

## **Developing Generic Design Alternatives For Dry Storage Of Used Nuclear Fuel At An Interim Storage Facility - 15480**

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### **ABSTRACT**

The Department of Energy (DOE) is beginning to lay the groundwork for implementing interim storage of used nuclear fuel (UNF) as recommended by the Blue Ribbon Commission on America's Nuclear Future in their report to the Secretary of Energy published on January 26, 2012. These plans include activities to 1) establish one or more Interim Storage Facilities (ISF) using consent-based siting, and 2) prepare for large-scale transport of UNF. The Administration released its Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste (Strategy) on January 11, 2013.

The Strategy includes a phased, adaptive, and consent-based approach to siting and implementing a comprehensive management and disposal system. The Strategy calls for an operational Pilot ISF by 2021, a Larger ISF by 2025, and a geological repository by 2048.

The DOE Nuclear Fuels Storage and Transportation Planning Project (NFST) prepared a report in April 2013 titled, "A Project Concept for Nuclear Fuels Storage and Transportation." This report developed the functions and requirements necessary for development of a Pilot and Larger ISF to meet the framework outlined in the Strategy as follows:

- The UNF inventory is limited for the Pilot and Larger ISF as described in the Strategy.
- It is assumed that bare fuel will be received in reusable transportation casks in significant quantities for the larger ISF and will not be solely limited to the receipt of fuel in dry storage canister (DSC) as is the Pilot ISF. This assumption was made because the method for accepting UNF from the utilities once the larger ISF begins operating has not yet been decided.
- UNF storage alternative concepts identified in previous reports must be more fully developed to support alternative analysis.

The purpose of this topic is to report on the development of the generic design alternatives that have been evaluated for the receipt and storage of the UNF at the initial Pilot ISF and Larger ISF. The generic design alternatives have been developed over the past few months by collaboration between the DOE and industry experts experienced in UNF facilities.

The design alternatives will enable volunteer host communities to investigate generic design alternatives that could be fully developed for a site-specific location based on their unique design requirements. The design alternatives provide flexibility for additional capabilities to be developed and executed in a modular fashion such that expansion from a Pilot ISF to a Larger ISF could be achieved in an orderly manner.

### **INTRODUCTION**

In July 2012, the DOE contracted with three teams to prepare design concept studies to investigate UNF storage and transportation. DOE was seeking to identify and evaluate concepts and approaches that could be deployed for the interim storage of commercial UNF to satisfy the Blue Ribbon Commission on America's Nuclear Future [1] and the DOE Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste [2]. The teams were tasked with identifying design concepts that address all activities required to take the commercial UNF and Greater-than-Class C (GTCC) low level radioactive waste from its current location and configuration, transport it to a location of interim storage, prepare the fuel as needed and place it in storage, operate and maintain the interim storage facility, and

prepare the used fuel for shipment to the permanent repository. The three teams, one of which was CB&I, submitted their design concept studies and issued reports in February 2013.

The results of the three team's reports were consolidated in the DOE Nuclear Fuels Storage and Transportation Planning Project report titled, "A Project Concept for Nuclear Fuels Storage and Transportation" (NFST Project Concept) [3]. This report developed the functions and requirements necessary to meet the framework outlined in the Strategy using the three design concept deliverables and the system architecture evaluation as principal input documents. The NFST Project Concept calls for the evaluation of five Alternative storage methods that could be used to store transportable canister-based dry fuel storage systems currently used at commercial plant sites at an ISF. CB&I was tasked with the evaluation and preparation of the study which is focused first on evaluating storage alternatives for a Pilot ISF sized to store up to 5,000 MTU of UNF from shut down plant sites and second on evaluating storage alternatives for a Larger expanded ISF sized to store an additional 5,000 MTU of UNF from the remaining nuclear plant sites. The remaining plant sites could consist of operating plants as well as newly shut down plant sites.

The five dry storage Alternative storage methods to be evaluated for storage of commercial UNF canisters at the Pilot ISF and larger ISF are as follows:

- Commercial DSCs using above ground storage (currently deployed and licensed above grade vertical and horizontal storage systems associated with each DSC design)
- Commercial DSCs using standardized overpacks (storage of DSCs in a single universal overpack could reduce the design and operation variables and permit a more simplified process at the ISF)
- Commercial DSCs using underground storage (DSCs placed underground in a below grade cylindrical vertical storage silo may provide better radiation shielding, and structural and security protection)
- Commercial DSCs using a below grade vault (DSCs stored in a below grade vault designed as a hardened reinforced concrete structure using natural ventilation cooling with an above grade structure providing an operating area for canister placement, storage, and removal via floor plugs)
- Commercial DSCs using an above grade vault (similar to the below grade vault)

## NOMENCLATURE

DFSS	Dry Fuel Storage System
DOE	U.S. Department of Energy
DSC	Dry Storage Canister
GTCC	Greater Than Class C Waste
HBU	High Burn-up
HLW	High Level Waste
HSM	Horizontal Storage Module
ISF	Interim Storage Facility
ISFSI	Independent Spent Fuel Storage Installation
MTHM	Metric Tons Heavy Metal
MTU	Metric Tons of Uranium
NRC	U.S. Nuclear Regulatory Commission
UNF	Used Nuclear Fuel
VSO	Vertical Storage Overpack

## **PILOT INTERIM STORAGE FACILITY**

Prior to 2013 there were nine shutdown reactor sites that stored UNF at an onsite Independent Spent Fuel Storage Installation (ISFSI) which utilize dry fuel storage systems (DFSS). These sites have been or are in the process of being decommissioned and dismantled. There is some urgency to remove the UNF in order to: 1) allow the sites to be used for other purposes, and 2) to consolidate the storage of the UNF into a centralized location reducing the overall storage activities and costs. The nine sites are Big Rock Point, Haddam Neck (Connecticut Yankee), Humboldt Bay, LaCrosse, Maine Yankee, Rancho Seco, Trojan, Yankee Rowe and Zion.

