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# Design Concepts and Options for Consolidated Interim Storage of Spent Nuclear Fuel in the United States

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**Abstract.**

The United States Department of Energy (DOE) is beginning to lay the groundwork for implementing interim storage of spent nucleat fuel (SNF) as recommended by the Blue Ribbon Commission on America's Nuclear Future (BRC). 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 SNF. The BRC's report to the Secretary of Energy was published on January 26, 2012[1]. The Administration's Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste was released on January 11, 2013[2]. The Strategy includes a phased, adaptive, and consent-based approach to siting and implementing a comprehensive management and disposal system.

As part of a series of ongoing foundational activities the DOE has completed initial studies to more fully develop and document a suite of generic design alternatives for an away from reactor interim storage facility focused on the receipt and storage of SNF in welded canisters. Concepts developed include:

- The currently deployed and U.S. licensed above grade vertical and horizontal storage systems associated with each canister design.
- A standardized storage overpack.
- Below grade cylindrical vertical storage cavity and closure lid that provides radiation shielding and structural protection during storage.
- Vault System above and below grade.

This paper will review some of the design concepts developed.

## 1. Commercial Spent Nuclear Fuel Inventory in the United States

Commercial Nuclear Power Reactors (NPRs) have operated in the U.S. since about 1960. A total of 130 commercial NPRs have been built for civilian nuclear power generation. Nine of these were early prototype or demonstration reactors which have since been or are in a state of being decommissioned and for which Spent Nuclear Fuel (SNF) no longer remains on site. The high temperature gas cooled Fort St. Vrain demonstration reactor which was also decommissioned and the SNF is stored in a DOE Independent Spent Fuel Storage Installation (ISFSI) near the reactor site. Of the remaining 120 NPRs, one was never operated at power to make electricity and was decommissioned. A second was disabled and the fuel debris is owned by the DOE and stored at the Idaho National Laboratory (INL).

Therefore, 118 commercial power reactors have SNF remaining on site in pools or dry storage casks. Of these, 19 reactors have shut down, currently leaving 99 NPRs licensed to operate. There are 4 new reactors under construction and 2 reactors being completed where the construction had been previously suspended. The General Electric facility at Morris, Illinois is currently the only Nuclear Regulatory

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Commission (NRC) licensed storage facility in operation that is not co-located at a reactor site. Figure 1 provides the approximate location of the SNF and identifies those sites that have implemented dry storage.

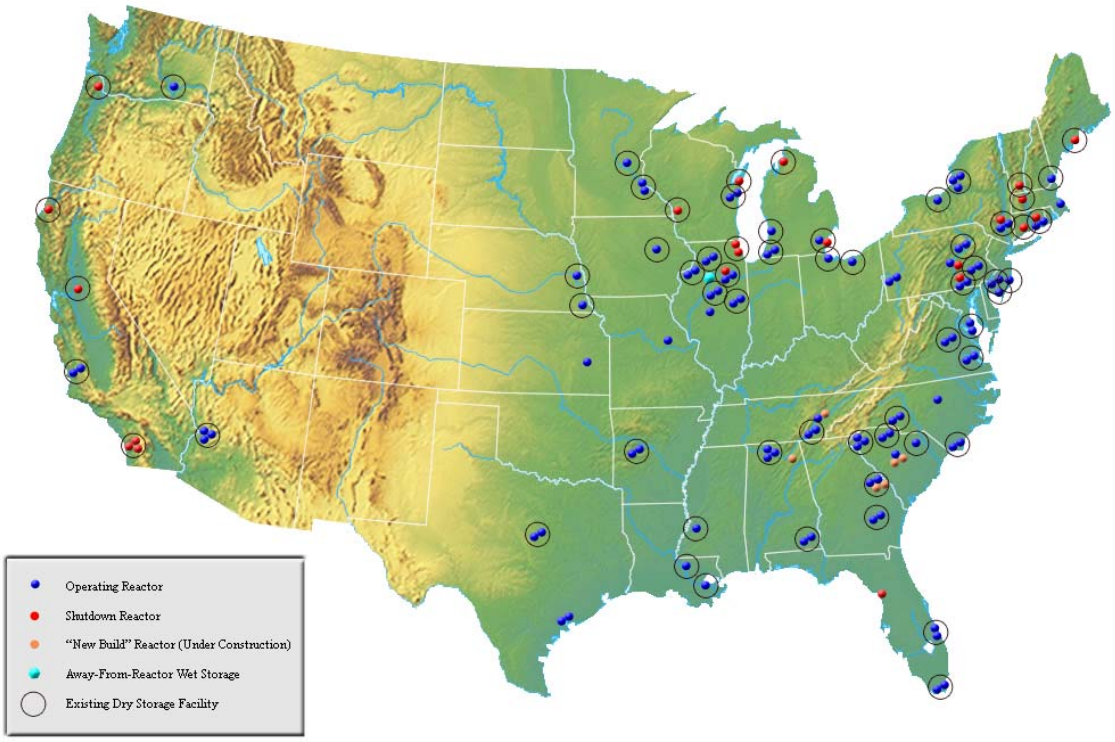


*Figure 1, Utility Owned Commercial Nuclear Power Spent Nuclear Fuel in the United States*

The 19 shutdown reactors are comprised of 4 groups. Ten reactors (on 9 sites) ceased operations prior to 2000. Reactor decommissioning is complete or nearing completion at these sites. The BRC identified these sites as "Stranded", since after reactor decommissioning, the only nuclear operations remaining will be monitoring the dry fuel and GTCC-LLW in storage. The SNF at these sites is in dry storage. Six reactors (on 4 sites) have either ceased power generation or ceased efforts to restart since 2013. These are often referred to as "Early Shutdown" reactors since they did not operate for the NRC allowed 60 years[1]. The current total number of shutdown reactors at sites with no continuing nuclear operations is 16 reactors on 13 sites. There are 3 permanently shutdown reactors on 3 sites co-located with operating reactors. Additionally Oyster Creek does not plan to operate for 60 years and has a utility-announced early shutdown date of 2019.

