Task Order 16

Generic Design Alternatives for Dry Storage of Spent Nuclear Fuel

Prepared for United States Department of Energy

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HOLTEC INTERNATIONAL

CB&I

LONGENECKER & ASSOCIATES

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To the extent that the discussions or recommendations in this report conflict with the provisions of the Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste, 10 C.F.R. § 961.11, the Standard Contract provisions prevail.

Contributing Authors

Section 1: Executive Summary	Gary Vine, Wayne Lewis
Section 2: Introduction	Gary Vine
Section 3: Study 1	Gary Vine, Charles Hess, Mike Duffy
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Section 5: Study 3	Gary Vine, Charles Hess, Mike Duffy
Section 6.1 Seismic Analysis	Bruce Brunsdon
Section 6.2 Thermal Analysis	Bruce Brunsdon
Section 6.3 Time and Motion Analysis	Charles Hess
Section 6.4 Occupational Dose Analysis	Bruce Brunsdon
Section 6.5 Equipment	Bruce Brunsdon
Section 7: Conclusions	Wayne Lewis, Dave Jansen
Appendices A1, A2, A3, A4, A5 (Study #1)	Charles Hess, Wayne Lewis
Appendix A6	David Jansen
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Project Glossary

Note: These descriptions and definitions apply only for this study.

Bare Fuel Cask—A metal cask with a bolted lid and a fuel basket inside designed for SNF storage and/or transportation. A bare fuel cask performs the confinement function during storage and the containment function during transportation. A bare fuel cask does not employ a canister.

Canister—A fully welded and inerted metal cylinder with a fuel basket inside that is placed inside an overpack for storage at an ISFSI or ISF, and into a transport cask for off-site transportation. The canister performs the confinement function during storage at the ISFSI or ISF.

Cask Handling Building (CHB)—A building at the ISF dedicated to receiving transport casks upon arrival, preparing transport casks for off-site shipment, and transferring loaded spent fuel canisters among containers, including transfer casks, transport casks, and overpacks.

Cask—A colloquial term that can mean a bare fuel cask, a transport cask, or an overpack. The term “cask,” in the context of the 10 CFR Part 72 regulations applies to bare fuel casks and dry fuel storage systems.

Cask Handling Crane (CHC)—The crane used to lift and move the transfer cask, transport cask, overpack, and/or canister.

Cask Vendor—The entity that is the design authority and supplier of a bare fuel cask, dry fuel storage system, or transportation package. The vendor is usually, but not always, the CoC holder.

Certificate of Compliance (CoC)—A 10 CFR Part 72 CoC is the document issued by the U.S. Nuclear Regulatory Commission (NRC) that indicates the acceptability of a cask or cask system for use at an ISFSI under a 10 CFR Part 72 general license or by incorporation of the design by reference into a Part 72 specific license. A 10 CFR Part 71 CoC is the document issued by the NRC that indicates the acceptability of a transportation package for use in transporting radioactive material, including spent nuclear fuel, outside the area controlled by the licensee responsible for the radioactive material. The CoC contains the terms, specifications, and conditions for using the cask, DFSS, or transportation package.

CoC Holder—The entity that holds the NRC-issued Certificate of Compliance under 10 CFR Part 72 and/or 10 CFR Part 71 for a bare fuel cask, dry fuel storage system, or transportation package design.

Consolidated Interim Storage (CIS)—The concept of transporting SNF from various locations around the country to one or more interim storage facilities to await further disposition.

Consolidated Storage Facility (CSF) – A facility designed, licensed and constructed to store, on a long term temporary basis, spent nuclear fuel from commercial reactors. The DOE Strategy uses the term Consolidated Interim Storage Facility to signify a larger facility than the Pilot ISF.

Design Life—The minimum duration for which the ISF and/or structures, systems, and components within the ISF are engineered to perform their intended function set forth in the design bases for the facility, if operated and maintained appropriately.

Dry Fuel Storage System (DFSS)—A SNF storage technology comprised of a canister inside an overpack or horizontal storage module used at an ISFSI or ISF.

Dual-Purpose Certified—The concept of designing and licensing a component, or combination of components for both SNF storage in accordance with 10 CFR Part 72 and transportation in accordance with 10 Part CFR 71. Dual-purpose designs become dual-purpose certified upon NRC issuance of the second of the two required approvals. For storage and transportation, both the component design and the contents to be stored or transported must be approved by the NRC in a 10 CFR Part 72 specific license or CoC, and a 10 CFR Part 71 CoC.

Dry Storage Canister (DSC)—a thin-walled metal container that stores SNF assemblies. DSCs are welded closed and can be placed in three different casks or overpacks that provide radiation shielding and physical protection. These three overpacks are: transfer casks (for transfer within a plant), transport casks (for shipping), and storage casks (for ISF or repository storage).

Dual Purpose Cask (DPC)—a term used interchangeably for Dry Storage Canister

Expanded ISF—An enlarged pilot ISF that can store up to 10,000 MTHM from shutdown reactor sites. For this study, a nominal 10,000 MTHM is assumed.

General License—A general license is a license that has been granted by NRC to 10 CFR Part 50 licensees to store SNF from a reactor at an ISFSI on the site of that reactor. The general license requires the use of a cask or DFSS that has received a CoC from the NRC in accordance with 10 CFR Part 72, Subpart L for the cask/DFSS design and contents.

Horizontal Cask Transporter (HCT)—A transporter designed and used to move horizontal canisters from the SNF pool to the Horizontal Storage Module in the ISFSI.

Horizontal Storage Module (HSM)—A ventilated concrete structure used to store a canister in the horizontal orientation at an ISFSI or ISF.

Important to Safety (ITS)—A term used to describe an item, function, or condition required:

- To maintain the conditions required to safely store SNF, high-level radioactive waste, or reactor-related greater than class C (GTCC) waste;
- To prevent damage to the SNF, the high-level radioactive waste, or reactor-related GTCC waste container during handling and storage; or
- To provide reasonable assurance that SNF, high-level radioactive waste, or reactor-related GTCC waste can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public or workers.

Independent Spent Fuel Storage Installation (ISFSI)—A complex designed and constructed for the interim storage of SNF, solid reactor-related GTCC waste, and other radioactive materials associated with spent fuel and reactor-related GTCC waste storage.

Interim Storage Facility (ISF)—A facility designed, licensed and constructed to store, on a long term temporary basis, spent nuclear fuel from commercial reactors.

MTHM—Metric tons heavy metal (metric tons Uranium or MTU sometimes used)

Not Important to Safety—An item, function, or condition related to the ISFSI, or its activities, that does not meet the definition of “Important to Safety.”

Operating Plant Site—A nuclear plant site with at least one operating reactor.

Overpack—A bolted lid metal cask or ventilated concrete cask used for storage of SNF in a canister at an ISFSI or ISF. Certain bolted-lid, metal overpack designs may also serve as transport casks for the SNF canisters if licensed to do so.

Owner Controlled Area – Area at a nuclear site under the control of the owner. The outer perimeter of the OCA does not necessarily require physical barriers or security controls, which typically start at the protected area boundary (an area inside the OCA)

Pilot ISF – The initial ISF designed to store SNF from shutdown reactor sites. For this study, a nominal 5,000 MTHM is assumed.

Protected Area (PA)—The area encompassed by physical barriers and to which access is controlled.

Reactor Site—A current or former nuclear generating station that has SNF stored on site and has, or had one or more reactors on the site.

Safe Shutdown Earthquake (SSE)—The earthquake that produces the ground motion for which those features of the ISF necessary for continued operation do not need to function, but must remain standing without significant damage.

Safety Analysis Report (SAR)—A document that contains the complete licensing basis for a 10 CFR Part 72 specific license, a 10 CFR Part 72 cask certification, or a 10 CFR Part 71 transport package certification.

Shutdown Reactor—A reactor that has permanently ceased operating. A shutdown reactor may be located on an operating plant site or a shutdown plant site.

Shutdown Reactor Site—A nuclear reactor site where all reactors have permanently ceased operating.

Single-Failure-Proof Lifting System—A lifting system designed such that a single failure will not result in the loss of the capability of the system to prevent an uncontrolled lowering of the load. A "lifting system," comprised of the crane, lifting devices, and interfacing lifting points, must meet the guidance of NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," Section 5.1.6, to be considered single-failure-proof.

Specific License—A license granted by the NRC to a specific entity to construct and operate an Independent Spent Fuel Storage Installation at a specific geographic location in response to an application submitted for review in accordance with 10 CFR Part 72.

Spent Nuclear Fuel (SNF)—Irradiated nuclear fuel removed from a nuclear reactor (also "used nuclear fuel").

Standardized Transportation, Aging and Disposal (STAD) canister system—A STAD system consists of a standardized canister, together with storage or aging overpack/module/vault, transfer cask, site transporter transportation overpack and transportation skid. In the future, a disposal overpack will be specified for the system, after repository requirements are known.

Transport Cask—A bolted-lid, metal container certified by the NRC in accordance with 10 CFR Part 71 for the off-site transportation of SNF. The transport cask may be a bare fuel cask or may contain a canister as part of a combined transportation package. The transport cask provides the 10 CFR Part 71 containment function for the transportation package.

Transfer Cask—A bolted-lid metal cask used to provide temporary shielding and structural protection for the spent fuel canister during SNF loading in a spent fuel pool and during transfer of the loaded canister to or from the storage overpack or transport cask. The transfer cask has lifting trunnions to permit engagement with other components such as a transfer trailer and cask handling crane lift yoke.

Used Nuclear Fuel (UNF)—Irradiated nuclear fuel removed from a nuclear reactor (also “spent nuclear fuel”).

Vault Storage System (VSS)—An alternative storage system to using casks to store the fuel-loaded canister whereby the canisters are stored in partially or fully subterranean individual silos with lids.