Since 2013, three more reactor sites (Kewaunee, Crystal River and San Onofre) have shut down. It has also been announced that Vermont Yankee and Oyster Creek will join this category within the next few years, increasing the need for a centralized ISF. All of the shutdown reactor sites currently have, or will have, UNF stored in storage systems that have DSCs that are transportable, i.e., can be shipped to the ISF in a transport cask. It should be noted that there are also shutdown reactors located at operating plant sites (Dresden 1, Indian Point 1, and Millstone 1). Since these reactors are located at operating plant sites, the removal of their fuel is not as urgent because the site will not be decommissioned for several years.

There are also several plants that are candidates for premature shut down due to financial issues. There may be more in the next decade before a Pilot ISF is constructed and ready to operate.

Along with the UNF, some of the DSCs contain GTCC waste which is loaded into canisters similar to those used for the UNF. These will need to be removed from the reactor site along with the UNF.

The conceptual storage capacity of the Pilot ISF is targeted to hold 5,000 MTHM received at an average rate of 1,000 MTHM/year with a maximum rate of 1,500 MTHM/year. The UNF accumulated from the 9 original identified shutdown sites plus the 3 newer identified sites (Kewaunee, Crystal River and San Onofre 1) represents the study basis for the Pilot ISF having a total of 4083 MTU representing 429 DSCs. Using this basis, the Pilot ISF module would consist of 267 vertical storage units and 98 horizontal storage units.

The UNF from the remaining shutdown sites (San Onofre 2 & 3, Vermont Yankee and Oyster Creek) are not considered in the Pilot ISF study basis because the resultant UNF in storage due to all the shutdown plants would be nearly 8,000 MTU, which exceeds the 5,000 MTU target. The UNF from these sites plus any UNF from currently operating reactors would be received as part of the Larger ISF.

For the purposes of the study, the number of DSCs represented for a 5,000 MTU facility was rounded up to 450 to simplify the layout of the storage area in each Alternative. The segregation into vertical and horizontal units was broken down to roughly follow the overall ratio between vertical and storage units currently in storage. Therefore, the definition for the fully implemented Pilot ISF was:

Total Storage Units = 450

Vertical Units = 300

Horizontal Units = 150

The DSCs that would be stored at the Pilot ISF is shown in Table 1.

Retrieval of the UNF from shutdown sites represents about 4 percent of the total anticipated UNF that will eventually need to be stored. The Pilot ISF is a small facility, designed for future growth, with minimum essential structures and components for receiving transport casks from these shutdown reactor sites. This approach makes the initial facility design simpler and the licensing process less complex, essentially allowing the ISF to be a pilot process with a well-defined success path. The UNF could be moved from the shutdown reactor sites to the Pilot ISF beginning the first year of the Pilot ISF operation in 2021 with receipt completion expected within 6 years.

TABLE 1. Pilot ISF Storage Systems – 12 Shutdown Reactor Sites

Storage System Overpack/Canister	Reactor	Number of Canisters	Total MTU
<b>Fuel Solutions</b>			
W150 / W74	Big Rock Point	7 UNF 1 GTCC	58
<b>Holtec</b>			
HI-STAR HB / MPC-80	Humboldt Bay	5 UNF 1 GTCC	29
TranStor / MPC-24E,EF	Trojan	34 UNF 0 GTCC	359
<b>NAC</b>			
MPC / MPC-26	Connecticut Yankee	40 UNF 3 GTCC	412
MPC / MPC-36	Yankee Rowe	15 UNF 1 GTCC	127
MPC / LACBWR	LaCrosse	5 UNF 0 GTCC	38
UMS / UMS-24	Maine Yankee	60 UNF 4 GTCC	542
MAGNASTOR / TSC-37	Kewaunee	24 UNF 2 GTCC <sup>1</sup>	341
MAGNASTOR / TSC-37	Zion 1 & 2	61 UNF 4 GTCC	1,019
<b>AREVA TN</b>			
NUHOMS / 32PTH	Crystal River	42 UNF 2 GTCC <sup>1</sup>	612
NUHOMS / 32PT	Kewaunee	14 UNF 0 GTCC	172
NUHOMS / 24PT	Rancho Seco	21 UNF 1 GTCC	228
NUHOMS / 24PT1	San Onofre 1	17 UNF 1 GTCC	146
<b>Total</b>	-	<b>345 UNF 20 GTCC</b>	<b>4,083</b>

Notes:

1. *Estimated*

All of the shutdown sites have UNF stored in canister-based DFSSs which are designed and licensed for both storage and transport. The DPCs are welded closed and do not need to be opened so the Pilot ISF would operate as a “start clean, stay clean” facility, which further reduces the equipment required for this ISF.