This shutdown reactor fuel represents a planning basis for the first consolidated Interim Storage Facility (ISF). Figure 2 provides additional details on the number of fuel casks, GTCC LLW casks, assembly count, and metric tons of heavy metal for these permanently shutdown reactors. This fuel is expected to be moved to dry storage to support site decommissioning. Figure 2 indicates the number of fuel casks loaded and those forecast. The first ISF focused on shutdown fuel could reasonably range from 250 to 660 fuel casks containing approximately 3,000 to nearly 10,000 metric tones (MT) of SNF. An additional 15 to 34 casks of GTCC-LLW generated by the decomissioning of the commercial power reactors will also be transferred to the ISF in order to completely deinventory the shutdown reactors sites of nuclear materials.

[1] The Nuclear Regulatory Commission licenses power reactors for an initial 40 year period and currently allows a single 20 year renewal period for a total of 60 years of operation.

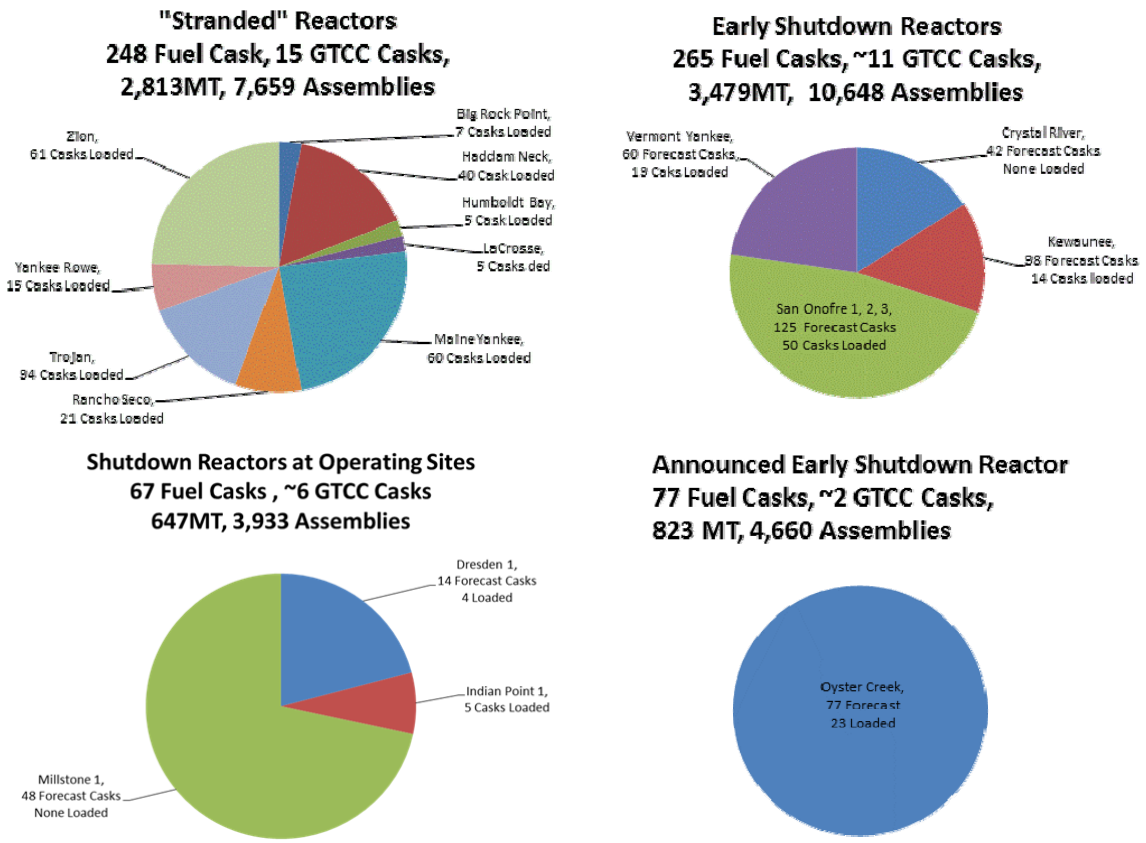


*Figure 2 Shutdown Reactor Fuel*

## 2. Currently Deployed Dry Storage Systems

During SNF loading and dual purpose canisters (DPC) transfer between the fuel pool and storage cask, a metal transfer cask provides physical protection and radiation shielding. During storage, a concrete overpack provides those functions. The storage overpack uses a bolted lid. The concrete storage overpacks provide passive heat transfer by natural convection from the DPC through air vents.

Two design variations of the canister-based system concept are vertical storage inside an overpack and horizontal storage of the DPC inside a concrete horizontal storage module. There are differences between the two systems in the concrete storage overpack design, canister orientation, and transfer process. Vertical storage overpacks are placed in arrays on the concrete storage pad. Horizontal storage modules, which are a pre-cast reinforced concrete structure, are placed side-by-side in a linear configuration on the concrete storage pad. The vertical DPC is typically transferred into a storage overpack in the nuclear plant and then transported to the concrete pad. The horizontal DPC is transported to the pad in the transfer cask and then transferred into the horizontal storage module.

