF is ultimately subjected to. Since the scenario that the UNF will be subjected to has not yet been established, these R&D activities are not near-term in nature.

10.4 Repository Support R&D Activities

In this assessment, the ultimate destination of the UNF is a repository with the UNF placed into the selected STAD options. Since the repository has not been specified, this report assessed the various STAD options against the various potential generic repository candidates (i.e., clay, shale, deep borehole, salt, crystalline, and volcanic tuft). In this section, potential R&D activities necessary to support the selected STAD options for disposal in a repository are identified at a high level due to the uncertainties associated with the type of repository to be selected and the regulation applied to the disposal activity (current or modified 10 CFR 60 or 10 CFR 63 or some completely new regulation).

10.4.1 Long-term Stability of Selected STAD Options

The primary safety function assigned to the selected STAD options would be the confinement of the UNF for at least the nearer term until the STAD has been disposed of or unloaded. The R&D activities associated with this nearer-term safety function are covered under the Storage R&D activities identified previously. However, once the selected STAD options have been emplaced into a repository, R&D activities will be necessary to establish how long the selected STAD options can maintain this confinement function, and whether or not it is a safety function or defense-in-depth function. For previous repository programs, an EBS was to provide the confinement safety function over the necessary time frame of disposal. Whether or not an EBS will be credited in future repositories for this safety function cannot be established at this time. Hence, two R&D activities that need be considered are: (1) establishing the long-term stability of the selected STAD options to each of the potential geological media suitable for disposal, and (2) establishing the long-term stability of the selected STAD options within an EBS.

Noting that the materials used to build the STAD options will be selected based on the geological media of the repository (e.g., for a reducing or oxidizing disposal media), the focus of the first R&D activity will be an investigation of the long-term behavior of these materials in the repository. Ideally the repository program could limit the scope of this investigation by identifying the extent and time frame for which the confinement boundary is a credited safety function for the selected STAD options. For example, if the confinement safety function were only credited for the first 200 years during which the fission products significantly decay and only some form of mitigating containment thereafter, then the focus of the R&D activity could be on the portions of the selected STAD options considered most vulnerable (e.g., welds) over this timeframe instead of over the entire STAD, and over the entire performance period of the repository.

In the absence of such guidance from the repository program, the scope of the R&D activity will likely require significantly more resources and depend more heavily on natural analogs to demonstrate the long-term ability to maintain confinement. Regardless of the approach, since this R&D activity will be a long-term activity, it is best suited to be performed in an in-situ underground laboratory that should be created as soon as a repository site has been selected.

The second R&D activity is related to the case where the selected STAD options are to be placed into an EBS prior to geologic disposal. In this case, the R&D activity involves the establishing of the long-term stability of the selected STAD options within an EBS. The scope of this R&D activity is dependent on whether or not there are performance requirements for the selected STAD options or if these STAD options only provide defense-in-depth to the safety demonstration of the repository. If there are performance requirements to be satisfied, then, depending on what they are exactly (e.g., do they assume the EBS maintains a confinement barrier?), the assessment described above will likely be required but potentially without an underground laboratory, as the environment in the EBS is expected to be far less taxing on the selected STAD options.

If the selected STAD options are only to provide defense-in-depth protection of the UNF, then the R&D activity may not be required at all or may be performed to establish some engineering data that will provide for a reasonable assessment of the selected STAD options to support this defense-in-depth protection depending on the actual protection necessary (e.g., containment, geometry control, moderator exclusion, etc.). This second R&D activity is not expected to require as arduous an experimental program as the first R&D activity because the EBS is expected to provide the primary boundary between the UNF and the repository environment. Nevertheless, the understanding of the long-term behavior of the selected STAD options will provide for a more robust safety argument by allowing either for the STAD options to be credited or for the design of the EBS to account for the potential failure mechanisms of these STAD options.

10.4.2 Stabilization/Immobilization of Waste Form in Selected STAD Options

In addition to the long-term stability of the selected STAD options, the impact of the waste form to the STAD and potentially to the EBS and the repository must be considered to ensure: the waste form poses no deleterious impact to the STAD, EBS, or repository, and the emplaced waste in a repository remains retrievable prior to permanent closure. In this R&D activity, the focus is on the waste form in the selected STAD options and the need to ensure that it does not adversely interact with the material of the STAD, EBS, or the repository in a manner that could negate the ability of these barriers to meet their performance requirements.

For the previous R&D activity, it was noted that the materials of construction of the selected STAD options will likely be compatible with the disposal path selected for these STAD options. An additional requirement is that the waste form in the selected STAD options must be compatible with these STAD options and potentially with the EBS (if the selected STAD option is not credited with meeting specified performance requirements over the disposal lifetime) and/or with the repository (if the EBS is not credited with meeting specified performance requirements over the disposal lifetime).