The Pilot ISF design must be capable of receiving UNF from the shutdown reactor sites without the need to open the DSCs or handle bare fuel assemblies. The pilot ISF design must also be modular, allowing for phased deployment over time in order to accommodate a Larger ISF, capable of storing UNF from all of the nation's reactor sites.

The Pilot ISF will need to provide facilities and infrastructure needed to receive and transfer the large DSCs from transport casks into an "efficient" storage system. Therefore, the Pilot ISF would need to employ the following:

- Rail yards to receive incoming train consists and prepare for outgoing train consists
- A canister transfer facility with:
  - A railcar bay and overhead crane to offload transport casks,
  - One or more shielded cells to transfer vertical type DSCs from transport casks to storage overpacks' and
  - An area to place horizontal type DSCs in transport casks onto a transporter for delivery to a horizontal storage module (HSM).
- A storage area consisting of one of the five alternatives (pad storage, standard overpack pad storage, underground storage, below grade vault storage or above grade vault storage)
- Support buildings, such as an office building, maintenance building, and security building
- Secured fenced areas to provide radiation and security protection

## EVALUTION OF ALTERNATIVES

Each of the five storage alternatives was evaluated for use at the Pilot ISF to determine their pros and cons and suitability for the application. The distinguishing factors promoting or demoting a particular storage method are primarily time to implement, cost and ease of use.

### Alternative 1, Pad Storage With Current Storage Overpacks

Alternative 1 represents the current method of storage at most of the reactor site ISFSIs. DSCs are stored in a heavily reinforced vertical concrete overpack (large vertical cylindrical cask as shown in Figure 1) or horizontal storage module (a rectangular prism as shown in Figure 2). Both of these storage methods use an 18" to 36" thick reinforced concrete pad to provide a seismically stable platform for the overpacks or modules. The pads are designed to store multiple storage units. The conceptual plan for the Pilot ISF is to use pads that can store up to 50 vertical overpacks or horizontal modules.



Figure 1 – Vertical Storage Overpacks



Figure 2 – Horizontal Storage Modules

### Pros

- Alternative 1 is the quickest to implement with minimal effort. All of these storage systems are already designed and licensed. Once a system receives its license from the NRC, a General License is typically employed for use at a reactor site ISFSI. However, a General License can only be used under a 10CFR50 license (reactor) and therefore cannot be used for the Pilot ISF. The Pilot ISF must use a Site Specific license under 10CFR72. A Site Specific license requires the initiation of a number of documents associated with the development of a new site such as a License Application, Environmental Report, Safety Analysis Report (SAR), Emergency Plan, Security Plan and Technical Specifications. Preparation of all these documents plus the Nuclear Regulatory Commission (NRC) review takes time. However, the material from existing storage system SARs could be incorporated by reference into the Site Specific license which would greatly streamline the licensing process.
- These systems performance capabilities are known. There are no unknowns that would need to be studied, designed for, or debated. The NRC has even determined that over several years, these storage methods are safe.
- The systems can be implemented over time, reducing their initial capital costs. Nuclear power plants create UNF over a 40 to 60 year average life span. As it is created, the UNF can be shipped to the Pilot ISF where concrete storage pads and vertical overpacks or horizontal modules housing the DSCs can be installed over several years.

### Cons

- Although all of the storage systems are licensed, placing them at a specific location may require some licensing revisions and therefore, prolong the duration required to implement the Pilot ISF. These changes are most likely to result from seismic conditions and ambient temperature extremes. The probability that a system will not meet a specific site condition is very small but the process to re-analyze the system and the NRC review of those analyses will take time and money.
- There are 13 different systems that need to be accommodated. Currently, each system has been designed to use its own specific equipment. This could affect lifting yokes, DSC transfer adapters, transporters, etc. (some of the transport casks are designed for multiple DSCs which somewhat cuts down their numbers). Employing 13 sets of equipment to lift and offload a transport cask, transfer the DSC from the transport cask to a storage overpack or module and move the DSC by crane or transporter could be burdensome. The creation of equipment that could be used for multiple systems would eventually come to pass to relieve much of the burden but probably not initially.
- Vertical systems require a more extensive DSC transfer process that most likely would require a canister transfer facility. This facility is a large structure that increases the cost of the pad storage alternative dramatically. There are methods of canister transfer that can be performed without such a

structure but they are more involved with increased manual steps that increases transfer time and personnel radiation dose. The horizontal storage system does not need the canister transfer facility because the transfer takes place at the storage module itself. However, innovated means of transfer on a daily basis will be necessary to reduce dose in the horizontal systems.

- Storing multiple systems will also affect the analysis (or increase the number of analyses) of the storage pads which need to consider size, weight, tipping potential, direct radiation, etc. The pad design would likely not change.
- Onsite fabrication is affected. Vertical overpacks are too large and heavy for standard shipping so they are manufactured in a vendor's plant in a lighter / smaller configuration so that the concrete can be applied at the site. Horizontal modules are typically manufactured in pieces that are shipped to the site and assembled there. The 13 storage systems require about 6 different storage overpack or module designs. Onsite fabrication of some sort will need to accommodate all 6 of these.