Four companies provide DPC systems. AREVA Transnuclear provides horizontal storage configurations, while EnergySolutions, Holtec International, and NAC International provide vertical storage configurations. The shutdown reactor ISFSIs have deployed 10 storage systems offered by these vendors in about a 60% / 40% vertical / horizontal ratio.

The shutdown reactor canister-based systems are dual purpose; licensed under Title 10 of the Code of Federal Regulations Part 72 (10CFR72) for storage and 10CFR71 for transportation. They use a DPC where SNF assemblies are placed into a welded sealed metal container which provides the primary confinement boundary for the SNF. Table 1 summarizes the deployed shutdown reactor ISFSI storage cask systems, comprised of 21 canister families, using potentially 33 DPC varients and requiring the use of 9 transportation overpacks to move the canisters from the reactor ISFSI to the ISF.

Table 1, Commercial Overpacks and Associated Canisters

| Cask System | Canister Family | Canister | Transport Cask | Total Canisters[a] |
|---|---|---|---|---|
| Fuel Solutions | W74 | W74T | TS125 | 7 loaded |
| HI-STORM 100 | MPC-32 (HI-STORM) | MPC-32 (HI-STORM) | HI-STAR 100 | 5 loaded |
| | MPC-68 (HI-STORM) | MPC-68 (HI-STORM) | HI-STAR 100 | 70 forecast, 13 loaded, remainder canister uncertain |
| | | MPC-68F (HI-STORM) | HI-STAR 100 | |
| | | MPC-68FF | Not Available | |
| | | MPC-68M | Not Available | |
| HI-STORM TranStor | MPC-24 (TranStor) | MPC-24E (TranStor) | HI-STAR 100 | 34 loaded, canister uncertain |
| | | MPC-24EF (TranStor) | HI-STAR 100 | |
| HI-STAR 100 | MPC-68 (HI-STAR) | MPC-68 (HI-STAR) | HI-STAR 100 | 4 loaded, canister uncertain |
| | | MPC-68F (HI-STAR) | HI-STAR 100 | |
| HI-STAR 100HB | MPC-HB | MPC-HB | HI-STAR 100HB | 5 loaded |
| Standardized NUHOMS | NUHOMS 32PT | 32PT-L100 | MP197 or MP197HB | 14 loaded, canister uncertain |
| | | 32PT-L125 | MP197 or MP197HB | |
| | | 32PT-S100 | MP197 or MP197HB | |
| | | 32PT-S125 | MP197 or MP197HB | |
| | NUHOMS 32PTH1 | 32PTH1-L | MP197 or MP197HB | 42 forecast, none loaded, canister uncertain |
| | | 32PTH1-M | MP197 or MP197HB | |
| | | 32PTH1-S | MP197 or MP197HB | |
| | NUHOMS 61BT | NUHOMS 61BT | MP197 or MP197HB | 125 forecast, 23 loaded, remainder uncertain, |
| | NUHOMS 61BTH | 61BTH Type 1 | MP197HB | |
| | | 61BTH Type 2 | MP197HB | |
| | NUHOMS FC-DSC | FC-DSC | MP187 | 18 loaded |
| | NUHOMS FF-DSC | FF-DSC | MP187 | 1 loaded |
| | NUHOMS FO-DSC | FO-DSC | MP187 | 2 loaded |
| Advanced NUHOMS | NUHOMS 24PT1 | NUHOMS 24PT1 | MP187 | 17 loaded |
| | NUHOMS 24PT4 | NUHOMS 24PT4 | MP197HB | 149 forecast, 33 loaded, remainder uncertain |
| NAC-MPC | CY-MPC, 26 Assy | CY-MPC, 26 Assy | NAC-STC | 40 loaded |
| | LACBWR | MPC-LACBWR | NAC-STC | 5 loaded |
| | Yankee-MPC | Yankee-MPC | NAC-STC | 15 loaded |
| NAC-UMS | UMS-PWR | TSC-Class 1 | Universal Transport Cask (UTC) | 60 loaded, canister uncertain |
| | | TSC-Class 2 | UTC | |
| | | TSC-Class 3 | UTC | |
| NAC-MAGNASTOR | TSC PWR | TSC PWR | MAGNATRAN | 85 forecast, 61 loaded |

[a] loaded canisters as of 9/30/2014, forecast quantities based on continued use of the same system

Figures 3, 4, 5 and 6 provide photographs and illustrations of the length and diameters of selected vendor systems currently deployed.