Vertical Cask Transporter (VCT)—A transporter designed and used to move vertical canisters from the SNF pool to the ISFSI.

Acronyms and Abbreviations

ACD	Alarm Communications and Display
ACI	American Concrete Institute
ACS	Access Control System
ADS	Access Delay System
AGV	Above Grade Vault
ALARA	As Low as Reasonably Achievable
AMP	Aging Management Program
ANS	American Nuclear Society
ASLB	Atomic Safety and Licensing Board
ASME	American Society of Mechanical Engineers
BGV	Below Grade Vault
BRC	Blue Ribbon Commission on America’s Nuclear Future
BRE	Bullet Resistant Enclosure
BWR	Boiling Water Reactor
CAS	Central Alarm Station
CCTV	Closed Circuit Television
CEC	Cavity Enclosure Container
CFR	Code of Federal Regulations
CHB	Cask Handling Building
CHC	Cask Handling Crane
CIS	Consolidated Interim Storage
CMF	Cask Maintenance Facility
CoC	Certificate of Compliance
COE	U. S. Corp of Engineers
CPU	Central Processing Unit
CRA	Control Rod Assemblies
CSF	Consolidated Storage Facility
CSNF	Commercial Spent Nuclear Fuel
CTF	Cask/Canister Transfer Facility
D&D	Decontamination & Decommissioning
DBT	Design Basis Threat
DCSS	Dry Cask Storage System
DFSS	Dry Fuel Storage System
DOE	U.S. Department of Energy
DPC	Dual Purpose Cask (see Dry Storage Canister)
DSC	Dry Storage Canister

EBS	Engineered Barrier System
ECP	Electronically Controlled Pneumatic
EIA	Energy Information Agency
EIS	Environmental Impact Statement (NRC)
EP	Emergency plan
EPRI	Electric Power Research Institute
ER	Environmental Report
FEMA	Federal Emergency Management Agency
FR	Federal Register
FSAR	Final Safety Analysis Report
FSV	Fort St. Vrain
FTE	Full Time Equivalent
FY	Fiscal Year
GPS	Global Positioning System
GTCC	Greater-than-Class C
GWD	Gigawatt-days
GWd/T	Gigawatt-days per Ton
HBU	High Burnup
HCT	Horizontal Cask Transporter
HHT	Heavy-Haul Tractor Trailer
HLW	High Level Waste
HSM	Horizontal Storage Module
HVAC	Heating, Ventilation, and Air Conditioning
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
IBC	International Building Code
ICCPS	Impressed Current Cathodic Protection System
ICS	Incident Control System
IDS	Intrusion Detection System
IEEE	Institute of Electrical and Electronics Engineers
IFA	Irradiated Fuel Assembly
IGSCC	Intergranular Stress Corrosion Cracking
ISF	Interim Storage Facility
ISFSI	Independent Spent Fuel Storage Installation
ISG	Interim Staff Guidance (NRC)
ITS	Important to Safety
LA	License Application
LEED	Leadership in Energy and Environmental Design
LLEA	Local Law Enforcement Agency

LLW	Low Level Radioactive Waste
LWR	Light Water Reactor
MCO	Multi Canister Overpack
MGR	Monitored Geologic Repository
MOX	Mixed Oxide Fuel
MPC	Multi-Purpose Canister
MRS	Monitored Retrievable Storage
MT	Metric Ton
MTU	Metric Tons Uranium
MTHM	Metric Tons Heavy Metal
MWd/MTHM	Megawatt-day per Metric Ton Heavy Metal
MUX	Multiplexers
MVDS	Modular Vault Dry Storage
NDE	Non Destructive Evaluation
NEC	National Electric Code
NEPA	National Environmental Policy Act of 1969, as amended
NFST	Nuclear Fuel Storage & Transportation
NMSS	Nuclear Material Safety and Safeguards (NRC)
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
NUREG	U.S. Nuclear Regulatory Commission Regulation
NWPA	Nuclear Waste Policy Act
NWTRB	Nuclear Waste Technical Review Board
OBE	Operating Basis Earthquake
OCA	Owner Controlled Area
OCC	Operations Control Center
OMC	Operations & Maintenance Cost
OTB	Overhead Traveling Bridge (crane)
PA	Protected Area
PAD	Concrete Pad Storage
PFS	Private Fuel Storage
PIDS	Perimeter Intrusion and Detection System
PIE	Post Irradiation Examination
PIN	Personal Identification Number
PIV	personal identity verification
PPE	Personal Protective Equipment
PPP	Physical Protection Plan
PPS	Physical Protection System
PSHA	Probabilistic Seismic Hazard Analysis

PWR	Pressurized Water Reactor
PTZ	Pan/Tilt/Zoom
PUC	Public Utility Commission
R&D	Research and Development
RA	Radiation Area
RAMI	Reliability, Availability, Maintainability, and Inspectability
RCA	Radiological Controlled Area
RCRA	Resource Conservation and Recovery Act
RM	Radioactive Material
ROM	Rough Order of Magnitude
RP	Radiation Protection
RTD	Resistance Temperature Detector
SAR	Safety Analysis Report
SAS	Secondary Alarm Station
SC	Storage Cask
SCC	Stress Corrosion Cracking
SCT	Shielded Canister Transporter
SE	Systems Engineering
SER	Safety Evaluation Report (NRC)
SFA	Spent Fuel Assembly
SFP	Spent Fuel Pool
SGI	Safeguards Information
SME	Subject Matter Expert
SNF	Spent Nuclear Fuel (used interchangeably with SNF)
SOW	Statement of Work
SRP	Standard Review Plan
SSC	Structure, System, and Component
SSE	Safe Shutdown Earthquake
STAD	Standard Transport Aging and Disposal (canister)
STC	Storage Transport Cask
STD	Standardized Storage
TAD	Transportation, Aging, and Disposal
TBD	To be determined
TC	Transport Cask
TEC	Total Estimated Cost
TLAA	Time-Limited Aging Analysis
TLD	Thermo-luminescent Dosimeter
TMS	Temperature Monitoring System

TOM	Transportation Operations Model
TOPO	Transportation Operations Project Office
TPC	Total Project Cost
TSC	Transportable Storage Canister
TSM	Total System Model
TSPA	Total Systems Performance Assessment
UL	Underwriters Laboratories
U.S.	United States
UFD	Used Fuel Disposition
UGS	Underground Storage
UNF	Used Nuclear Fuel
UPS	Uninterruptable Power Supply
USCG	U.S. Coast Guard
USDOT	U.S. Department of Transportation
UT	Ultrasonic Testing
UTC	Universal Transport Cask
VBS	Vehicle Barrier System
VCC	Vertical Concrete Cask
VCT	Vertical Cask Transporter
VDS	Vacuum Drying System
VOC	Volatile Organic Compound
VSO	Vertical Storage Overpack
VSS	Vault Storage System
VVM	Vertical Ventilated Module
WAST	Waste Acceptance, Storage and Transportation
WBS	Work Breakdown Structure
WH	Waste Handling
YMP	Yucca Mountain Project

EXECUTIVE SUMMARY

The Department of Energy (DOE) is laying the groundwork for implementing interim storage 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 (ISFs) using consent-based siting, and 2) prepare for large-scale transport of spent nuclear fuel (SNF). The BRC's report to the Secretary of Energy was published in January 2012[1]. In response, the Administration released its Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste in January 2013[2]. The Strategy includes a phased, adaptive, and consent-based approach to siting, and implementing a comprehensive management and disposal system.

The Strategy report defines these facilities:

- A Pilot ISF with limited capacity capable of accepting used nuclear fuel and high-level radioactive waste and initially focused on serving permanently shutdown reactors;
- A larger consolidated ISF, potentially co-located with the Pilot ISF and/or with a geologic repository, that provides the needed flexibility in the waste management system,
- A permanent geologic repository for the disposal of used nuclear fuel and high-level radioactive waste.

This report addresses the Scope of Work (SOW) for Task Order 16, "Generic Design Alternatives for Dry Storage of Used Nuclear Fuel," issued in March 2014 by the Department of Energy's (DOE's) Office of Nuclear Energy (DOE-NE). It develops and documents a suite of generic design alternatives for the receipt, processing and storage of the SNF and greater than Class C (GTCC) waste for the initial Pilot ISF, assuming the SNF and GTCC is derived from shutdown reactors. This report also seeks to provide DOE with maximum flexibility for additional capabilities to be developed and executed in a modular fashion such that the option for an Expanded Pilot ISF could be achieved in an orderly and cost effective manner.