An R&D activity will likely be required to demonstrate one or more of the following:

- There is no interaction between the waste form and the item(s) required to meet the performance requirements to prevent/mitigate a release.
- The waste form itself will prevent/mitigate a release or adverse reaction (e.g., criticality) regardless of interaction.

- There are no consequences associated with a release from the waste form by the time the interaction has compromised the performance requirements.

This R&D activity could result in a recommended immobilizing or retarding agent being added to the interior of the selected STAD option or a coating on a waste form to prevent/mitigate a release of the waste. The activity could also recommend requirements for the waste form (e.g., minimum age of UNF to be packaged and stored). This activity could include examining the benefits and/or drawbacks of potential waste forms (e.g., UNF in consolidated fuel rods, UNF in fuel assemblies, immobilized fission products in borosilicate glass, etc.) to meeting the performance requirements of the selected STAD options, the EBS, and the repository, noting the importance of treating the repository as limited resource commodity.

Furthermore, until the repository is permanently closed, there will be a period during which the emplaced wastes must be retrievable (up to 50 years after emplacement). Thus, this R&D activity must also consider the impact the waste form has on the retrievability of the EBS and potentially on the selected STAD options or waste form itself, depending on the extent of the material to be retrieved and whether or not the canister or the waste form is credited for retrievability. Retrievability of the waste form (UNF) and the canister are discussed under the Section 10.1.

This R&D activity includes the need for the EBS, loaded with the selected STAD options, to be retrievable from the repository and potentially also expands the time frame the selected STAD options or waste form need to remain retrievable to include the time period prior to permanent closure of the repository.

Since no repository program currently exists and there is no EBS design to evaluate, this R&D activity has no near-term demand but should be considered when trying to establish an integrated waste management system.

10.4.3 Interface R&D between Selected STAD Options and Engineered Barrier System

An R&D activity involving the optimization of loading the selected STAD options into the EBS (if utilized) should be considered to: minimize operator exposure; improve operator, public, and repository safety; maximize loading of an EBS; and minimize space utilization in the repository. These goals are not necessarily inclusive and since some may contradict one another in certain aspects (e.g., improving repository safety while maximizing loading of an EBS), the objective of this R&D activity is to assess how each of these goals can be met and then perform an optimization analysis to establish the preferred outcome(s).

Some of the loading options that should be considered include: vertical (lifting) versus horizontal (pushing) loading of an EBS (noting that the number of operations is significant and likely to result in a drop or misalignment), remote controlled/automation, dry transfer versus wet transfer with vacuum drying, and loading multiple smaller STADs into an EBS versus loading fewer larger STADs into an EBS.

Since no repository program currently exists and there is no EBS design to optimize the loading with, this R&D activity has no near-term demand but should be considered when trying to establish an integrated waste management system.

10.4.4 Interface R&D between Engineered Barrier System/STAD and Repository

The final R&D activity associated with supporting repository activities involves demonstrating that characteristics identified as important to each geological media in this report (e.g., thermal criteria for volcanic/tuft media) are met by the selected STAD options for both the existing range of UNF presently discharged from the reactors and the potential range of UNF discharged from current and near-term reactors (e.g., AP1000, EPR™, and small modular reactors).

Although this report identified STAD options applicable to the potential geological media of specified repository types, an R&D activity should be planned to ensure the selected STAD options satisfy all the requirements of the to be consent-based, selected repository. This R&D activity would address limitations associated with thermal, dose, weight, criticality, pressure/explosive gas production (e.g., from radiolysis), and confinement/containment.

The result of this activity may be changes to the design of the STAD, limitations on the number of UNF assemblies to be loaded, limitations on the minimum age (since discharge from reactor) or maximum burnup of the UNF to be loaded, and specification on the minimum duration and extent of the drying process. Once a specific repository(s) has been selected and its requirements for waste packages developed, this R&D activity should be performed to ensure the specific requirements are satisfied.

10.5 Summary of R&D Activities

The R&D activities identified in this section support the mission of moving UNF from existing sites (i.e., SFPs or ISFSIs) into the selected STAD options and preparing them for disposal. Additional R&D activities could be identified that support other potential elements of a waste management system, such as the optimal approach to removing UNF from the selected STAD options in a recycling plant and the impact of loading canistered vitrified HLW into a STAD; however, the identity of these other elements is uncertain and thus, their associated R&D activities would be speculative and are considered beyond the scope of this report. Table 10-1 lists the R&D activities identified in this section and the potential time frame these R&D activities are recommended to take place.