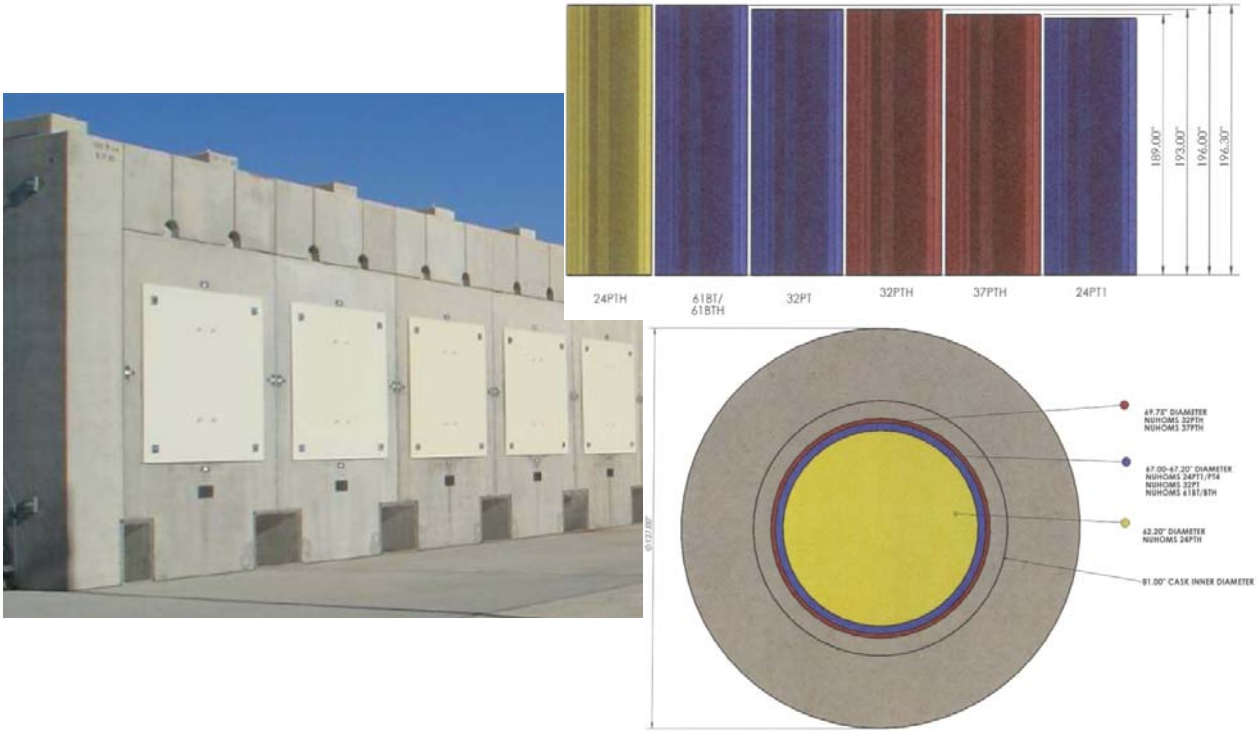


*Figure 3 AREVA Transnuclear NUHOMS Storage System*
*Licensed Canister Diameters and Lengths Illustrated*

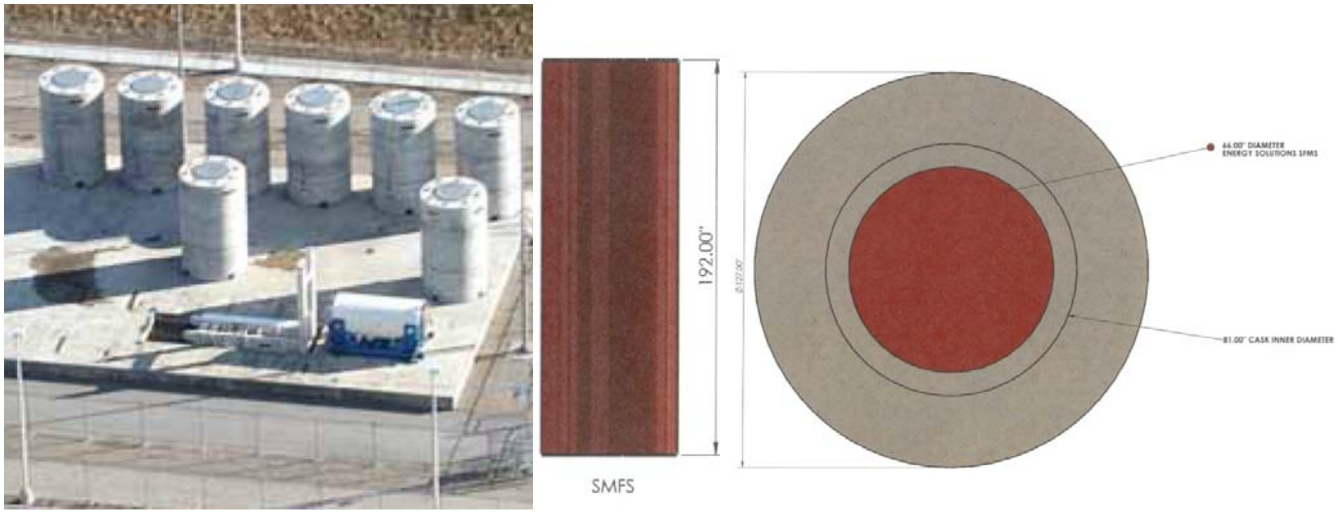


*Figure 4 Fuel Solutions Storage System at the Big Rock Point ISFSI*
*Licensed Canister Diameters and Lengths Illustrated*