An artist's view of a Pilot ISF using existing storage systems is shown in Figure 3.

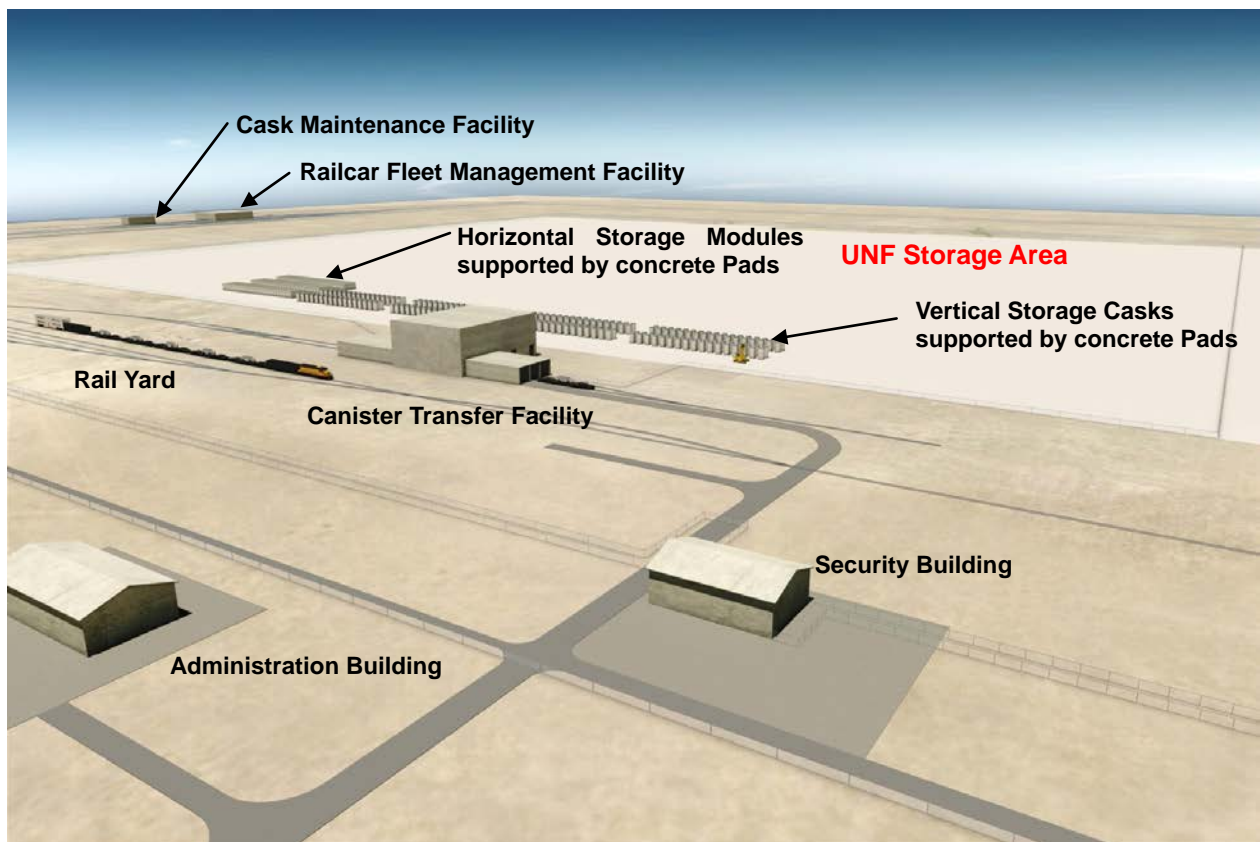


Figure 3 – Pilot Interim Storage Facility Using Pad Storage

### Alternative 2, Pad Storage With Standard Storage Overpacks

Alternative 2 exchanges the existing storage overpacks or modules with standardized overpacks that consist of a single design. The standardized overpack could be a vertical or horizontal storage method or even one of each in an effort to reduce the design and operation variables and permit a more simplified process at the ISF. This alternative would also use a reinforced concrete storage pad to support the storage systems. The storage pads would be designed to store up to 50 vertical overpacks or horizontal modules like in Alternative 1.

### Pros

- A single overpack design would simplify overpack fabrication. Up to 6 overpacks or modules would need to be fabricated in Alternative 1 yet Alternative 2 could lower that number to one and reduce equipment as well as the number of variations that the crew would need to be trained for and execute.
- The concrete pad design would only need to consider one storage type rather than 13, reducing the analyses, design and licensing time.
- If the standardized overpack were a horizontal module to store all the DSCs, a canister transfer facility would not be required. (However, it should be noted that in order to transfer vertical DSCs into a storage module, the transport cask would need a removable port on the bottom side to engage the ram that slides the DSCs into the vault. Therefore, some costs would be expended to change the transport cask design and licensing albeit much less than a canister transfer facility.)