It is important to note what this report does <u>not</u> include. It does not address other key elements of the Strategy that are prerequisites to achieving an operational Pilot ISF, including the consent based siting process, the transportation system needed to move SNF from shutdown reactors to the Pilot ISF, and the governance and funding elements of the Strategy. The following figure from the Strategy displays the Strategy's key elements. This report addresses the first system

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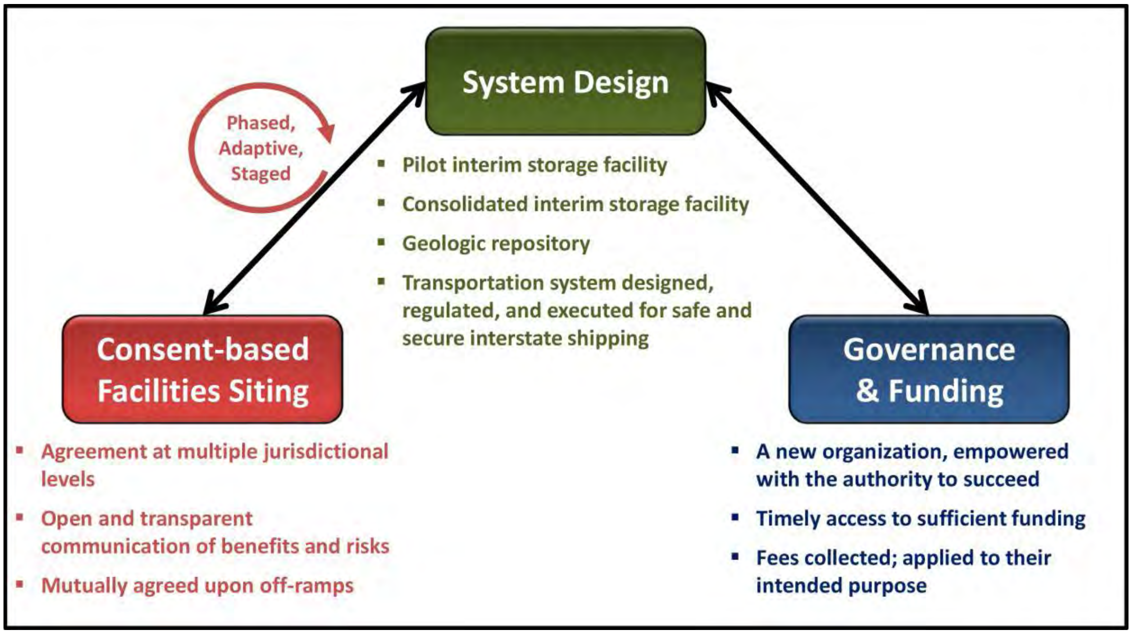
[1] http://brc.gov/sites/default/files/documents/brc_finalreport_jan2012.pdf (Ref. 2)

[2] http://energy.gov/downloads/strategy-management-and-disposal-used-nuclear-fuel-and-high-level-radioactive-waste (Ref. 3).

design strategy shown in green (the Pilot ISF), plus a limited discussion of how that Pilot ISF could be expanded, should that expansion occur at the same site.



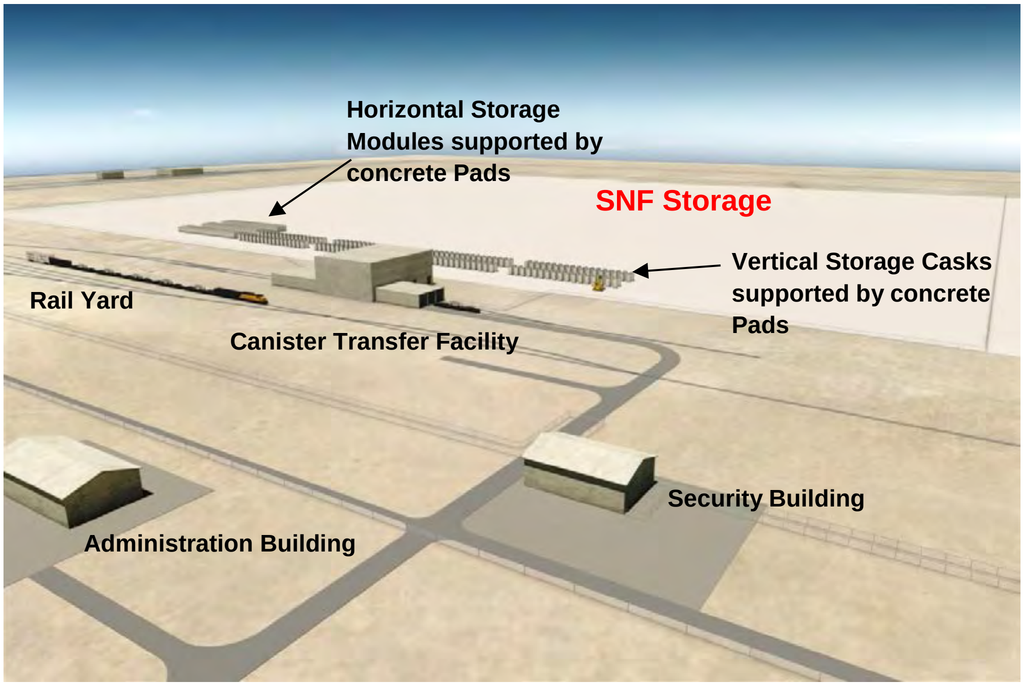
Further, this report provides DOE with a comparative basis to make decisions on which design alternative or combination of alternatives best address DOE's needs, which might depend in part on the site selected for the Pilot ISF. This would allow for collaboration with the host site on design options, considering community interests, the specific site characteristics, local infrastructure, and other factors that might impact optimum design.

The Pilot Interim Storage Facility and the Expanded Interim Storage Facility

DOE envisions various facilities and infrastructure that would be needed to transfer large dry storage dual purpose canisters (DPCs) from transport casks into dry storage. DOE's concept for the ISF includes building and operating a Cask Handling Building (canister transfer facility), a Storage Cask Fabrication Facility, an Administration Building, and a Visitors Center.

One square mile would provide ample space for the Pilot ISF and Expanded ISF. However, DOE's land purchase needs to include more land to account for other considerations. For example, the Owner Controlled Area boundary should be set at approximately ½ mile from the nearest storage unit to comply with NRC regulatory dose limits; and additional space should be added for off-site support facilities that are not part of ISF operations (e.g., rail car and cask maintenance facilities). A land purchase of at least four square miles would allow space for these considerations.

An artists' concept of what the Pilot ISF might look like follows. Rail yards and the Canister Transfer Facility are in the foreground; concrete pad storage of DPCs from shutdown plants is in the background.



Artist's View of a Pilot ISF Using Existing Storage Systems

This study employs a modular approach, based on an initial Pilot ISF capacity of 5,000 MTHM (metric tons heavy metal), with the capability to expand to 10,000 MTHM on the same site (the Expanded Pilot ISF; inclusive of the initial 5,000 MTHM). The Pilot ISF is to be initially capable of receiving and processing SNF shipments at a minimum rate of 1,500 MTHM/year. Given the current commercial storage systems, this is roughly equivalent to a capacity of 450 DPCs, with a throughput of 135 DPCs per year. Per the BRC and the Strategy, priority is given to DPCs from shutdown reactors. The Pilot ISF design is capable of receiving SNF in DPCs from shutdown reactors, without the capability to open the dry storage canisters or handle bare fuel assemblies. Since the Pilot ISF design will be modular (allowing for phased deployment), the specific shutdown nuclear power plants (NPPs) which are included in the scope of the pilot facility are not critical to the Pilot ISF design.

Dry Fuel Storage Systems

There are currently four companies that provide dry cask storage systems: Holtec International, Inc., NAC International, Inc., EnergySolutions LLC., and AREVA TN Inc. Of the four, EnergySolutions only maintains systems from legacy companies Sierra Nuclear and Westinghouse and does not provide new systems at this time.

There are two types of storage systems: cask-based and canister-based. The canister-based systems are further broken into vertical configurations and horizontal configurations. All SNF currently stored at shutdown sites is in canister-based systems. Cask-based systems are outside the scope of this report.

Dual purpose canister-based systems are licensed under 10 CFR Part 72 for storage as well as 10 CFR Part 71 for transportation. The DPC is a metal container that is welded closed after the SNF assemblies have been loaded. The DPC can be placed in three different casks or overpack configurations, which provide radiation shielding and physical protection. During handling or transfer operations at a plant, the DPC is placed in a transfer cask; for transport, the DPC is placed in a transport cask; and during storage the DPC resides in a storage overpack or module.

The storage overpack or module is a thick concrete and steel or all metal container that provides physical protection of the DPC while resting on a concrete pad, as well as radiation shielding to personnel and members of the public. Two design variations of the storage container are vertical storage of the DPC inside a concrete or metal storage overpack, and horizontal storage of the DPC inside a concrete horizontal storage module. The significant differences between the two variations are the overpack or module design, the DPC orientation, and the DPC transfer process. In vertical systems, the DPC is transferred from the transfer cask into the storage overpack by stacking the transfer cask on top of the overpack and lowering the DPC into the storage overpack or transport cask. This is typically done in a building with a large overhead crane but can be done by other lifting means such as a vertical cask transporter (VCT). In horizontal systems, the DPC is transferred from the transfer cask or transport cask at the storage module. The transfer or transport cask is resting horizontally on a special trailer with a hydraulic ram. The trailer is backed up against the storage module opening and a ram pushes the DPC into the Horizontal Storage Module (HSM).

Vertical and Horizontal System Canister Transfer Operations

Both concrete storage overpacks and storage modules provide a means for passive heat transfer by natural convection from the DPC through air vents built into the overpack or module. The metal storage overpacks provide passive heat transfer by conduction through the overpack body.

Concrete overpacks are not considered to be transportable for the purposes of this study. Therefore, prior to DPCs being shipped from the shutdown plant to the ISF in a transport cask, new overpacks must be constructed at the ISF and be ready to receive the DPCs prior to their arrival. Also prior to arrival, all of the handling equipment, including transfer casks, lift yokes, cranes etc., should be in place and ready to receive.

Design Alternatives for Storage at the Pilot ISF

This report evaluates alternative approaches that can be constructed in a modular fashion for the Pilot ISF and facilitate an orderly expansion for the Pilot ISF and future larger ISF. To accomplish this objective, three design studies were considered:

- Design Study #1. Alternative storage systems for commercial DPCs
- Design Study #2. Alternative cask handling methods and configurations
- Design Study #3. Alternative storage systems for standardized dry storage canisters

The process of evaluating the alternatives included engineering evaluations, staffing studies, time and motion studies, and cost/schedule analyses, all based on uniform assumptions that were made and applied consistently to each alternative. For example, the same support facilities were assumed for each alternative; and the same single shift rotational scheme was assumed for each. Key output variables include total cost, manning requirements, total dose to workers, throughput achieved (i.e., canisters placed in storage per week), and schedule estimates.