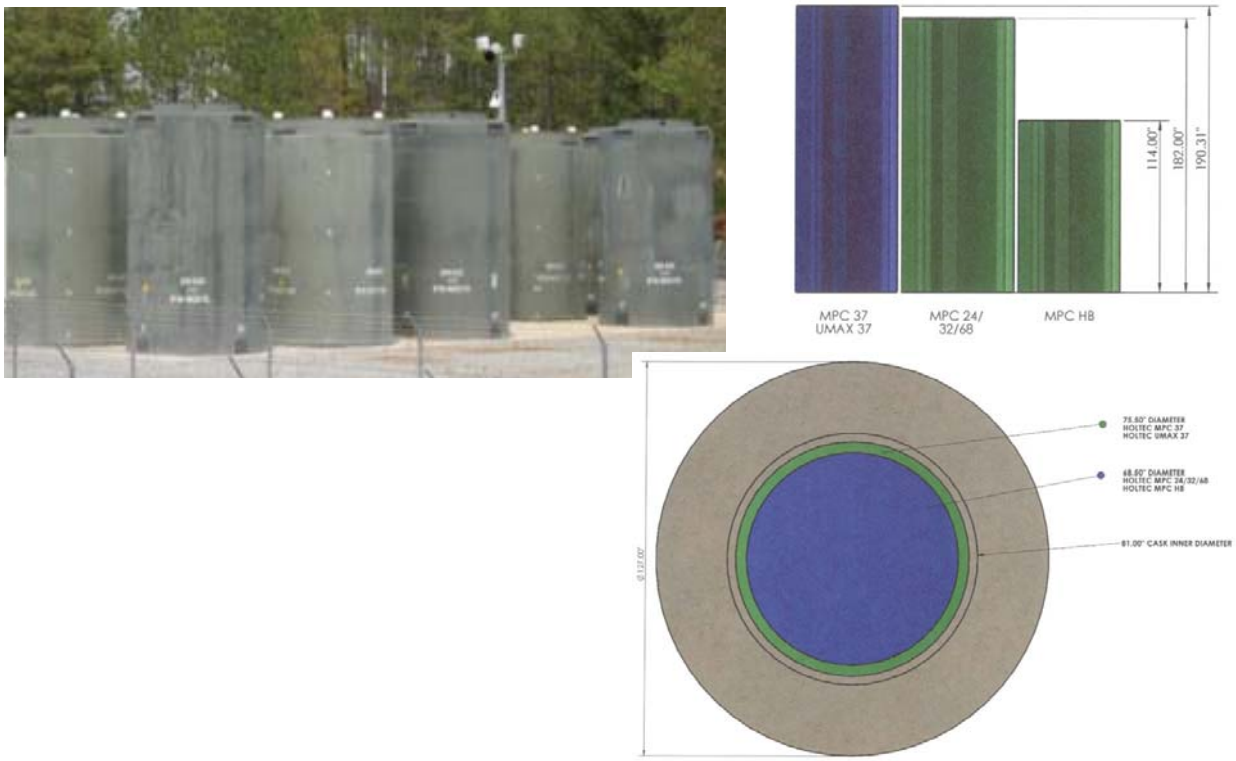


*Figure 5, Holtec HI-STORM Storage System at the Plant Hatch ISFSI*
*Licensed Canister Diameters and Lengths Illustrated*

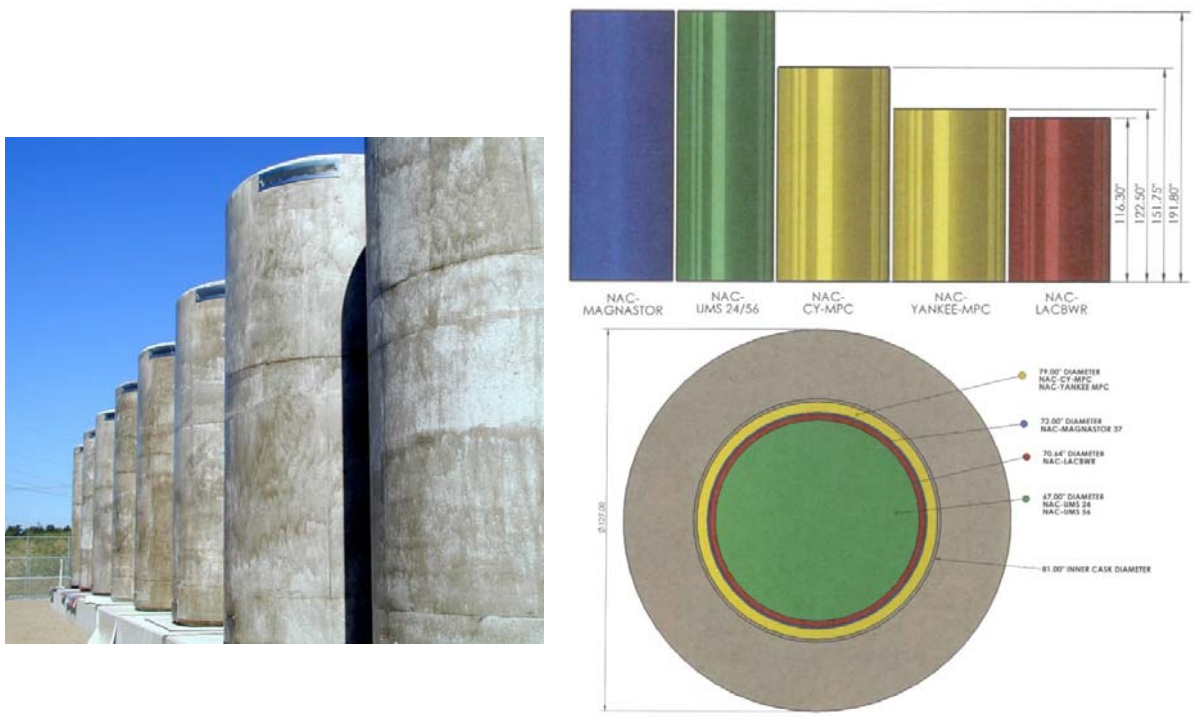


*Figure 6, NAC UMS Storage System at the Maine Yankee ISFSI*
*Licensed Canister Diameters and Lengths Illustrated*

While the ISF will be a "new" facility, DOE recognizes that the welded canisters being placed into storage are existing components and some will have been in reactor ISFSI storage for more than their

initial term authorized by the license under which they were stored at the site ISFSIs. Therefore the ISF will need to address aging management issues normally associated with an ISFSI license renewal.