### Cons

- Obtaining a single license could be difficult with the four vendor's proprietary designs. The industry is highly competitive so it is unlikely that any one of the four vendors would be willing to release design information to one of its competitors or even a third party. To force such a move would cost time due to legal challenges. Because of this, it might be more prudent to let each vendor develop and license their own standardized overpack that is universal in size with all the overpacks. Of course, this raises the potential of 4 distinct fabrication processes which is better than 6 but not as efficient as one. Increasing the number of overpack designs eventually defeats the advantage of having a standardized overpack.
- No standardized overpack exists so it would take at a year or two to design and two to three more years to license. Since the overpack would house a number of DSC types, the design would have to prove to the NRC how all parameters (structural, thermal, radiological) are accomplished within a single design. DOE's Strategy for an operational Pilot ISF by 2021 could be challenged.
- A one-size-fits-all overpack would have to accommodate 13 different sizes of DSCs. There are also more DSC designs beyond the 12 shutdown reactors which would need to be figured into the single overpack plan. The overpack would need to be constructed for the largest DSC. This would in turn necessitate design and fabrication provisions for the smaller DSCs such as shims or spacers to insure they would not: 1) be battered around during an earthquake, or 2) require ventilation ducting to insure adequate heat removal.
- Horizontal DSCs cannot be lifted from the lid and would therefore require some type of lifting cage to lift and place into a vertical position. This is not a difficult task but it would add steps to the canister transfer process and the lifting cage would accrue additional costs.
- Placing vertical DSCs in a horizontal position or horizontal DSCs in a vertical position requires analysis and licensing time. Performing the new analyses required to store DSCs in a different position would be very involved and possibly difficult. Design features would need to be accommodated in a difference storage positions. A thermal analysis would need to be performed to show the DSC could release enough heat to keep all the UNF and DSC material below design limits. A structural analysis would need to be performed to determine, for example, how a vertical canister responds to an earthquake when stored in a horizontal module. Significant loads where the canister contacts the rails would need to be analyzed. A shielding analysis would need to be redone for each case. Dose rates may not be prohibitive when a vertical canister is stored in a horizontal module, and vice versa. The dose rate numbers associated with each case would be different and they would need to be determined by analysis and documented. Therefore, the use of a single vertical overpack and a single horizontal module would be most efficient and avoid unnecessary analyses.



- Like Alternative 1; a canister transfer facility would be required to accommodate vertical canister transfer and to re-package the horizontal canisters into a lifting cage. This large facility would increase the cost of the Alternative.

### Alternative 3, Storage In An Underground Storage System

Alternative 3 does away with pad storage altogether and places each DSC into an underground silo. The Holtec UMAX system utilizes this type of storage method and is in the process of being licensed by the NRC. No ISFSIs currently are in operation to prove the merits of this system but there are two ISFSIs under development using the UMAX system expected to be operational in the next 2 -3 years. Like Alternative 2 this storage alternative creates a single overpack that stores all the DSCs. An artist's view of a Pilot ISF using an underground storage system is shown in Figure 4.

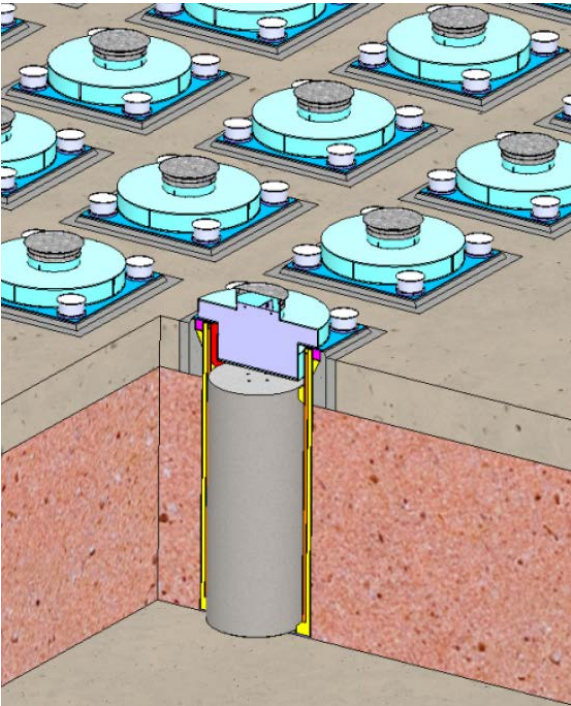


Figure 4 – Holtec UMAX Storage System

#### Pros

- Accomplishes the single overpack concept promoted by Alternative 2.
- Removes the possibility of overpack tipover or sliding caused by an earthquake since the DSC is locked into position within the ground.
- Greatly reduces direct radiation from the sides of the DSC by using the earth as a shield.
- Minimizes security concerns since the DSCs are underground, and are more protected from design basis explosions or unauthorized intrusions. In addition, security staff can observe the entire storage area since the system lids protrude only a few inches above the ground.
- The storage system is visually obscured.
- Once the UMAX is licensed, the SAR can be referenced into a Site Specific license reducing the overall licensing duration.