Design Study #1 investigated five alternative storage systems for commercial DPCs. The alternatives evaluated for storage of DPCs at the Pilot ISF and the Expanded ISF are as follows:

1. Commercial DPCs using above ground storage (currently deployed and licensed above grade vertical and horizontal storage systems associated with each DPC design). Report abbreviation: **"C-PAD"**
2. Commercial DPCs using standardized overpacks (storage of DPCs in a single universal overpack that could reduce the design and operation variables and permit a more simplified process at the ISF.). Report abbreviation: **"C-STD"**
3. Commercial DPCs using licensed and deployed underground storage (DPCs placed underground in a below grade cylindrical vertical storage silo with a closure lid). Report abbreviation: **"C-UGS"**
4. Commercial DPCs using a below grade vault (DPCs 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.). Report abbreviation: **"C-BGV"**

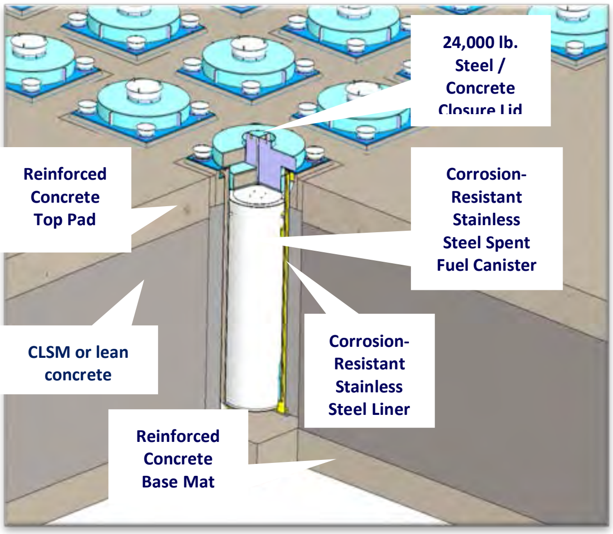
5. Commercial DPCs using an above grade vault (similar to the below grade vault). Report abbreviation: **"C-AGV"**

With **C-PAD**, SNF currently stored in vertical overpacks would be stored at the Pilot ISF in newly constructed vertical overpacks using components provided by the respective DPC supplier. SNF currently stored in horizontal storage modules would be stored at the Pilot ISF in newly constructed horizontal modules using components provided by the DPC supplier. Concrete pads with vertical and horizontal storage at existing NPPs are shown below:

Vertical DPCs in Overpacks, at the Zion ISFSI

DPCs in Horizontal Modules, at the Rancho Seco ISFSI

SNF stored in the **C-STD** alternative would appear essentially the same as C-PAD, but the vertical and horizontal overpacks would be of a standard size, capable of storing the largest DPC to be shipped to the ISF. Smaller DPCs would be accommodated in these standard overpacks with spacers. As above, SNF would be stored at the ISF in the same orientation as at the NPP.



C-UGS is shown here in both a simple graphic and an actual construction project – installing this system at the Callaway NPP in Missouri, where it will soon be operational.

DPCs will be stored underground in the UMAX system at the Callaway ISFSI

The two vault alternatives (**C-BGV and C-AGV**) would be new technology for current light water reactor SNF requiring detailed design and licensing. However, the concept has been applied to much smaller SNF canisters from a high temperature gas reactor. The photo to the left shows the licensed vault containing SNF from the shutdown Ft. St. Vrain reactor in Colorado. The study determined that a vault has limitations to passively remove heat. Horizontal storage of DPCs was determined unacceptable due to the need for active cooling and DPC retrieval difficulties.

Each of the above design alternatives were evaluated for the Pilot and Expanded Pilot ISF, and for high seismic region siting (0.75g) and low seismic region siting (0.25g). Primary differences between these evaluations were that the Expanded Pilot ISF could accept DPCs from operating reactors, and that the Expanded Pilot ISF was evaluated to handle higher processing rates (3,000 to 4,500 MTHM/year, instead of 1,500 MTHM/year, as required for the Pilot ISF (equivalent to 270 to 405 DPCs/year instead of 135 DPCs/year). This flexibility resulted in a requirement that the Cask Handling Building (CHB) contain two railbays to allow parallel handling operations. Dual railbays also provide flexibility for maintenance and training.

The following table summarizes the pros and cons of each Study #1 design alternative:

Alternative	Pros	Cons
C-PAD	• Quickest and easiest to implement – already licensed • Performance capabilities are known • Can be constructed in phases allowing earlier operations	• Multiple overpack designs to fabricate, maintain and monitor • Canister transfer facility may be required for a high throughput operation • Overpacks may need to be bolted to pad to mitigate a hypothetical tip-over at high seismic sites • Some licensing revisions may be required • Equipment is needed to accommodate 13 storage systems • Multiple systems complicate pad analysis
C-STD	• Simplifies overpack fabrication • One storage overpack to consider for pad design • Can be constructed in phases allowing earlier operations	• Obtaining single storage license difficult with multiple vendor proprietary designs • Canister transfer facility mayl be required for a high throughput operation • Overpacks may need to be bolted to pad to mitigate a hypothetical tip-over at high seismic sites • Design and licensing time required for overpack • One size fits all requires design and installation of shims • Horizontal canisters require lifting cage • Possible horizontal to vertical DPC fuel orientation concerns

Alternative	Pros	Cons
C-UGS	• No tipover due to an earthquake • Ground provides radiation shielding • Ground shields DPCs from view • Already licensed for a limited number of licensed canisters • Reduces security staffing • Can be constructed in phases allowing earlier operations	• Obtaining single storage license difficult with multiple vendor proprietary designs • Canister transfer facility may be required for high throughput operation • Large sections of storage area construction required up front • One size fits all requires design and installation of shims • Horizontal DPCs require lifting cage to place in vertical position • Possible horizontal to vertical DPC fuel orientation concerns
C-BGV	• Controlled storage environment (indoors) compared to outdoor storage • All operations are maintained within structure • Shields DPCs from view easing security concerns • Provides good radiation shielding using the earth • Removes a seismic tipover event since DPCs are locked in place • Lower bldg. / crane height	• Storage concept with commercial DPCs unproven • Large nuclear structure increases engineering and initial capital costs • Requires long design and licensing time • Thermal performance capability limited to the design of current transport casks • Obtaining single storage license difficult with multiple vendor proprietary designs • One size fits all requires design and installation of shims • Horizontal DPCs require lifting cage for vertical position • Possible horizontal to vertical DPC fuel orientation concerns • Entire vault needs to be constructed to be operational
C-AGV	• Same Pros as C-BGV except: no underground radiation shielding or lower bldg. / crane height	• Same Cons as C-BGV • Taller vault complicates seismic design • Vault wall requires radiation/explosion pressure design

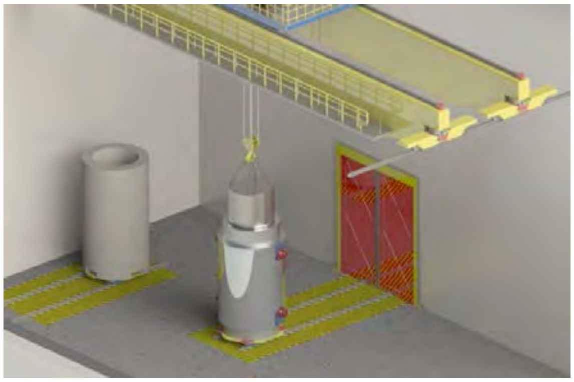
Design Study #2 evaluated various cask handling methods and configurations, given a range of DPC receipt rates. The objective was to determine which alternative methods improve time and motion for each process step in handling DPCs and reduce worker radiation doses. Successful implementation of the Pilot ISF requires more than selecting the best storage system. Equally important is careful consideration of various cask handling methods for various SNF receipt rates. State-of-the-art technologies in automation, handling equipment, etc., were evaluated to ensure that optimum operations could be matched with the optimum storage system.

Cask handling operation activities at the Pilot ISF are envisioned to be performed in a facility such as a Cask Handling Building (CHB) that receives incoming transport casks and uses the appropriate transfer cask to transfer the DPC to a storage configuration. This process can be optimized to improve efficiency, reduce cost, and reduce exposure.

The alternative cask handling configurations and methods that were evaluated under this study are as follows:

1. Current canister transfer methods used at most nuclear power plants using the system-specific transfer cask. Report abbreviation: **"C-OPS"** (shown on page 4)
2. Automated canister transfer using a fixed-movement standard transfer cask and other features that remove labor and dose intensive steps. Report abbreviation: **"A-OPS"**
3. Remote canister transfer without a transfer cask which requires a radiation shielded facility (hot cell). Report abbreviation: **"R-OPS"**
4. Simplified Cask Handling Operations that would not require a CHB but involve more labor intensive steps: **"S-OPS"**

A-OPS



R-OPS (above)

S-OPS at Diablo Canyon (below)

The results of Study #2 were useful in that a number of concepts and approaches were identified that could benefit future ISF handling operations. The table below illustrates the differences in the throughput and worker dose. For vertical DPC transfer, A-OPS decreased the time by 8 hours. Although R-OPS eliminated the use of the automated transfer cask, no substantial time was saved over A-OPS. All of the concepts require 2½ to 4 shifts per canister transfer operation. The benefit from the reduced time of R-OPS may not outweigh the remote failure recovery efforts required for a hot cell. The dose for A-OPS and R-OPS is nearly half of C-OPS - a meaningful reduction. For horizontal DPC transfer, the duration and dose is relatively the same since the transfer occurs at the storage overpack. There was a slight reduction in time using more efficient transporter technology. S-OPS, although more labor-intensive, did provide a significant opportunity for an earlier implementation schedule but with lower throughput and

15% higher doses than C-OPS. S-OPS might be a useful option to initiate storage while the CHB and other infrastructure are being constructed.