## 3. Task Order 16

DOE contracted with Chicago Bridge and Iron to develop and document a suite of generic design alternatives for an ISF for the receipt and storage of the SNF and greater than Class C (GTCC) waste. The contract statement of work (SOW) required the contractor to develop concepts for "facilities and infrastructure needed to transfer large dry storage canisters from transportation casks into dry storage. This concept includes building and operating a Canister Handling Building, Canister Transfer Facility, a Storage Cask Fabrication Facility, an Administration Building, Visitors Center, and expandable storage capacity. This storage capacity is estimated to hold 5,000 MTHM received at an average rate of 1,000 MTHM/year with a maximum rate of 1,500 MTHM/year". Concepts were developed to provide DOE with maximum flexibility for additional capacity with planned execution such that expansion could be achieved in an orderly manner.

## 4. ISF Concept for Currently Licensed Storage Systems

Use of the currently licensed storage systems is a straightforward application of multiple UNF storage technologies brought together at a common site. For vertical systems, the DPC transfer from the transport cask to the Storage Overpack will require a canister transfer facility or Cask Handling Building (CHB) to simplify dry storage canister transfer operations. For horizontal systems, the transport cask will be unloaded from the railcar and the DPC transfer from the transport cask to the horizontal storage module will be performed at the pad. Figure 7 provides the conceptual layout for this alternative.

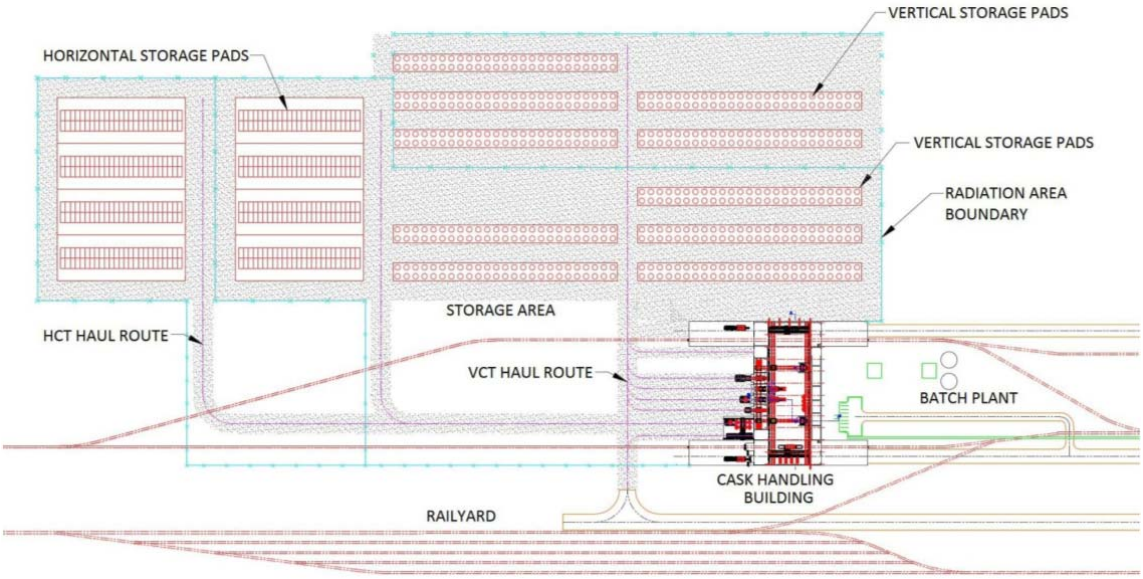


*Figure 7, ISF Concept for Currently Licensed Dry Storage Cask Systems*

The cask handling operations are impacted by several labor intensive steps that slow the overall throughput process and add radiation doses to workers. These impacts affect horizontal DPC transfer operation to some degree and vertical DPC transfer operations to a larger degree. The contactor developed cask handling building (CHB) concepts to 1) receive UNF shipments (railcar and transport cask) in an environmentally controlled and radiologically shielded area; 2) provide the facilities to offload transport casks from railcars and place them on the horizontal cask transporter for horizontal systems or 3) offload transport casks to an radiological shielded area and transfer the DPCs from the transport casks to storage overpacks for vertical systems.

The CHB concept incorporates automation features to improve throughput and operation as well as reduce radiation dose to workers. The building (Figure 8) consists of two sets of a rail bay and truck bay servicing 2 vertical type canister transfer cells.

The CHB has two dedicated 200 ton single-failure-proof overhead bridge cranes that can be used across the entire building but can travel independently from rail/truck bay to the transfer cells so that two cask handling operations can be performed at one time. When performing the operations evaluation, it was determined that a single rail/truck bay and 2 transfer cells would accommodate the required throughput of 1,500 MTU. The second half of the building is added for redundancy so that any one equipment failure will not jeopardize the required throughput.