#### Cons

- Like Alternative 2, this storage method needs to obtain a single license for systems owned by four different vendors. Unlike Alternative 2 however, this is a patented design that does not lend itself to allowing each vendor to develop and license their own storage silo. Therefore, the use of this method may incur proprietary conflicts that will cost time and money to overcome legal issues.
- The underground storage system replaces ongoing overpack fabrication activities at the ISF (a good thing) with construction of large sections of the storage area at one time. But unlike pads that can be poured as the Pilot ISF grows, the large sections of the underground storage system must be constructed together. The system is designed with a large reinforced base pad, steel silos, soil or low strength concrete around each silo, an upper reinforced concrete pad and the silo lids.
- The underground storage method is also a one-size-fits-all system that would have to accommodate all the different DSC sizes. The underground silo would need to be constructed for the largest DSC. This would in turn necessitate design and fabrication provisions for the smaller DSCs

such as shims or spacers to ensure they would not be battered around during an earthquake or ducting to insure adequate heat removal.

- Horizontal DSCs cannot be lifted from the lid and would require some type of lifting cage to lift and place it into a vertical position. This is not a difficult task but it would add steps to the canister transfer process and the lifting cage would accrue additional costs.
- Placing horizontal DSCs in a vertical position would require additional analyses. New thermal, structural and shielding analyses would need to be performed to show the horizontal DSCs could be placed in the vertical position without adverse effects.
- Like Alternative 1; a canister transfer facility would be required to accommodate vertical canister transfer and to re-package the horizontal canisters into a lifting cage. This large facility would increase the cost of the Alternative.
- The underground system may not be as easily inspected as with above ground systems. As aging becomes more important with longer UNF storage times, the ability to inspect and ensure the system is not deteriorating over time is heightened.

#### **Alternative 4, Below Grade Vault Storage**

Like Alternative 3, the use of a vault does away with pad storage and places each DSC into a large single structure that is self-contained. The ISFSI at the former Fort St. Vrain (FSV) reactor site in Colorado shown in Figure 5 uses vault storage. Fort St Vrain is an above grade vault. Vaults are designed as robust hardened reinforced concrete structures. The vaults are typically laid out so that the DSCs can be hung from a concrete floor much like a test tube rack. An overhead bridge crane can access the entire vault storage area and provides the means to move DSCs from the unloading point to its designated storage slot. Cooling of the DSCs is accomplished through passive stack effect from an inlet vent in the side of the vault through the storage area to a chimney with a height designed to draw the desired amount of air flow. The entire facility is enclosed with walls and a roof. The vault width is typically limited to the span of the bridge crane and can be of various lengths to accommodate the desired storage capacity.

The below grade vault would be designed so that the ground level would be at the operating floor and the storage area would be below grade.



Figure 5 – Fort St. Vrain ISFSI Vault Storage

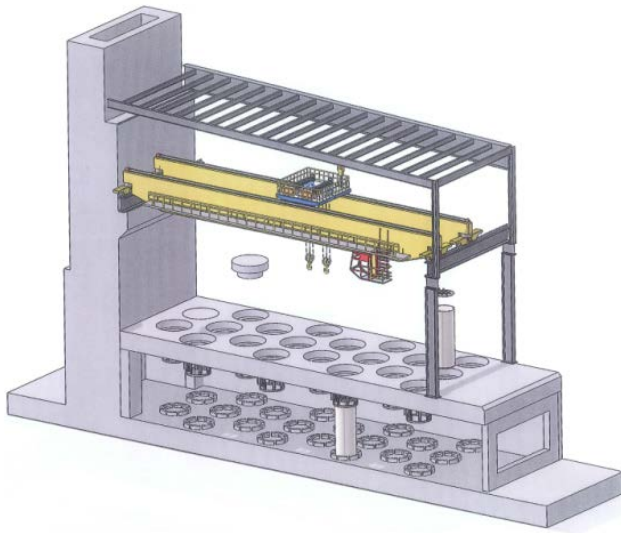
#### Pros

- Since the DSC storage is effectively indoors, the vault Alternative may provide a more controlled environment than other Alternatives. The DSCs are stored within the building largely away from the effects of weather (although there is some effect since the cooling air is drawn into the building past the DSCs. The DSCs would likely feel humidity changes during wetter weather and temperature changes between summer and winter).
- All operations such as cask offload, canister transfer from the transport cask to the vault and storage are maintained within the structure. Once the railcar enters the facility there are no outdoor operations. A canister transfer facility would not be required since all canister transfer operations would be performed in the vault.

- A vault shields DSCs from view, easing security concerns.
- The below grade vault positions the DSCs so that direct radiation from the sides of DSCs is shielded by the ground.

### Cons

- Unlike other storage methods, vault storage for large commercial DSCs is still conceptual. Canisters stored in existing vaults do not have the increased performance issues such as weight and thermal loading characteristic of commercial DSCs. Since the performance capability of a vault is unknown, rigorous analyses will need to be performed to show that the vault could perform as desired.
- A vault is a large nuclear structure impacted by potential seismic, construction, cost overrun issues typically associated with large nuclear projects. In order to store 450 DSCs, a vault 100 ft in width would need to be about 800 ft long increasing the complexity of the structure.
- Design time and licensing would be extensive and involve much more time than the other storage methods. The FSV vault is a site specific license and cannot be referenced under a General License nor has the NRC licensed a vault system for large commercial DSCs. The performance characteristics of a vault would need to be licensed as part of the Pilot ISF Site Specific License which would require considerable development in the ISF SAR costing more NRC reviewing time. The duration to design, resolve technical issues, license and construct a vault most likely cannot be accomplished for a Pilot ISF start date of 2021.
- Like Alternative 2 and 3, this storage method needs to obtain a single license for systems owned by four different vendors. Therefore, the use of this method may incur proprietary conflicts that will cost time and money to overcome legal issues.
- The vault is a one-size-fits-all system that would have to accommodate all the different DSC sizes. Each floor opening would likely be the same diameter which would require some means to keep smaller DSCs secure. This would necessitate design and fabrication provisions for the smaller DSCs such as shims or spacers to ensure they would not be battered around during an earthquake.