Alternative	**Storage Configuration**	**Duration of Transfer (hour)**	**Radiation Dose per Transfer (mrem) (Total Worker Dose)**	**Throughput (DPCs/week)**	**Throughput (DPCs /year)**
C-OPS, Current Typical Canister Transfer	Vertical	29	391	5	260
	Horizontal	24	203		
A-OPS, Automated Canister Transfer	Vertical	21	251	5	260
	Horizontal	22	198		
R- OPS, Remote Canister Transfer	Vertical	21	248	5	260
	Horizontal	Horizontal canister cannot be transferred remotely			
S-OPS, Simplified Canister Transfer	Vertical	29	458	1.7 to 5*	88 to 260*
	Horizontal	24	203		

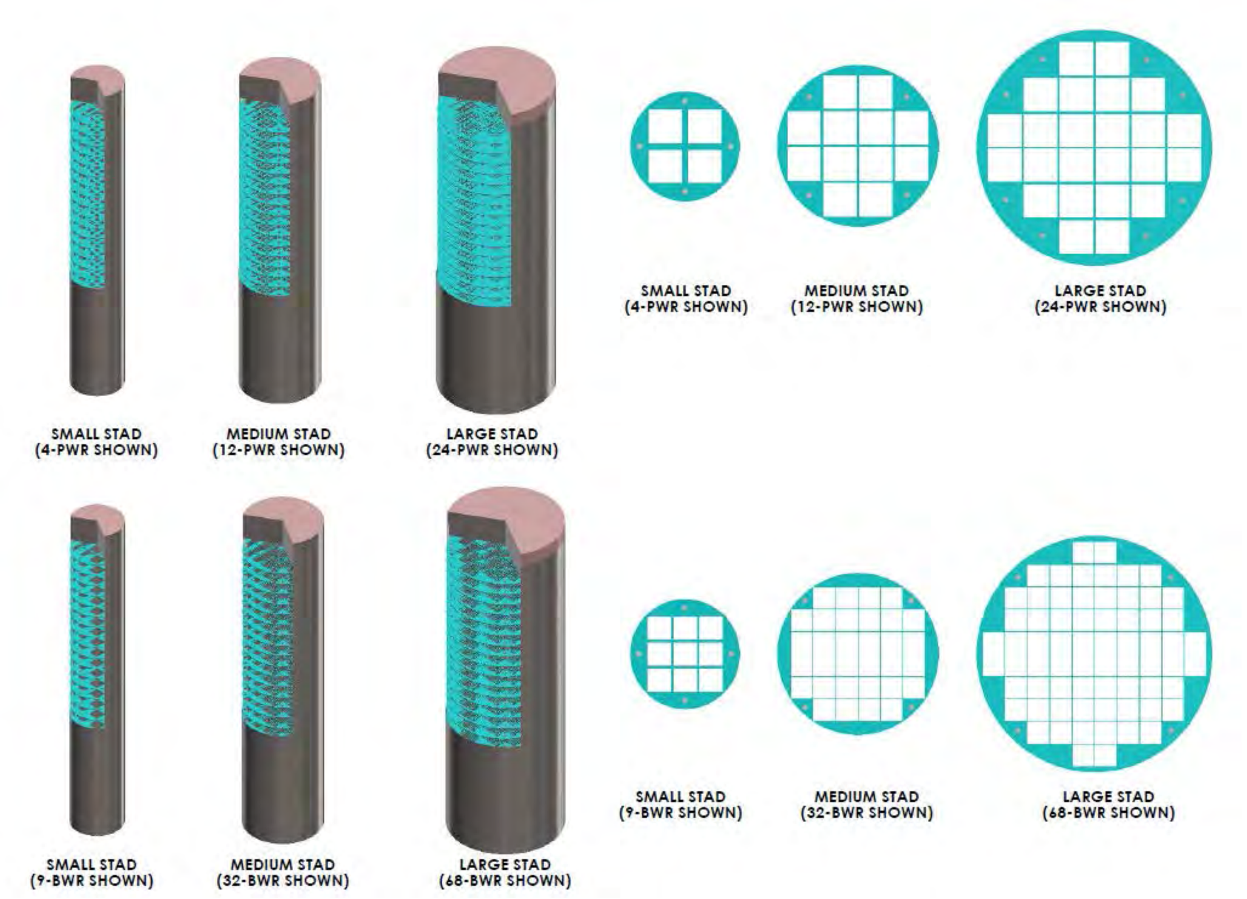
* A throughput of 5 DPCs/week requires 2 gantry cranes, 2 outdoor canister transfer facilities, 2 horizontal cask transporters and 2 vertical cask transporters.

A summary of the pros and cons for Study #2 are provided below.

Alternative	**Pros**	**Cons**
C-OPS	• Proven method of canister transfer • Equipment already licensed and deployed at existing plants	• Multiple systems/steps add time, dose, equipment • Requires Cask Handling Building
A-OPS	• Equipment replaces manual tasks • Standardizes transfer equipment • Reduces time, dose, equipment • Improves safety	• Requires Cask Handling Building • Higher cost than C-OPS • Shielding innovations required
R- OPS	• Eliminates transfer equipment • Reduces time, dose, equipment	• Requires hot cell • Failure Mitigation required • Higher cost than C-OPS
S-OPS	• No CHB - Easy to implement • Proven method of canister transfer • Licensed for use • Lowest cost	• Labor intensive; adds higher dose. Experience shows that dose may be minimized using proper precautions • Low throughput

Design Study #3 responds to the renewed emphasis on standardization of storage and transportation systems in the BRC report and the DOE Strategy. This is a challenge, given the high degree of diversity among current on-site storage systems at NPPs. However, an orderly transition to standardization, focused on optimizing systems and operations at the ISF, could reap benefits as SNF is shipped and ultimately placed in a permanent geologic repository.

Design Study #3 evaluated storage system alternatives that rely on standard SNF canisters, including ones that may be received at the ISF already loaded in “Standard Transport Aging and Disposal” or STAD canisters. Since repository requirements are not yet determined, design alternatives specified in the SOW assumed various disposal container sizes, including the following small, medium and large STADs:



Alternatives evaluated under Study #3 for storage of standard canisters at an ISF are essentially the same as for Study #1, and are as follows:

1. STAD canisters would be placed in above ground storage overpacks similar to the currently deployed above ground storage systems. Report abbreviation: **“S-PAD”**
2. Below grade storage. STAD canisters would be placed into a below ground storage similar to the underground system for Study #1. Report abbreviation: **“S-UGS”**
3. Vault System below grade. STAD canisters would be placed into a below-grade vault, similar to the vault design developed for Study #1. Report abbreviation: **“S-BGV”**
4. Vault System above grade. STAD canisters would be placed in an above grade vault similar to the below ground alternative. Report abbreviation: **“S-AGV”**

Since most STAD designs under consideration are smaller than existing commercial DPCs, they will require more shipments to move the equivalent SNF to the ISF (see table below) which increases the cask handling operations at the ISF for placement in storage. This increases staffing requirements and reduces throughput to what can be achieved for the corresponding commercial DPC alternatives examined under Study #1. Further, radiological doses per canister transfer will be similar to commercial DPC transfer resulting in increased doses for workers.

STAD	**Shipment Configuration**	**Cask Capacity**		**MTHM per Overpack**	**STAD throughput for 3000 MTHM/yr.**	**DPC throughput for 3000 MTHM/yr.**
		PWR	**BWR**			
Small	4 STADs/cask	16	36	7.3	~410	~260
Medium	1 STAD/Cask	12	32	5.4	~556	
Large	1 STAD/Cask	21	44	9.5	~316	

Since most shutdown nuclear plants have decommissioned their spent fuel pools, it is unlikely that STADs would be implemented for the Pilot ISF, but they could be employed later at the Larger ISF. No STAD designs have been licensed by NRC, so it will take some time before SNF can be packaged into STADs. At that time, utilities must be willing and able to load SNF into STADs in order for that fuel to be shipped in a STAD configuration to the ISF.

The additional number of STADs would substantially increase the ISF foot print to provide more storage pads, underground silos or a larger vault. For example, a vault housing 5,000 MTHM increased from about 800 ft. long for commercial DPCs to about 1,500 ft. long for small STADs.

A summary of the pros and cons for Study #3 is provided below.

Alternative	**Pros**	**Cons**
S-PAD	• Pad storage is proven technology • Easiest to implement	• Overpacks must be designed for seismic stability
S-UGS	• No tipover due to an earthquake • Ground provides radiation shielding • Ground shields STADs from view	• Large sections of the storage area must be constructed at one time
S-BGV	• Bldg provides environment control • Ground provides radiation shielding and explosion protection to vault • Lower bldg. and crane height improves seismic resistance • Vault shields STADs from view • No tipover due to an earthquake	• Large nuclear structure requires more design / construction time • Passive heat removal limited • Vault throughput is limited due to cask handling congestion in the storage hall
S-AGV	• Bldg provides environment control • Vault shields STADs from view • No tipover due to an earthquake	• Large nuclear structure requires more design / construction time • Passive heat removal limited • Vault throughput is limited due to cask handling congestion in the storage hall • Vault walls must provide radiation shielding • Higher crane height increases seismic loads

Cost Analyses:

Cost information (total estimated cost, total project cost, total life cycle cost (LCC)) was developed for hundreds of combinations of alternatives and scenarios, for the Pilot ISF and the Expanded Pilot ISF, and for low and high seismic region siting. Consistent assumptions were used throughout, carefully including within the scope of each cost analysis those ISF features essential to receipt of first SNF at the Pilot ISF (e.g., CHB, concrete batch plant, on-site rail infrastructure, security), as well as those features most important to differentiating the cost drivers among the alternatives. Some significant features and functions of the Pilot ISF were not included because they were not required for alternative comparison purposes, or because they were excluded items: costs associated with transportation of SNF to the Pilot ISF (rolling stock, transportation casks, transportation costs), costs associated with the consent-based site selection process (community support; any cost that might be incurred prior to “decision to proceed”), and costs associated with any capability to handle bare fuel (hot cell facilities, SNF pools) which are beyond the expected capability of the Pilot ISF.