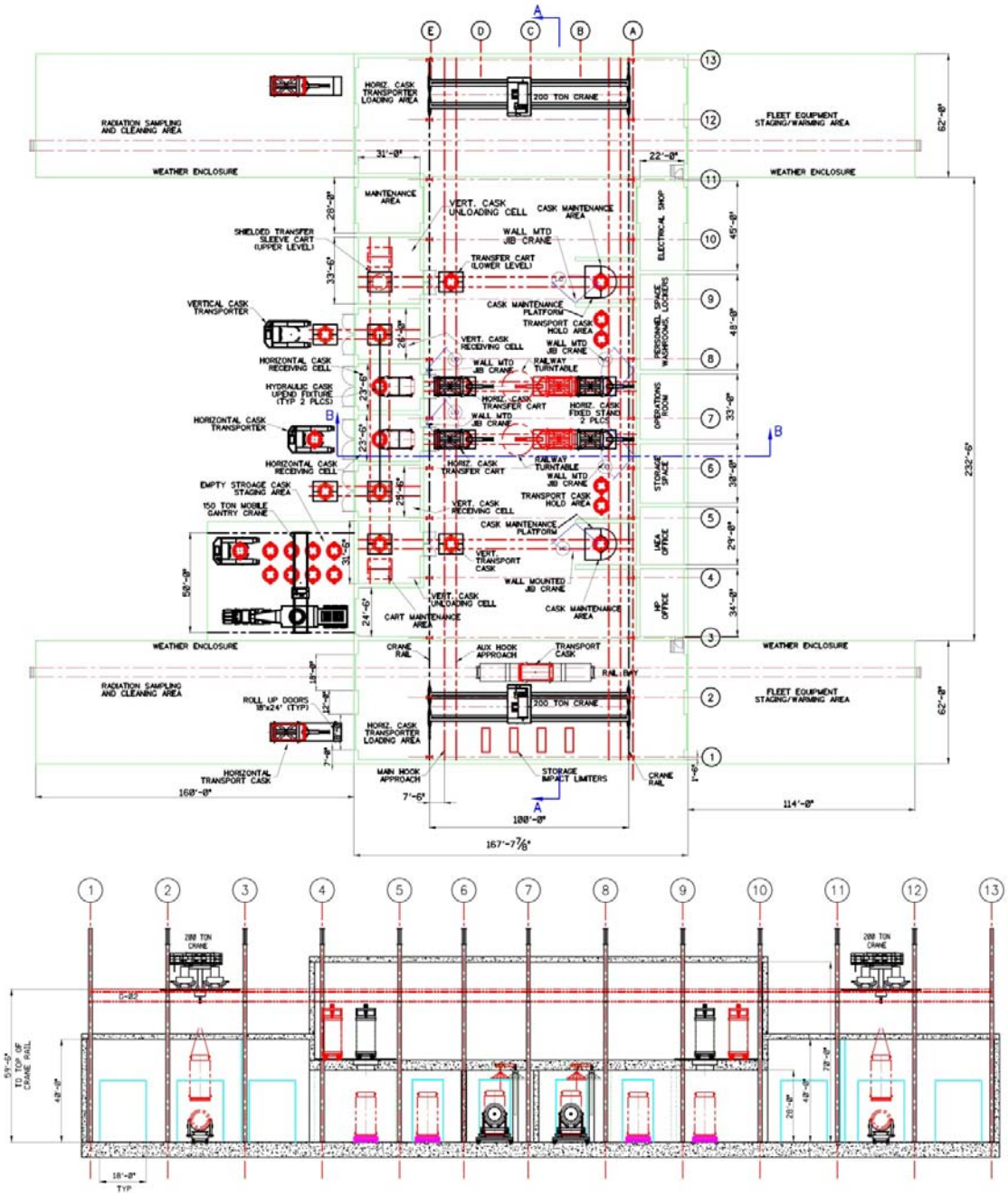


*Figure 8, Cask Handling Building for Improved Throughput and Reduced Dose Plan and Elevation Views*

## 5. Underground Storage Concepts

Another concept evaluates storage of commercial DPCs in an underground silo. Currently only Holtec International provides an underground storage system designated as the UMAX system.

The Callaway nuclear plant is constructing the first UMAX system. The UMAX storage system is an underground UNF storage concept that consists of a thick monolithic block of concrete (low strength concrete sanwiched between a top and bottom reinforced consrete pad) with embedded metallic cavity enclosure containers (CECs). Each DPC is stored individually in one of these underground CECs. Each storage location is individually cooled via passive cooling channels in the UMAX vertical ventilation module (VVM). The VVM consists of the Closure Lid, the Divider Shell and the CEC. The DPC is placed inside the Divider Shell that is concentric to the CEC with air inlets at the bottom. The air inside the Divider Shell is warmed by the decay heat from the fuel inside the DPC and rises and is released from the stack built into the Closure Lid. Cool air is drawn into the VVM via cool air inlets at the periphery of the Closure Lid and introduced into the inside of the Divider Shell via the penetrations at the bottom of the Divider Shell. The inlets and exhaust stacks on the closure lid have been designed to be able to function regardless of wind blowing across the storage site. Figure 9 illustrates the underground storage concepts.