Table 10-1. R&D Activities and Potential Time Frames

Activity Requiring Support	R&D Activities	Recommended Time Frame
Loading	Retrievability of UNF and Canister	Prompt/Long Term
	Automation of Loading Activities for STAD	Near Term
	Optimization of Vacuum-Drying Activities	Prompt
	Loading of Outlier UNF Assemblies	Near Term
	Investigation of Consolidation Activities	Prompt/Not Necessary
	Transfer of UNF from Dry Storage	Prompt/Near/Long Term
Transportation	Support of High Burnup UNF Transportation	Prompt
	Support of Transportation after Extended Storage	Near Term
	Standardized Canister Testing for Transportation	Near/Long Term
Storage	Support of Extended Storage of High Burnup UNF	Prompt
	Support for Retrievability	Prompt/Long Term
	Support of Storage after Transportation after Extended Storage (Wet or Dry)	Long Term
Repository	Long Term Stability of Selected STAD Options	Long Term
	Stabilization/Immobilization of Waste Form in Selected STAD Options	Long Term
	Interface Between Selected STAD Options and EBS	Long Term
	Interface Between EBS/STAD and Repository	Long Term

11.0 REGULATORY AND LICENSING REQUIREMENTS

11.1 Introduction

The regulatory and licensing requirements for dry storage of commercial UNF are well known and very mature. Approximately 70,000 MTU (Jan 2013) has been discharged from reactors with nearly 20,000 MTU of that total loaded into various vendor designs certified by the NRC under 10 CFR Part 72[25] (Part 72). These onsite storage systems utilize either a vertical or horizontal storage orientation. In general, the industry uses UNF storage systems that are either unshielded stainless steel canisters that require some form of storage overpack or shielded heavy-walled casks. These system designs are either storage only or dual purpose (designed for both storage and transportation). The most commonly used system is a dual-purpose canister comprised of a relatively thin-walled stainless steel shell with a UNF basket designed for storage and transportation. The canister for this type of system is interchangeable and uses a storage overpack for onsite storage (typically concrete and steel construction) or a transportation overpack (typically heavy-walled steel with neutron shielding). The canister with its storage system overpack must meet the regulatory requirements of Part 72. The canister with the transportation overpack must meet the regulatory requirements of 10 CFR Part 71[26] (Part 71).

At present, UNF is loaded into a DSC in a nuclear power plant SFP licensed under 10 CFR Part 50[27] (Part 50). During the loading process, some portions of Part 72 related to criticality may preempt existing Part 50 regulations. The canisters are initially placed in a shielded, reusable transfer cask for loading in the SFP. The transfer cask then transfers the canister to a large robust concrete/steel storage overpack (either vertical or horizontal) that provides both physical and radiological shielding protection. For the transportation counterpart to storage, the transfer cask is used to transfer the canister to a similar metal overpack that is designed to withstand the rigorous NRC certification requirements under Part 71. Some of the transportation metal overpack designs are also certified for storage under Part 72 eliminating a transfer step when the stored UNF is ultimately transported off-site to either one or more CSFs or a repository for disposal. It is this standardized canister concept, as part of an overall dry storage system, that forms the application approach and subsequent regulatory environment applicable to the STAD options discussed in this report. Many of the individual STAD options are variations on storage and transportation systems in use today and therefore inherently do not introduce significant new challenges to the regulatory environment. This is not to say that significant justifications

---

[25] Title 10 CFR Part 72, Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste, 2012-01-01

[26] Title 10 CFR Part 71, Packaging and Transportation of Radioactive Material, 2012-01-01

[27] Title 10 CFR Part 50, Domestic Licensing of Production and Utilization Facilities, 2012-01-01

with supporting analyses are not required, but that the technical issues are well known and understood.

Non-canister-based systems do exist and are in service whereby UNF spent fuel assemblies are directly placed into a heavy-walled, shielded metal cask with an internal basket (storage or transportation), rather than within an unshielded canister and its internal basket. These non-canister-based systems, while licensed to the same regulatory regime, are not directly applicable to the STAD options developed within this report.

As a variant on current practices, fuel rod consolidation techniques were considered in the development of a suite of STAD options to improve the volumetric efficiency of the storage system. Fuel rod consolidation is the process of removing rods from fuel assemblies and placing them into a consolidated fuel rod can with the intent of achieving a fuel compaction ratio on the order of two to one (i.e., the fuel rods from two fuel assemblies taking up no more volume than one fuel assembly). The discarded fuel assembly skeleton structure could be disposed of as GTCC waste at a ratio of about one skeleton can for every ten UNF fuel rod cans.

11.2 Nuclear Power Plant Perspective

The NRC licensed the first ISFSI at the Surry Nuclear Power Plant in 1986. This was done as a cost-effective means of adding onsite UNF storage capability when pool re-racking was no longer feasible and the subsequent lack of SFP storage space impacting continued operations. Since that time, dry storage systems have been implemented at many nuclear power plant sites across the country. Looking to the future, as higher burnup fuels are discharged, the on-site thermal aging requirements prior to shipment to either a CSF or repository will continue to lengthen. It is expected, for these thermally hotter fuels, that a nominal 20-year aging time frame or longer will be required at the power plant site before off-site shipment can meet regulatory limits driven by compliance to Part 71. This time frame falls well within the current license period for both dry storage systems and dry storage facilities of 40 years with the potential for one or more 40-year renewal periods.