A sampling of the comparative cost results are displayed below for Study #1. Similar data are contained in the report for Study #2 and #3 and for the Expanded Pilot ISF. All costs are escalated based on a 10-year completion schedule. These numbers do not account for varying times to implement the alternatives. For example, C-PAD can begin operations 4 years after the decision to proceed, C-UGS could begin 5 years after the decision to proceed and C-BGV and C-AGV cannot be operational until about year 10, so escalation applied for these alternatives is appropriate.

Design Study #1

Cost Table 1 - Pilot ISF Comparative Costs ($M) using commercial DPCs in Low Seismic area

Alternative	Capital Cost	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-PAD	$780- $970	$39	$91	$1,226 $2,177 (EV)	$1,429 $4,252 (EV)
C-STD	$809 - $998	$40	$93	$1,269 $2,254 (EV)	$1,481 $4,411 (EV)
C-UGS	$793 - $990	$39	$118	$1,152 $2,213 (EV)	$1,290 $4,293 (EV)
C-BGV	$784 - $1,252	$39	$187	$1,178 $2,387 (EV)	$1,299 $4,657 (EV)
C-AGV	$838 - $1,383	$39	$181	$1,222 $2,437 (EV)	$1,345 $4,691 (EV)

Cost Table 2 - Pilot ISF Comparative Costs ($M) using commercial DPCs in High Seismic area

Alternative	Capital Cost	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-PAD	$863 - $1,076	$39	$104	$1,229 $2,309 (EV)	$1,377 $4,422 (EV)
C-STD	$892 - $1,112	$40	$105	$1,260 $2,373 (EV)	$1,414 $4,567 (EV)
C-UGS	$846 - $1,056	$39	$140	$1,208 $2,338 (EV)	$1,341 $4,487 (EV)
C-BGV	$852 - $1,368	$38	$187	$1,236 $2,469 (EV)	$1,358 $4,740 (EV)
C-AGV	$875 - $1,414	$39	$187	$1,256 $2,497 (EV)	$1,378 $4,740 (EV)

Cost Table 3 - Expanded ISF Comparative Costs ($M), commercial DPCs in Low Seismic area

Alternative	Capital Cost	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-PAD	$1,094 - $1,347	$77	$161	$1,486 $2,796 (EV)	$1,622 $5,085 (EV)
C-STD	$1,153 – 1,418	$77	$164	$1,554 $2,916 (EV)	$1,697 $5,292 (EV)
C-UGS	$1,099- $1,353	$77	$170	$1,472 $2,779 (EV)	$1,599 $5,021 (EV)
C-BGV	$1,055- $1,780	$77	$232	$1,463 $2,888 (EV)	$1,576 $5,298 (EV)
C-AGV	$1,157 – 1,985	$77	$232	$1,552 $3,013 (EV)	$1,664 $5,422 (EV)

Cost Table 4 – Expanded ISF Comparative Costs ($M), commercial DPCs in High Seismic area

Alternative	Capital Cost	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-PAD	$1,170 - $1,445	$77	$179	$1,560 $2,938 (EV)	$1,692 $5,283 (EV)
C-STD	$1,228 - $1,515	$77	$182	$3,058 $3,058 (EV)	$1,767 $5,490 (EV)
C-UGS	$1,136 - $1,359	$77	$179	$1,508 $2,848 (EV)	$1,633 $5,118 (EV)
C-BGV	$1,143 - $1,944	$77	$247	$1,546 $3,035 (EV)	$1,656 $5,490 (EV)
C-AGV	$1,194 - $2,043	$77	$259	$1,596 $3,132 (EV)	$1,703 $5,626 (EV)

Notes:
1. There is greater uncertainty in the Vault estimates, since they have not been licensed, built, or operated.
2. Life Cycle costs are based on the Point Estimate (Low Range) for Capital Cost

It is important to appreciate that total capital cost, generally in the range of $1 billion, does not include excluded costs, which will increase total programmatic cost.

Design Study #2

Cost Table 5 - Pilot ISF Comparative Costs ($M) using different operation alternatives

Alternative	Capital Cost	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-OPS	$795 - $1,001	$39	$91	$2.009	$3,205
A-OPS	$801 - $1,008	$39	$91	$2.016	$3,212
R-OPS	$812 - $1,015	$39	$91	$2,025	$3,221
S-OPS	$653 - $820	$51	$73	$1,812	$3,045

Design Study #3

Cost Table 6 - ISF Comparative Costs ($M) using STAD Canisters in Low Seismic area

Alternative	Description	Capital Costs	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-PAD	DPC	$780 - $970	$39	$91	$1,226 $2,177 (EV)	$1,429 $4,252 (EV)
S-PAD	Large STAD	$895 - $ 1,108	$39	$96	$1,333 $2,331 (EV)	$1,534 $4,421 (EV)
S-PAD	Med. STAD	$1,153 - $1,417	$39	$123	$1,580 $2,714 (EV)	$1,776 $4,885 (EV)
S-PAD	Small STAD	$962 - $1,188	$39	$171	$1,435 $2,612 (EV)	$1,622 $4,928 (EV)
C-UGS	DPC	$796 - $990	$39	$118	$1,152 $2,213 (EV)	$1,290 $4.293 (EV)
S-UGS	Large STAD	$890 - $1,106	$39	$110	$1,233 $2,309 (EV)	$1,372 $4,365 (EV)
S-UGS	Med. STAD	$935 - $1,332	$39	$131	$1,281 $2,419 (EV)	$1,416 $4,537 (EV)
S-UGS	Small STAD	$1,726 - $2,108	$39	$215	$2,003 $3,605 (EV)	$2,120 $5,984 (EV)
C-BGV	DPC	$748 - $1,252	$39	$187	$1,178 $2,387 (EV)	$1,299 $4,657 (EV)
S-BGV	Large STAD	$795 - $1,274	$39	$133	$1,163 $2,256 (EV)	$1,295 $4,364 (EV)
S-BGV	Med. STAD	$823 - $1,328	$39	$144	$1,192 $2,318 (EV)	$1,322 $4,459 (EV)
S-BGV	Small STAD	$879 - $1,434	$39	$211	$1,271 $2,567 (EV)	$1,287 $4,911 (EV)
C-AGV	DPC	$838 – 1,383	$39	$181	$1,222 $2,437 (EV)	$1,345 4,691 (EV)
S-AGV	Large STAD	$840 - $1,387	$39	$138	$1,204 $2,324 (EV)	$1,335 $4,448 (EV)
S-AGV	Med. STAD	$844 - $1,392	$39	$149	$1,212 $2,357 (EV)	$1,341 $4,513 (EV)
S-AGV	Small STAD	$906 - $1,515	$39	$191	$1,285 $2,545 (EV)	$1,406 $4,829 (EV)

Notes:

- Small STADs require a 4-pack multi-can container or 8-pack block overpack system.
- O&M costs are during load in period and include cask handling costs. O&M costs are lower following load in period.

Schedule Analyses:

The time to design, license and construct the Pilot ISF is significantly impacted by the alternative selected. The table below shows each storage option from Study #1 and the time frame until operation can begin. NOTE that time zero cannot start until the site is selected, environmentally investigated, and given a ‘Decision to Proceed.’.

Storage Alternative	Transfer Alternative	Years to Implement after 'Decision to Proceed'										Notes
		1	2	3	4	5	6	7	8	9	10	
C-PAD	S-OPS No transfer Bldg.	🟨	🟨	🟩	🟩	🟧 🟩						Base Case - site, pads, transfer facility, overpacks 2 yrs. to const. 1st pads, transfer facility, overpacks
C-PAD	C-OPS Transfer Bldg.	🟨	🟨	🟨	🟩	🟩	🟩	🟧 🟩				+1 yr. to design & license transfer bldg. +1 yr. to construct transfer bldg.
C-STD	C-OPS Transfer Bldg.	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟧 🟩			+2 yrs. to design & lic. std. overpacks/transfer bldg. +1 yr. to const. standard overpack/ transfer bldg.
C-UGS	S-OPS No transfer Bldg.	🟨	🟨	🟨	🟩	🟩	🟧 🟩					+1 yr. to license canisters
C-UGS	C-OPS Transfer Bldg.	🟨	🟨	🟨	🟩	🟩	🟩	🟧 🟩				+1 yr. to design & license transfer bldg. +1 yr. to construct transfer bldg.
C-BGV or C-AGV	C-OPS Transfer Bldg.	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟧	+2 yrs. to design & license vault and transfer bldg. +3 yrs. to construct vault and transfer bldg.

🟨 Engineering & Licensing
🟩 Fabrication and Construction
🟧 1st year of operation (some alternatives can begin operation while construction continues)

Conclusions

Despite the significant variations in design approach among the alternatives in Study #1, bottom line costs do not vary dramatically among the many scenarios evaluated. The same trend was observed in Studies #2 and #3. This observation suggests that other metrics, in addition to cost, could be used in making design decisions. Central to the conclusions that might be drawn from other metrics are issues that impact schedule. NRC licensing is expected to have significant impacts on schedule. Overall project schedules can become protracted when NRC is asked to review and approve new technology, or to review design or operational approaches that lack a track record or operating experience. STAD options evaluated in Study #3 will require extensive design and licensing work. Other less onerous issues that could cause additional licensing time include storing fuel contained in horizontal canisters in a vertical configuration and storing vertical canisters in a horizontal configuration.