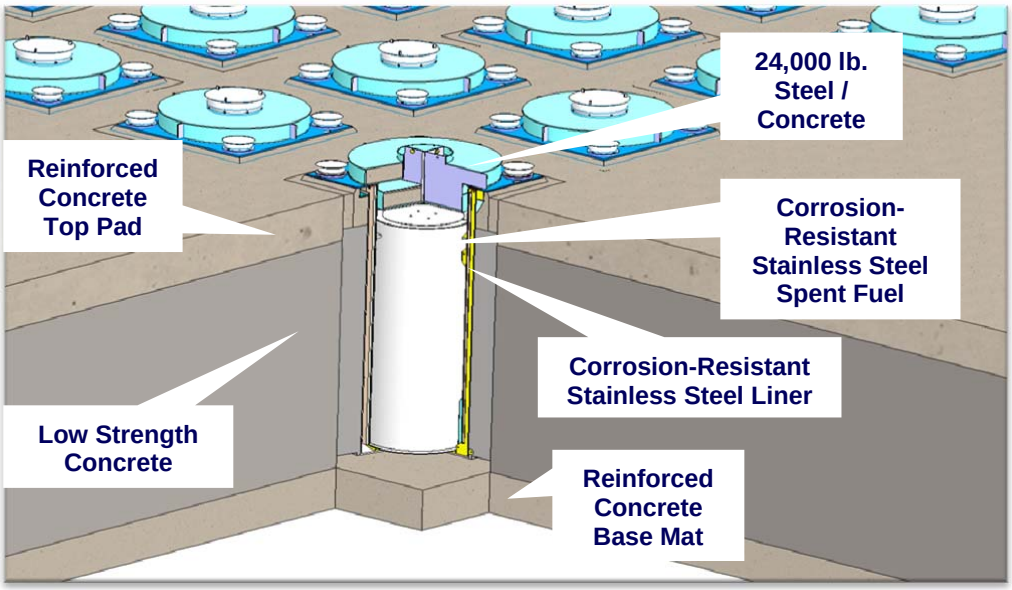


*Figure 9, Underground Storage Concept*

This approach is more resistant to seismic events than other approaches and is less exposed to environmental and other hazards than above ground approaches. It provides greater shielding for the radiation given off by the UNF in storage since it is underground. The Closure Lid is very substantial and is designed to withstand a wide range of postulated events. This concept also presents a more acceptable appearance to the public than conventional above ground SNF storage systems. More importantly, the low profile of the finished storage location makes it easier for the site security team to visually ascertain that no intruders are advancing on the site using the storage overpacks as cover for their movement.

However there are licensing challenges to adapt the wide variety of existing canisters to this concept, including the need to rotate the current horizontal configurations to a vertical orientation. Due to the existing lifting mechanisms the most direct approach to rotation involves a lifting cage and results in the assembly being turned upside down relative to its in reactor orientation. The various canister

diameters and lengths also require the use of spacers to ensure canister tipover and movement during sesimic events are acceptable.

## 6. Vault Storage Concepts

Another alternative evaluates the use of below grade, air-cooled vaults to store DPCs. Internationally, air-cooled vaults have been used to store SNF and high level wastes from reprocessing plants. An air-cooled vault design was chosen to house the SNF from the decommissioned Fort St. Vrain (FSV) High Temperature Gas Cooled Reactor.

A large shielded structure is constructed that houses an array of storage locations into which DPCs from legacy sites can be placed. It has a large service hall covered by an overhead traveling bridge crane. The floor of this hall is the shield structure covering the air-cooled vault. A shield plug is fitted into the floor over each storage location. Below this shield plug is a seismic restraint system that secures the DPC in a way that prevents movement in the event of a seismic event. The vault area beneath this shield floor is designed to encourage passive air flow around the DPCs. Exhaust stacks on one side of the vault allow the air warmed by the DPCs to escape while air inlets on the other side of the vault draw cool outside air into the building. This natural draft system provides bulk cooling to remove the decay heat from the UNF. Figure 10 illustates the below grade valult system.

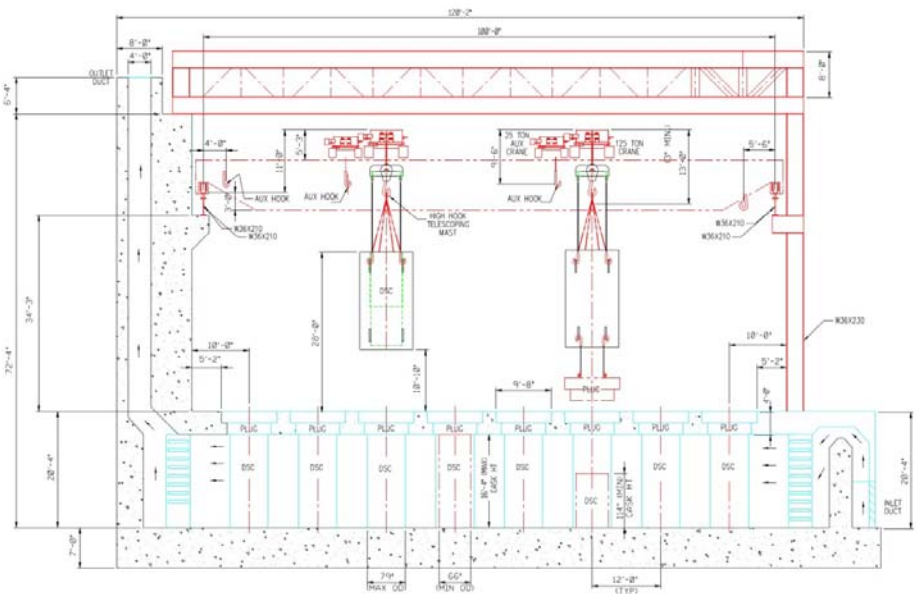


*Figure 10, Below Grade Vault Cross Section*

The concept is challenged by licensing issues similar to those described for the underground system.

**ACKNOWLEDGEMENTS**

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