- Most DSCs in existing dry fuel storage systems are much hotter than the FSV canisters. The study performed by CB&I determined that heat removal using stack effect in a vault is limited to thermal outputs much less than the licensed limits in existing storage methods. Some newer DSCs with hotter UNF may not be able to be adequately cooled in a vault which would require longer pool cooling prior to storage.

- Like Alternatives 2 and 3, the horizontal DSCs cannot be lifted from the lid and would require some type of lifting cage to lift and place into a vertical position. This is not a difficult task but it would add steps to the canister transfer process and the lifting cage would accrue additional costs.

Figure 6 – Vault Bay for Commercial DSC Storage.

A model of a single bay of a vault showing the crane, storage positions, and the chimney used to passively cool the DSCs is shown in Figure 6.

### **Alternative 5, Above Grade Vault**

This Alternative is nearly identical to the below grade vault except that the ground level is at the vault floor rather than the operating floor.

#### Pros

- The above grade vault shares all of the advantages as the below grade vault except one; since the storage area is above grade, the ground does not provide any radiation shielding of the DSCs. The walls of the structure itself would need to be thick enough to shield the DSC radiation.

#### Cons

- The above grade vault shares the disadvantages of the below grade vault with additional disadvantages.
- The above grade vault would be taller than the below grade vault exacerbating seismic design issues increasing design and construction costs.
- The vault walls surrounding the DSCs may need to be designed to withstand a design basis explosion since they are not protected by the ground as in the below grade vault. This disadvantage can be resolved with longer standoff distances to security boundaries.

## **LARGER INTERIM STORAGE FACILITY**

The Larger ISF would be an expansion of the Pilot ISF with more storage capability such that additional UNF could be handled from other shut-down and/or operating reactors. The capacity of the larger ISF is currently targeted at 10,000 MTHM (inclusive of the 5,000 MTHM in the Pilot ISF).

Although the Larger ISF could be a second ISF, it is more likely to be co-located with or an expansion of the pilot facility and/or with a geologic repository.

Currently, nearly all commercial nuclear plant sites utilize transportable DSCs at their ISFSIs. At the end of 2014, approximately 20,000 MTU of UNF was stored in over 1,500 DSCs of various designs, representing approximately 75 percent of the total UNF currently in dry storage. Another 2,200 MTU of UNF is stored in 166 DSCs ready to be licensed for transport at some point in the future and 3,150 MTU is currently stored in 288 canisters not designed for transport. The balance of UNF currently stored at ISFSIs is stored in bare fuel casks, both transportable and non-transportable.

Of the total 140,000 MTU estimated to be ultimately discharged by reactor sites, a large majority of the UNF is likely to be stored in DSCs. New reactors that are under construction or planned will also likely utilize DSCs thereby adding to the number of DSCs that need to be retrieved. Therefore, retrieving DSCs from reactor sites and storing them at the ISF is necessary to address the majority of the government's UNF collection burden. The Larger ISF is targeted to begin operation in 2025 and continue through license expirations of all reactor sites (approximately 2055) plus 20 to 30 years until the UNF is cool enough to enable transport.

The Pilot ISF would continue operating as designed and evolve into the Larger ISF by simply expanding the number of storage units. The same "essential equipment" used in the Pilot ISF would serve the Larger ISF needs. Since there would not be any need to open canisters, the Larger ISF would continue to operate as a "start clean, stay clean" facility.

UNF stored in DSCs would be retrieved from all of the operating reactor sites. However, since the plants are in operation, much of the UNF is freshly out of the reactor and must cool for a prescribed time before

it can be loaded for transportation because transport casks generally require longer cooling times than storage systems.

In addition, many reactors are discharging fuel with increasingly high burn-up (HBU) fuel and very few transport casks are presently licensed to ship HBU fuel, though transport cask vendors are currently pursuing licensing of their transport casks for HBU fuel. Additional research and development (R&D) will be needed to qualify HBU fuel for transport.

The Larger ISF would be designed to initially store 10,000 MTU (approximately 900 DSCs), depending on the capacity of future DPCs.

Each of the Alternative storage methods was applied to the Larger ISF to determine if there were any additional pros or cons due to the larger storage area. The following additional pros and cons were determined:

#### Pad Storage

- No additional pros or cons were noted for a Larger ISF. The number of pads and storage units increase proportionally with the number of DSCs.

#### Standard Overpacks

- No additional pros or cons. The number of pads and standardized storage units increase proportionally with the number of DSCs.

#### Underground Storage

- No additional pros or cons. The number of underground storage units increase proportionally with the number of DSCs.