There are a number of approaches that could impact schedule, including considerations outside the scope of this report (e.g., government project rules vs. commercial projects that can start site preparation and early construction activities “at risk” while licensing efforts are in progress).

As discussed above, this report is focused on generic design alternatives for storing SNF at a Pilot ISF, with maximum flexibility to accommodate a larger ISF. Conceptual plot plans, CHB layouts and equipment drawings, time and motion studies, cost analyses, seismic analyses, and radiation dose analyses developed in this report provide information that can assist decision makers in selecting options for the Pilot ISF. This report does not address other key elements of the Strategy that are prerequisites to achieving an operational Pilot ISF, including the consent based siting process, the transportation system needed to move SNF from shutdown plants to the Pilot ISF, and the governance and funding elements of the strategy.

Other approaches that could support more timely initial Pilot ISF operations can be gleaned from the analyses in this report. A prime example is the use of “S-OPS” to begin pad (“C-PAD”) storage of DPCs shipped to the Pilot ISF, while the cask handling building is still under construction. “S-OPS” equipment and operational procedures are proven at existing NPPs, so NRC approval should be straightforward. This strategy might lead to an operational Pilot ISF four years or less after a site is identified (under the consent-based siting approach) and DOE achieves a “decision to proceed.” Similarly, the use of “S-OPS” in combination with below grade storage of DPCs (C-UGS) might lead to an operational Pilot ISF five years. In contrast, other alternatives would likely require 6-9 years from that decision to completion of the Pilot ISF.

2.0 INTRODUCTION

This report addresses the Scope of Work (SOW) for Task Order 16, "Generic Design Alternatives for Dry Storage of Used Nuclear Fuel," issued in March 2014 by the Department of Energy's (DOE's) Office of Nuclear Energy (DOE-NE). (Reference 2-1)

2.1 Background

The Department of Energy (DOE) is laying the groundwork for implementing interim storage 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 spent nuclear fuel (SNF). The BRC's report to the Secretary of Energy was published in January 2012[1]. In response, the Administration released its Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste (hereafter referred to as the Strategy) in January 2013[2]. The Strategy includes a phased, adaptive, and consent-based approach to siting and implementing a comprehensive management and disposal system.

As discussed below in **Sections 2.1.1 and 2.1.2**, the Strategy defines these facilities:

- A Pilot ISF with limited capacity capable of accepting spent nuclear fuel and high-level radioactive waste and initially focused on serving shut-down reactors;
- A larger ISF, potentially co-located with the Pilot ISF and/or with a geologic repository, that provides the needed flexibility in the waste management system,
- A permanent geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste.

In July 2012, the DOE-NE contracted the CB&I team under its Fuel Cycle Research and Development (R&D) Indefinite Delivery/Indefinite Quantity (IDIQ) program, along with two other industry teams, to prepare independent design concept studies for the ISF. These reports, prepared under IDIQ Task Order 11, "Development of Consolidated Storage Facility Design Concepts," focused primarily on the layout and design of the ISF, with minimal emphasis on storage methodology details. In fact, Task Order 11 did not specify the type or size of the storage containers that would be utilized at the ISF. The three teams[3] completed their design concept studies and issued reports in February 2013 (References 2-4, 5, 6).

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[1] http://brc.gov/sites/default/files/documents/brc_finalreport_jan2012.pdf (Reference 2-2)

[2] http://energy.gov/downloads/strategy-management-and-disposal-used-nuclear-fuel-and-high-level-radioactive-waste (Reference 2-3).

[3] The three teams were headed by CBI Federal Services (formerly Shaw Environmental and Infrastructure), AREVA Federal Services, and EnergySolutions.

Since the completion of the Task Order 11 reports coincided with the publication of DOE's Strategy, they did not benefit from key aspects of that strategy, including DOE's emphasis on establishing a pilot ISF focused on receipt of waste from the initial nine shutdown reactor sites (discussed below). Nor did the Task Order 11 studies address DOE's renewed interest in standardized canister options. Those insights were incorporated in the SOW for this Task Order 16, "Generic Design Alternatives for Dry Storage of Used Nuclear Fuel."

The purpose of this report to DOE is to take the next logical step following these Task Order 11 reports, in defining the storage and operational functions of the ISF. This report more fully develops and documents a suite of generic design alternatives for the receipt and storage of the SNF and greater than Class C (GTCC) waste for the initial Pilot ISF, assuming the SNF and GTCC are derived from nine shutdown reactors named in the SOW. This report also seeks to provide DOE with maximum flexibility for additional capabilities to be developed and executed in a modular fashion such that expansion from a Pilot ISF to an Expanded ISF, could be achieved in an orderly and cost-effective manner.

Four intervening studies (between completion of Task Order 11 and start of Task Order 16) also guided the development of the Task Order 16 SOW and various details in this report:

- "Used Fuel Management System Architecture Evaluation, Fiscal Year 2012," published in October 2012 by a team of three national laboratories (Reference 2-7).

- "A Project Concept for Nuclear Fuels Storage and Transportation" (hereafter referred to as the Project Concept), published in April 2013 by the Nuclear Fuels Storage and Transportation Planning Project (NFST) (Reference 2-8).

- "Preliminary Evaluation of Removing Used Nuclear Fuel from Nine Shut-down Sites" (hereafter referred to as the shut-down site evaluation), published in September 2013 by a team of three national laboratories (Reference 2-9).

- "Nuclear Fuels Storage and Transportation Planning Project Inventory Basis", published in August 2013. Table 2-9 of that report provides the SNF inventory and its current location (hereafter referred to as "Inventory") (Reference 2-10).

2.1.1 The Pilot Interim Storage Facility

From DOE's Strategy (Ref.3):

> "Consistent with legislation recently under consideration in Congress, the Administration supports the development of a pilot interim storage facility with an initial focus on accepting used nuclear fuel from shut-down reactor sites. Acceptance of used nuclear

> fuel from shut-down reactors provides a unique opportunity to build and demonstrate the capability to safely transport and store used nuclear fuel, and therefore to make progress on demonstrating the federal commitment to addressing the used nuclear fuel issue." …

The SOW for Task Order 16 further defines the Pilot ISF as follows:

> "The Pilot ISF will provide facilities and infrastructure needed to transfer large dry storage canisters (DSC) from transportation casks into dry storage. Priority would be given to DSCs from the shut-down sites. This concept includes building and operating a Canister Handling Building, Canister Transfer Facility, a Storage Cask Fabrication Facility, an Administration Building, Visitors Center, and expanded storage capacity. This storage capacity is estimated to hold 5,000 metric tons heavy metal (MTHM) received at an average rate of 1,000 MTHM/year with a maximum rate of 1,500 MTHM/year."

The SOW further specified the SNF that will be accepted at the pilot ISF as coming from nine initial shutdown reactor sites, with inventory details provided in the Inventory document (current locations, dry storage systems used at these locations, etc.). These nine initial sites include: Maine Yankee, Yankee Rowe, Connecticut Yankee, Humboldt Bay, Big Rock Point, Rancho Seco, Trojan, La Crosse, and Zion.[4] The pilot ISF design is to be capable of receiving SNF from these shut-down sites without the need or capability to open the dry storage canisters or handle bare fuel assemblies. The pilot ISF design will also be modular, allowing for phased deployment. As discussed below, the specific nuclear power plants (NPPs) included in the scope of the pilot facility is not critical to this study, which for purpose of simplicity conservatively assumes that the pilot facility will be capable of initially handling 5,000 MTHM. Also, as discussed in **Section 3**, 5,000 MTHM is a good basis for the concept of a "Module."

2.1.2 Expanded Pilot Interim Storage Facility

From the DOE Strategy:

> "Beyond a pilot-scale facility, the Administration supports the development of a larger consolidated interim storage facility with greater capacity and capabilities that will provide flexibility in operation of the transportation system and disposal facilities. In addition, a larger-scale facility could take possession of sufficient quantities of used nuclear fuel to make progress on the reduction of long-term financial liabilities. Depending on the outcome of a consent-based process, this facility could have a capacity of 20,000 MTHM or greater, and could be co-located with the pilot facility or the eventual geologic repository. In the context of the overall waste management system, the

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[4] Note that as of 2015, four additional plants have shutdown, in addition to these initial nine plants: Kewaunee, Crystal River, San Onofre (three units) and Vermont Yankee. Also, Oyster Creek is planned to shut down by 2019.

> Administration supports the goal of siting, designing, licensing, constructing and commencing operations at a consolidated interim storage facility by 2025."

The SOW for Task Order 16 further defines an "Expanded Pilot ISF" as follows:

> "The Pilot ISF may provide expanded storage capability such that additional SNF could be handled from other shut-down and/or operating reactors that have Dual Purpose Canisters (DPCs) and transportable storage casks (TSC) available to ship. This expanded capacity is estimated to hold up to 10,000 MTHM (inclusive of the 5,000 MTHM described above)."

In order to support DOE's need for the capability to expand the Pilot ISF to an Expanded ISF (or potentially to an even larger ISF) with maximum flexibility, this report presents an approach that can be executed in a modular fashion such that expansion could be achieved in an orderly manner. Note that the Expanded Pilot ISF specified in the SOW is not identical to the "larger Consolidated ISF" discussed in the Strategy. The larger Consolidated ISF could have a capacity of 20,000 MTHM or greater, and could be co-located with the pilot facility or be located at the eventual geologic repository. The "Expanded Facility" specified in the SOW is specifically limited to 10,000 MTHM, but its expansion, should it occur, would be on the same site.