The required regulatory submittal to the NRC for the review and approval of a dry storage system design is contained within Part 72, Subpart L. Once a dry storage system design receives an NRC Certificate of Compliance (CoC), it is then subjected to the rulemaking process to be placed on the list of approved storage systems within Part 72. Part 72, Subpart K contains the conditions for a general license (72.210) issued to all Part 50 commercial nuclear power plant facilities, as well as the list of approved storage systems (72.214). The conditions of use for these systems are specified in the storage system NRC-approved CoC. As an alternate approach to the use of a general license, a site-specific license for an ISFSI under Part 72, a commercial nuclear power plant can also utilize Subpart C. This would be the approach taken for a CSF, as it is assumed to be an away-from-reactor site not tied to a Part 50 license.

For the application of the preferred STAD options developed within this report at a commercial nuclear power plant, the Core Team anticipated that repackaging (if necessary) or direct use would occur far in the future, and therefore the industry will continue to utilize, as they do today, respective dry storage systems approved under Part 72. The inventory of UNF in dry storage systems capable of shipment from the various ISFSIs across the country will likely be sent at the appropriate time to one or more CSF facilities for repackaging into one of the preferred STAD options. Over the years, in response to more cost-effective solutions for nuclear utilities, the dry storage industry has been moving to larger and larger storage capacity systems. This reality does create the only potential limitation related to which individual storage canisters in storage service at a power plant can be directly shipped to a CSF from a power plant site. This potential constraint is driven by compliance to the transportation-related requirements from within Part 71 and the railroad industry shipping requirements propagated by AAR—meaning too hot, too heavy, too large will be problematic and likely require repackaging into the largest shippable canister before shipment to the CSF.

11.3 Consolidated Storage Facility Perspective

One or more CSFs, when implemented, would provide similar dry storage capability as that implemented presently at nuclear power plant sites through the addition of an ISFSI, but on a far larger capacity scale (50,000 MTU verses 1000 MTU). The use of a preferred STAD concept at the CSF affords an opportunity to mix-and-match UNF with “hotter” or “colder” decay heat, whether individually by UNF assembly loaded into a single STAD canister, or as a group of STADs loaded into a single storage or transportation overpack or even longer term into a disposal overpack (if used) at a repository.

The CSF can be viewed as a staging and aging facility for UNF from power plant sites prior to shipment to a repository location for disposal. Following a suitable aging time frame at the power plant site (at present more than 5 years to a nominal 20 years for future UNF enrichments), a loaded DSC would be shipped to the CSF within a transportation overpack. The licensing basis of the CSF must umbrella all of the anticipated storage systems in use at the power plant sites that would in turn be utilized for storage at the CSF. Thus, the dry storage systems, practices, and interfaces already in place at power plant locations would be leveraged for use at the CSF as they are today notwithstanding improvements and optimization along the away.

As previously discussed, while Part 72 is the controlling implementing regulation, an away-from-reactor CSF can only be licensed as a site-specific facility rather than also having the option of utilizing the General License provisions of Part 72 afforded to Part 50 power plant license holders. For a CSF, the difference in approach is driven by the required content of the application, meaning a site-specific license, as the name suggests, contains a comprehensive safety and environmental evaluation for a green field site rather than taking credit for some licensing requirements already present and approved at a power plant site. While not trivializing all the other work required, the regulatory review process will bring a focus to the storage system whether for incoming UNF receipt and storage at the CSF (utilizing existing designs in service at nuclear power plant sites) or for repackaging. This means that rigorous evaluations will be done against the existing storage system or STAD design basis to ensure they bound site-specific conditions. It is assumed in this report that fuel rod consolidation techniques utilized in some of the STAD options will not be implemented in a production mode at commercial nuclear power plants prior to any potential use at a CSF site. Therefore, its implementation at the CSF would be done from a licensing perspective by direct inclusion in the facility design/licensing basis subject to review and site-specific license issuance by the NRC.

The license term for the CSF is identical to a power plant ISFSI such that the initial license period is 40 years with the potential for one or more 40-year renewal periods. Dry Storage systems are licensed for the same time periods. It should be noted that from the existing dry storage system perspective, some stored UNF at power plants might have already gone through a license renewal process potentially limiting its deployment service life at the CSF. The STAD would inherently be capable of utilizing its full service life since it is initially loaded at the CSF. The existing systems used at the CSF or the STAD will follow a renewal process involving engineering evaluations to ensure the package and its contents remain compliant with the regulations for initial and renewal periods as appropriate.