#### Below Grade Vaults and Above Grade Vaults

- Additional storage at vaults creates some difficulties. Vaults nearly a 1,000 ft long are not likely to be lengthened in order to provide more storage. Therefore, additional vaults would be required. The initial Pilot ISF vault contained the equipment and necessary provisions to offload the transport cask and perform canister transfer operations. A second vault could also incorporate these functions providing the rail line could be added to the second vault. However, this would seem to be more difficult as subsequent vaults are added. Perhaps a better method would be to employ the offload and canister transfer capabilities into the first vault and then use wheeled or tracked transporters to move the DSCs from the first vault to the second vault, and so on. This would maximize the use of the equipment and provide cost reductions for additional vaults.

## **CONCLUSIONS**

The pros and cons of each alternative are summarized in Table 2.

TABLE 2. Summary of Pilot Alternatives.

Alternative	Pros	Cons
1. Pad Storage-Current Overpacks	<ul style="list-style-type: none"> <li>• Quickest and easiest to implement – already licensed</li> <li>• Performance capabilities are known</li> <li>• Can be implemented incrementally over time</li> <li>• Can easily be expanded</li> </ul>	<ul style="list-style-type: none"> <li>• Some licensing revisions may be required</li> <li>• Equipment is needed to accommodate 13 systems</li> <li>• Canister transfer facility required for vertical systems</li> <li>• Multiple systems complicate pad analysis</li> <li>• Multiple overpack designs to fabricate</li> </ul>
2. Pad Storage-Standard Overpacks	<ul style="list-style-type: none"> <li>• Simplifies overpack fabrication</li> <li>• One storage overpack to consider for pad design</li> <li>• Canister transfer facility could be eliminated if the standardized overpack is horizontal modules (if vertical DSCs can be licensed for horizontal position)</li> <li>• Can easily be expanded</li> </ul>	<ul style="list-style-type: none"> <li>• Obtaining a single license difficult with multiple vendor proprietary designs</li> <li>• Design and licensing time for overpack required</li> <li>• Not an efficient design for smaller DSCs</li> <li>• Horizontal DSCs require lifting cage</li> <li>• Placing vertical DSCs in horizontal position or vice versa complicates design analyses</li> <li>• Canister transfer facility required for vertical systems</li> </ul>
3. Underground System	<ul style="list-style-type: none"> <li>• Accomplishes standardized overpack concept</li> <li>• Removes overpack tipover potential by earthquake</li> <li>• Provides better radiation shielding using the earth</li> <li>• Minimizes security concerns</li> <li>• Is visually obscured</li> <li>• Reduces site specific licensing duration once UMAX is licensed</li> <li>• Can be expanded in sections</li> </ul>	<ul style="list-style-type: none"> <li>• Obtaining a single license difficult with multiple vendor proprietary designs</li> <li>• Large sections of storage area construction required up front</li> <li>• Not an efficient design for smaller DSCs</li> <li>• Horizontal DSCs require lifting cage to place in vertical position</li> <li>• Horizontal DSCs placed in vertical position requires additional design analyses</li> <li>• A canister transfer facility required</li> <li>• More difficult to inspect</li> </ul>
4. Below Grade Vault	<ul style="list-style-type: none"> <li>• More controlled storage environment</li> <li>• All operations are maintained within the structure</li> <li>• Shields DSCs from view easing security concerns</li> <li>• Provides better radiation shielding using the earth</li> </ul>	<ul style="list-style-type: none"> <li>• Storage concept with commercial DSCs unproven</li> <li>• Complicated nuclear structure increases engineering and construction costs</li> <li>• Extensive design and licensing time</li> <li>• Obtaining a single license difficult with multiple vendor proprietary designs</li> <li>• Not an efficient design for smaller DSCs</li> <li>• Thermal performance capability limited</li> <li>• Horizontal DSCs require lifting cage to place in vertical position</li> <li>• Expansion will likely not be an extension of the vault but additional vaults</li> </ul>
5. Above Grade Vault	<ul style="list-style-type: none"> <li>• More controlled storage environment</li> <li>• All operations are maintained within the structure</li> <li>• Shields DSCs from view easing security concerns</li> </ul>	<ul style="list-style-type: none"> <li>• Storage concept with commercial DSCs unproven</li> <li>• Complicated nuclear structure increases engineering and construction costs</li> <li>• Extensive design and licensing time</li> <li>• Obtaining a single license difficult with multiple vendor proprietary designs</li> <li>• Not an efficient design for smaller DSCs</li> <li>• Thermal performance capability limited</li> <li>• Horizontal DSCs require lifting cage to place in vertical position</li> <li>• Taller vault complicates seismic design</li> <li>• Resistance from design basis explosion limited</li> <li>• Expansion will likely not be an extension of the vault but additional vaults</li> </ul>

## **REFERENCES**

1. “Blue Ribbon Commission on America’s Nuclear Future,” Report to the Secretary of Energy, U.S. Department of Energy, Washington, D.C., 2012.
2. “Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste,” U.S. Department of Energy, Washington, D.C., 2012.
3. “A Project Concept for Nuclear Fuels Storage and Transportation” U.S. Department of Energy, Washington, D.C., 2013. FCRD-NFST-2013-000132

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