Although precedence exists today for license renewal activity for dry storage systems and facilities at power plant sites, this has not included the possible effects on storage systems from long distance transportation to another storage facility site. While there would be no known basis for concluding that this would be onerous to pursue at this time, it must also be recognized that this is beyond the historical knowledge base of today. The facility renewal process would mirror that being used today for power plant onsite ISFSIs under Part 72. Aging management programs would likely be developed for the STAD well in advance of CoC or license renewal so that definitive arguments can be made in the future supporting such renewals.

Focusing now on the STAD itself, the principle design concepts related to canister/internal basket configurations while using an overpack for physical and radiological shielding protection remain largely unchanged from the existing systems licensed and in service today. It is expected that the materials used in these existing systems would be equally suitable for STAD service, thereby introducing limited change from the approved designs and underlying technical basis. The preferred STAD options utilize one (Option 3a) that is significantly smaller in diameter; a second medium sized option (Option 5); and a third (Option 7) that is very similar in size to most canister systems in service today. As such, the physical features for Option 3a, the smallest STAD, supporting loading, drying, inerting, welding, and handling may be more customized than is in current practice for this application but functionally remain the same. The smaller sized STAD-enabled storage or transportation overpacks (Option 3a and 5) will utilize some form of internal handling frame for containing multiple STADs similar to the current UNF canister basket concept for individual UNF assemblies; again introducing limited change from existing approved design concepts. It is also anticipated that the processes and procedures used today in the loading and handling of DSCs under the nuclear power plant operating license (Part 50) would be equally applicable to STAD service at the CSF.

As a process enhancement to current practices, fuel rod consolidation can offer a meaningful increase of efficiency in terms of UNF pounds per volumetric package with a resulting reduction in shipment costs from the CSF to the repository. This enhancement at the same time presents much more regulatory uncertainty that must be overcome. Current nuclear power plant regulations under Part 50 permit utilization of fuel rod consolidation under a license amendment to increase the amount of spent fuel that can be stored in the pool based on criticality, thermal, structural, and seismic engineering evaluations. While some field demonstration experience exists only on PWR fuel (from the 1980s to early 1990s), it never developed beyond the demonstration stage due to:

- Concerns related to gap activity releases from potential rod breakage or cracking caused by the process.
- The potential for removal of the outer layer of fuel rod oxide protection during the handling of the rods leading to increased fuel cladding corrosion.
- The process itself is a time consuming activity that could interfere with plant operations.
- It was not cost effective as compared to the addition of onsite dry storage.

Implementing fuel consolidation capability means that the CSF, in some respects, is much more akin to a power plant and must provide the necessary fuel consolidation production facilities (one or more pools) and related systems rather than being a much more passive storage-only facility likely only containing a relatively small mitigation and recovery pool. If implemented, the inclusion of fuel consolidation capability does raise a basic regulatory question of whether Part 72 would be the owning regulation. The Team believes that fuel consolidation is a handling technique during loading and as such affects geometry related to the UNF assembly but not its inherent composition. Advance discussions with the NRC's Office of Nuclear Material Safety and Safeguards (NMSS), Division of Spent Fuel Storage and Transportation (SFST) indicate similar thinking in the applicability of Part 72. It is possible that alternately, the NRC could take a final position of utilizing another regulation such as 10 CFR Part 70[28] (Part 70) when the time comes to generate an actual license application. While the true answer to this issue is not known at this time, it is expected that dialog with the NRC early in the planning stages of such a facility will identify a satisfactory licensing approach. Early dialog will also allow time for the NRC to pursue any necessary rulemaking and/or issue staff guidance and review plans on specifics related to this subject.

Setting aside the base regulation question, the advantage of implementing fuel consolidation, as a storage technique at a CSF over a power plant location, is the needed systems would be designed as part of the facility and their operation part of the normal process as opposed to a power plant adding the ability to consolidate. The issues to surmount for applying fuel consolidation techniques at a power plant such as criticality, thermal, structural, and seismic engineering evaluations would become part of the CSF design basis rather than defending minimal or no impact to existing systems at a power plant. The technical issues are well known but do require advanced equipment design features for the disassembly of UNF assemblies and handling of individual fuel pins with subsequent reloading into a fuel can. Assuming these designs can be developed, appropriate prototype demonstrations will be required to demonstrate the technical viability and ease of licensing of this approach for application and production use at a CSF.

---

[28] Title 10 CFR Part 70, Domestic Licensing of Special Nuclear Material, 2012-01-01

11.4 Repository Perspective

The repository regulatory requirements are unclear as compared to those of dry storage. The most recent implementing regulation is 10 CFR Part 63[29] (Part 63). It is specific in application to only the Yucca Mountain site which leaves the older, generic 10 CFR Part 60[30] (Part 60) as the owning regulation for some notional understanding of STAD deployment as it relates to ultimate disposal. In January 2012, the administration's Blue Ribbon Commission urged, among other recommendations, the near-term development of new generic repository regulations by both the NRC and Environmental Protection Agency (EPA). It would be expected that the current NRC Part 63 and EPA's 40 CFR 197[31] (Part 197), as the dose standard for Yucca Mountain, would be the starting point for future regulations but that remains as speculation. However, extrapolation from current dry system designs and the DOE standardized canister approach contained within the Yucca Mountain License Application would suggest that the STAD repository interface presents the same or similar interfaces and needs. It is likely that future repository designs will still use some form of a waste package/disposal overpack synonymous with the need and usage of storage or transportation overpacks.

Once again, the processes and procedures of putting STADs into an appropriate storage or transportation overpack would be similar to that potentially utilized at a repository for emplacement and disposal. The use of the smaller preferred STAD concepts (Option 3a and 5) would provide an opportunity to mix and match various UNF decay heats into a common waste package supporting thermal constraints prior to disposal if needed. This again is more of a functional feature than a departure from current or anticipated regulatory perspectives. Presumably, any needed thermal aging would be accomplished prior to repository site arrival leveraging time spent at the power plant point of origin and/or at the CSF. This would effectively streamline operations at the repository to focus on emplacement with some amount of delivery staging capability to optimize operations and minimize upsets.

11.5 **Licensing** Conclusion

There are no known significant impediments, from a regulatory perspective, for the implementation of existing dry storage designs or the preferred STAD options at a CSF. Rigorous engineering analyses to defend the specific design and its application at the CSF for dry storage can be expected. The fuel consolidation approach does introduce some regulatory uncertainty since it inherently changes the configuration of a UNF assembly rather than just

---

[29] Title 10 CFR Part 63, Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada, 2012-01-01

[30] Title 10 CFR Part 60, Disposal of High-Level Radioactive Wastes in Geologic Repositories, 2012-01-01

[31] Title 40 CFR Part 197, Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada, 2012-07-01

handling it as is within the present day loading and storage regime. Longer storage time frames at a nuclear power plant or CSF will require commensurate analyses to support license renewal, but again, much precedence does exist to support implementation.

While a definitive regulatory regime for disposal at a repository is uncertain, the inherent design approach and application flexibility of the preferred STAD options would suggest they would not introduce meaningful impediments to their use for disposal.

12.0 COST SUMMARY

This section provides order of magnitude estimates for the lifecycle costs of the recommended STAD options. Lifecycle costs presented include upfront costs, operations costs, and D&D costs in small, medium, near-TAD size, and TAD size categories. This is an American Association of Cost Engineers (AACE) Class 5 level, Order of Magnitude estimate used to determine the cost of the facility's construction and demolition.

12.1 Approach and Methodology

This section consists of order of magnitude estimates for the lifecycle costs of the chosen STAD options including:

- Upfront Costs
    - Design
    - Testing
    - Licensing

- Operations Costs
    - Hardware
    - Dose Control
    - Loading and Unloading
    - Infrastructure
    - Utility, CSF, and Repository Storage
    - Repository Placement
    - Special Nuclear Material (SNM) Accountability
    - Quality Inspections and Record Keeping

D&D Costs

Costs associated with the use of 10 CFR Part 72 licensed Dry Cask Storage Systems (DCSS) are used as one basis for the estimated costs. Input was also solicited and received from DCSS users relative to operational costs and DCSS vendors for fabrication, delivery, and transportation costs. Where appropriate, cost estimates prepared for the Consolidate Storage Facility were used as input and adjusted as required. Major assumptions include:

- STAD Option 7 (21 PWR/42 BWR UNF assemblies) is considered the base case and the most comparable to Part 72 DCSS. Where appropriate, costs estimated for Option 7 are factored for the other STAD options.

- All UNF is assumed to be packaged using a single option.

- For the purpose of the cost estimate, the we assumed a quantity of STADs to package 50,000 MTU of UNF with BWR UNF facilities accounting for 57 percent of the total packaged.

- Upfront costs are assumed the same for all options.
- Transportation costs are estimated using the CSF cost estimates as a basis.

Table 12-1 presents a Level 1 summary of the estimated lifecycle costs.

Table 12-1. STAD Lifecycle Cost Summary Table
($Millions)

	SMALL				MEDIUM	NEAR TAD-SIZE	TAD-SIZE	
	Option 2 (2/4/13.4" OD/C	Option 3 (1/1/13.1" OD/U)	Option 3a (1/2/15.0" OD/U)	Option 4 (2/4/ 8.4" sq/C)	Option 5 (4/9/ 31.0" OD/U)	Option 6 (12/24/ 43.25" OD/U)	Option 7 (21/44/ 66.25"OD/U)	Option 8 (42/88/ 63.0" sq/C)
1.1 Upfront Costs (canisters)	$220	$220	$220	$220	$220	$220	$220	$220
1.2 Operations Costs	$18,173	$32,942	$26,128	$24,010	$19,623	$10,903	$7,537	$5,803
1.3 D&D Costs	$452	$1,149	$822	$258	$785	$616	$346	$185
TOTAL	$18,845	$34,312	$27,710	$24,488	$20,629	$11,739	$8,103	$6,208

12.2 Upfront Costs

Upfront costs include those costs for conceptual, preliminary, and final design; prototype testing for both regulatory compliance and development of operations; and licensing in accordance with 10 CFR Part 71 and Part 72. These costs are assumed to be the same for all options.

12.3 Operations Costs

Operations costs include all lifecycle costs starting with fabrication and delivery and ending with transportation to and placement at the final geological repository. The cost for the materials and fabrication of the particular STAD option considers both the cost to produce the canister, as well as the quantity of STADs required.

Storage costs assume that the smaller capacity STADs will be stored within their handling frame/canister overpack. Transportation costs assume the same configuration. Transportation costs are factored based on the number of shipments required for a particular STAD option.

12.4 D&D Costs

There are no D&D costs associated with the STAD canisters. D&D costs include those for disposition of storage overpacks used at the CSF and for disposition of handling frames and canister overpacks. D&D costs for storage overpacks used at utility sites are not included.

13.0 SCHEDULE SUMMARY

This section provides a summary of overall anticipated schedule to design and fabricate the STAD. We describe the conceptual, preliminary, and final design stages, as well as licensing and fabrication processes. Figure 13-1 provides a visual summary for an optimistic schedule to develop and deliver the STAD as soon as possible after the repository site selection is complete. The main schedule elements include:

- Conceptual Design
- Preliminary Design
- Final Design and Testing
- Licensing
- Fabrication

Element	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Conceptual Design		■	■												
Re-assess STAD options, CD				■											
Preliminary Design					■	■									
Re-assess STAD options, PD							■								
Fianl Design								■	■						
Prototype Testing									■	■	■				
Licensing							■	■	■	■	■	■			
Initial Fabrication											■	■			

Figure 13-1. STAD Design & Fabrication Summary Schedule

13.1 Conceptual Design

Conceptual design will include activities to evaluate different design concepts for the selected STAD options (3a, 5, and 7) and provide recommendations regarding the design concepts. One example is a bolted versus welded closure. Materials will be reviewed relative to current UNF dry storage licensing requirements and concepts associated with the final geological repository.

Additional work will also be required in the area of criticality and setting of UNF parameters such as cooling time, burnup, and initial enrichment.

Conceptual Design is a predecessor to Preliminary Design.

13.2 Preliminary Design

Prior to starting Preliminary Design, the Core Team recommends that the STAD options and their conceptual designs be reviewed against the UNF dry storage and transportation regulations and concepts for the final geological repository in place at the time of Preliminary Design. Changes in regulations and repository concepts may require revisions to the STAD options recommended by this report and/or their conceptual design.

Assuming no major changes in STAD concept, Preliminary Design will further refine the Conceptual Designs. The result should be information that can be used to start the Final Design and Licensing Process.

During this time period, prototypes based on the Preliminary Design will be manufactured and used as proof of concept and to refine the design as well as loading and associated procedures. Testing associated with regulatory requirements may also be performed.

Preliminary Design is a predecessor to Final Design.

13.3 Final (Detailed) Design

Final Design is not recommended to start until the final geological repository is licensed and the acceptance criteria for waste packages have been established. As with Preliminary Design, it is recommended that the STAD options and their Preliminary Designs be reviewed against the UNF dry storage and transportation regulations and the final geological repository requirements in place at the time of Final Design. Changes in regulations and repository requirements may require revisions to the STAD options that are recommended by this report and/or their Preliminary Design.

Assuming no major changes in the STAD Preliminary Design, the Final Design will use information gathered during testing of the Preliminary Design to enhance the Final Design. The Final Design will be used as input to the STAD license application and will also provide the information required to manufacture the STAD.

13.4 Licensing

Activities during this time period include preparation of licensing documents (Safety Analysis Report, Technical Specifications, etc.), submittal of the license applications to the NRC, review by NRC, and preparation of responses to NRC Requests for Additional Information (RAIs). There may also be a component of the STAD licensing process that is tied to licensing of the final geological repository.

Prototype testing of the Final Design will also be performed during this time period. Testing will be performed to support the license application and to refine the design with respect to manufacturing and use. The prototypes may also be used to develop and refine loading, preparation, storage, and transportation procedures.

13.5 Initial Fabrication

Initial fabrication of the STAD will commence after the license application has been approved. STADs fabricated during this period will likely be shipped to the CSF where the processes required for their use will be tested and refined. After this initial fabrication time period, it is anticipated that full production of the STAD will commence with deliveries to both reactor sites and the CSF.

14.0 CONCLUSIONS

The AREVA Team of subject matter experts conducted a systems engineering evaluation in accordance with the procedure in DOE order 430.B that considered the use of eight different designs of STADs loaded wet and dry at the reactor site, CSF, geological repository, or a combination of all loading options while optimizing the system to take into account one of five final geological repositories. The study considered loading the STAD while the reactor was still in operation and when it was shut down. The AREVA Team's recommendation is to carry forward three canister options (one small, one medium, and one large) to the conceptual and preliminary design phases. We further recommend that STAD options and the path forward be re-assessed at the completion of the conceptual and preliminary design phases as regulatory and performance requirements for UNF disposal mature and become more certain.

Based on the timeline outlined by DOE a pilot facility in 2021, CSF in 2025, a geological repository by 2048, and assuming a licensing timeline similar to Yucca Mountain, the site selection process would be complete in early 2026. Assuming optimum in parallel development and licensing for the STAD, it may be possible that the STAD could be licensed for use at the end of 2026. By this time a significant amount of UNF will be located at the CSF, and it is recommended that this fuel be loaded into the STADs and shipped to the geological repository.

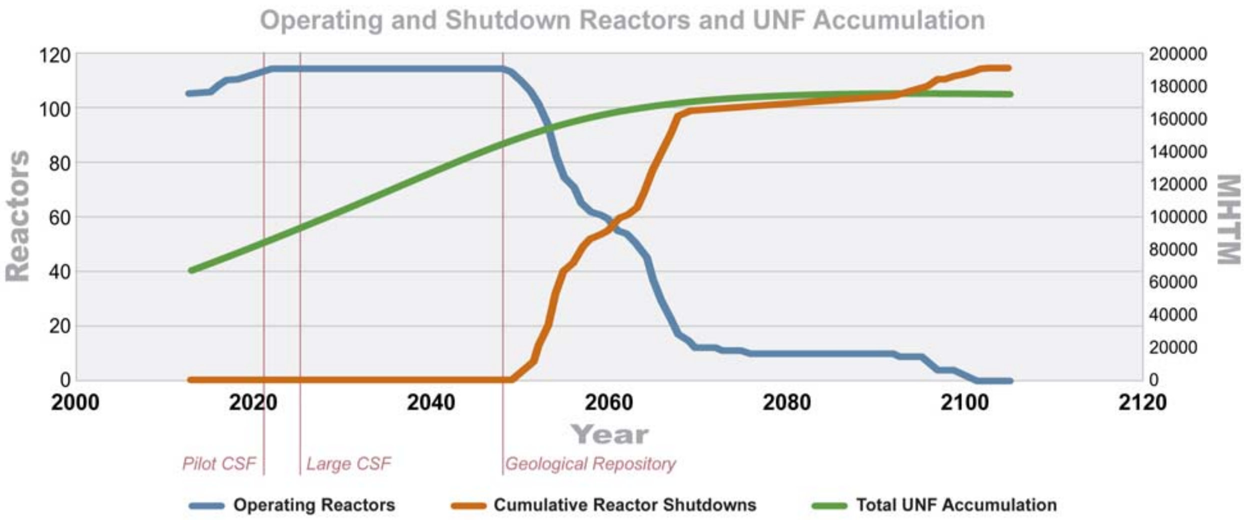


Figure 14-1. UNF Management Scenario Assuming Operational Reactors Operate for 80 Years

Extensive studies were conducted and documented in white papers to explore loading STADs in normal operations at the plant. The Team spoke with and researched a large cross section of utilities to develop a time and motion study and identify places where the process time could be shortened. In the large majority of cases, the current physical constraints of the SFP and the surrounding infrastructure was the limiting factor that stopped the processing of multiple STADs at once without redesigning the SFP building and associated infrastructure.

A lot of discussion with our utility partners and advisory panel revolved around the use of STADs at the reactor site. Common ground was found when considering loading the STADs in the SFP when the reactor shuts down and the utility has a financial incentive to load fuel quickly into dry storage and close the SFP. Loading UNF STADs during reactor shutdown could allow approximately 40 percent of the UNF generated to be loaded at the reactor site. This number should be caveated with the fact that this is highly dependent on when reactors shut down and the individual utility.

Several of the utilities we spoke with have made the offer to consider loading STADs now. We strongly encourage DOE to continue the study to explore this in more detail and develop a business plan that would consider a demonstration of STAD loading to proceed.

Recommendations

The AREVA Team suggests that DOE:

- Continue the design of small, medium, and large STADs until such time as the repository is selected.
- Develop a business plan for the adoption of the STAD when the reactor enters D&D.
- Enter into discussions with the utility partners that have offered to load STADs as a demonstration of the technology. After discussing the STAD concept with utility partners, we have made a lot of progress. It is important that we maintain this momentum.