To accomplish this objective, the SOW calls for three design studies to be conducted:

- Design Study #1. Alternative storage systems for commercial DPCs
- Design Study #2. Alternative cask handling methods and configurations
- Design Study #3. Alternative storage systems for standardized dry storage canisters

The results of these three design studies are provided in **Sections 3, 4 and 5** of this report, and are summarized briefly in **Sub-section 2.4** below.

2.1.3 Spent Nuclear Fuel Technology Summary

For the convenience of the reader, the following summary of various SNF storage technologies is provided, with an emphasis on those technologies employed at the shutdown sites.

Dry Fuel Storage Systems (DFSSs)

There are currently four companies that provide DFSSs (or Dry Cask Storage Systems (DCSSs)): Holtec International, Inc., NAC International, Inc., EnergySolutions LLC., and AREVA TN Inc. Of the four, EnergySolutions only maintains systems from legacy companies Sierra Nuclear and Westinghouse and does not provide new systems at this time.

There are two types of DFSSs: cask-based DFSSs and canister-based DFSSs. The canister-based systems are further broken into vertical configuration and horizontal configuration. All SNF currently stored at shutdown sites uses canister-based DFSSs. Thus, receipt and storage of bare fuel in casks is assumed to be outside the scope of this study. (Note that for the larger "Consolidated ISF", the DOE "Nuclear Fuels Storage and Transportation Planning Project" (Reference 2-8) assumed that bare fuel will be received in reusable transportation casks in significant quantities, and will not be solely limited to the receipt of fuel in DPCs as is the case for the Pilot ISF and probably for the Expanded Pilot ISF. It is conceivable that some bare fuel cask shipments could occur to the Expanded Pilot ISF, but that possibility is not analyzed in this report.)

Cask-Based Systems

Cask-based systems are designed to meet storage requirements of 10 CFR Part 72 for storage and transportation requirements of 10 CFR Part 71. Cask–based systems are very robust, being constructed of thick steel for confinement and radiological gamma shielding. The casks typically have additional materials for neutron shielding incorporated into their design. The cask shell provides the primary confinement boundary. The casks typically have a basket permanently mounted into the cask interior for SNF assembly support and geometry control. Cask-based systems utilize a bolted lid with double metallic seals. Since they employ a bolted lid, the SNF assemblies can be loaded or unloaded from the cask with relative ease. Therefore, for this report, they are referred to as bare fuel casks.

Canister-Based Systems

Canister-based systems are licensed under 10 CFR Part 72 for storage as well as 10 CFR Part 71 for transportation. They use a dual-purpose canister (DPC), which is a metal container that is welded closed after the SNF assemblies have been loaded. The DPC (plus the fuel cladding) provide the confinement boundary. The DPC can be placed in three different cask or overpack configurations, which provide radiation shielding and physical protection. During handling or transfer operations at a plant, the DPC is placed in a transfer cask; during transport, the DPC is placed in a transport cask; and during storage the DPC resides in a storage overpack or module.

The transfer cask is a metal container with trunnions or lift blocks with high strength bolts that provide physical protection of the DPC, radiation shielding to personnel, and a means to be lifted and handled by the crane. The transport cask is a metal container with trunnions that protect the DPC from any credible accident that might occur during shipping, in accordance with 10 CFR Part 71. The metal cask is fitted with impact limiting devices for additional protection during transit.

The storage overpack or module is a thick concrete and steel or all-metal container that provides physical protection of the DPC while resting on a concrete pad, as well as radiation shielding to personnel and members of the public. Two design variations of the storage container are vertical storage of the DPC inside a concrete or metal storage overpack, and horizontal storage of the DPC inside a concrete horizontal storage module. The significant differences between the two variations are the overpack or module design, the DPC orientation, and the DPC transfer process. In vertical systems, the DPC is transferred from the transfer cask into the storage overpack by stacking the transfer cask on top of the overpack and lowering the DPC into the overpack. This is typically done in a building with a large overhead crane. The DPC is also transferred into the transport cask using the same stack-up method by placing the transfer cask on top of the transport cask and lowering the DPC into the transport cask. In horizontal systems, the DPC is transferred from the transfer cask or transport cask at the storage module. The transfer or transport cask is resting horizontally on a special trailer with a hydraulic ram. The trailer is backed up against the storage module opening and the ram pushes the DPC into the Horizontal Storage Module (HSM).

Concrete overpacks are not considered to be transportable for the purposes of this study. This allows an accurate comparison between the various storage methods. Therefore, prior to DPCs being shipped from the shutdown plant to the ISF in a transport cask, new overpacks must be constructed at the ISF and be ready to receive the DPCs prior to their arrival. Also prior to arrival, all of the handling equipment, including transfer casks, lift yokes, cranes etc., should be in place and ready to receive.

Both concrete storage overpacks and storage modules provide a means for passive heat transfer by natural convection from the DPC through air vents built into the overpack or module. The metal storage overpacks provide passive heat transfer by conduction through the overpack body.

2.1.4 Dry Fuel Storage Systems (DFSSs) at Shutdown Plants

Many of the nine shutdown power plants named in the SOW have been partially or fully dismantled and may no longer have on-site capability to lift heavy loads, such as a transfer cask or canister, to accomplish the operations required to transfer a canister from a storage overpack to a transfer cask and from the transfer cask to the transport cask. It will be necessary to install temporary cranes or canister transfer facilities at these sites or to bring in mobile cranes to enable loaded canisters to be transferred from the storage overpacks and HSMs to transport casks, and to lift the loaded transport casks and impact limiters onto the railcar or heavy-haul vehicle in preparation for shipment off site. The Pilot ISF design is to be capable of receiving SNF from these sites without the need to open the dry storage canisters or handle bare fuel assemblies.

Table 2-1 identifies the storage system data for the nine shutdown sites listed in the SOW plus seven more shut down reactors at five plant sites: San Onofre units 1, 2 and 3, Crystal River, Kewaunee, Vermont Yankee, and Oyster Creek. Oyster Creek is planned to be shut down by 2019.

Table 2-1
DFSS Types and Quantities – 17 shutdown reactors at 14 Shutdown Plant Sites

Storage System Overpack/Canister	Reactor	Number of Canisters	Number of UNF Assemblies	Total MTHM
Fuel Solutions				
W150 / W74	Big Rock Point	7 UNF, 1 GTCC	441	58
Holtec				
HI-STAR HB / MPC-80	Humboldt Bay	5 UNF, 1 GTCC	390	29
TranStor / MPC-24E,EF	Trojan	34 UNF, 0 GTCC	780	359
HI-STORM 100 / MPC-68	Vermont Yankee	58 UNF, 3[2] GTCC	3,880	530
UMAX / MPC-37	San Onofre 2&3[2]	87 UNF, 4[2] GTCC	2,668	1,128
NAC				
MPC / MPC-26	Connecticut Yankee	40 UNF, 3 GTCC	1,019	412
MPC / MPC-36	Yankee Rowe	15 UNF, 1 GTCC	533	127
MPC / LACBWR	LaCrosse	5 UNF, 0 GTCC	333	38
UMS / UMS-24	Maine Yankee	60 UNF, 4 GTCC	1,434	542
MAGNASTOR / TSC-37	Kewaunee[3]	24 UNF, 2[2] GTCC	887	341
MAGNASTOR / TSC-37	Zion 1 & 2	61 UNF, 4 GTCC	2,226	1,019
AREVA TN				
NUHOMS / 32PTH	Crystal River	39 UNF, 2[2] GTCC	1,244	584
NUHOMS / 32PT	Kewaunee[3]	14 UNF, 0 GTCC	448	172
NUHOMS / 24PT	Rancho Seco	21 UNF, 1 GTCC	493	228
NUHOMS / 24PT1	San Onofre 1[2]	17 UNF, 1 GTCC	395	146
NUHOMS / 24PT4	San Onofre 2, 3[2]	33 UNF, 0 GTCC	792	146
NUHOMS / 61BT,BTH	Oyster Creek[1]	77 UNF, 4[2] GTCC	4,660	823
Total	-	345 UNF, 20 GTCC	22,623	6,682

1 Oyster Creek scheduled to shutdown in 2019
2 San Onofre has SNF in both UMAX and NUHOMS systems
3 Kewaunee has SNF in both NAC and NUHOMS systems

The total SNF inventory at the nine shutdown plants named in the SOW (highlighted in yellow above) is about 2800 MTHM. The assumed capacity of the Pilot ISF (5,000 MTHM) conservatively bounds this total. If the SNF inventory from the five additional plant sites is added to this subtotal, the cumulative inventory is about 6700 MTHM. The assumed capacity of the Expanded Pilot ISF (10,000 MTHM) conservatively bounds this total. Since the Pilot ISF design will be modular, which specific shutdown nuclear power plants (NPPs) are included in the scope of this study is not critical to the design of the Pilot ISF. The Expanded Pilot ISF capacity of 10,000 MTHM bounds the total anticipated capacity requirements from all reactors currently anticipated to be shut down at the time the Pilot ISF would go into operation. Thus, this modular approach would give DOE maximum flexibility to accommodate future policy decisions.

2.1.5 Organization of Report

Sections 3, 4 and 5 provide a summary of Studies 1, 2, and 3 respectively. **Section 6** addresses a number of cross cutting topics that are central to all three studies: seismic analysis, thermal analysis, time and motion analysis, occupational dose analysis, and equipment (cranes, transporters, carts, yokes, etc.). **Section 7** provides results and conclusions, focused on comparisons among alternatives related to cost, schedule, staffing, throughput, etc. Appendices provide additional supporting details, drawings, etc.

Unless otherwise noted, all photographs, graphics and figures are provided by CBI.

2.1.6. Independent Senior Review Team

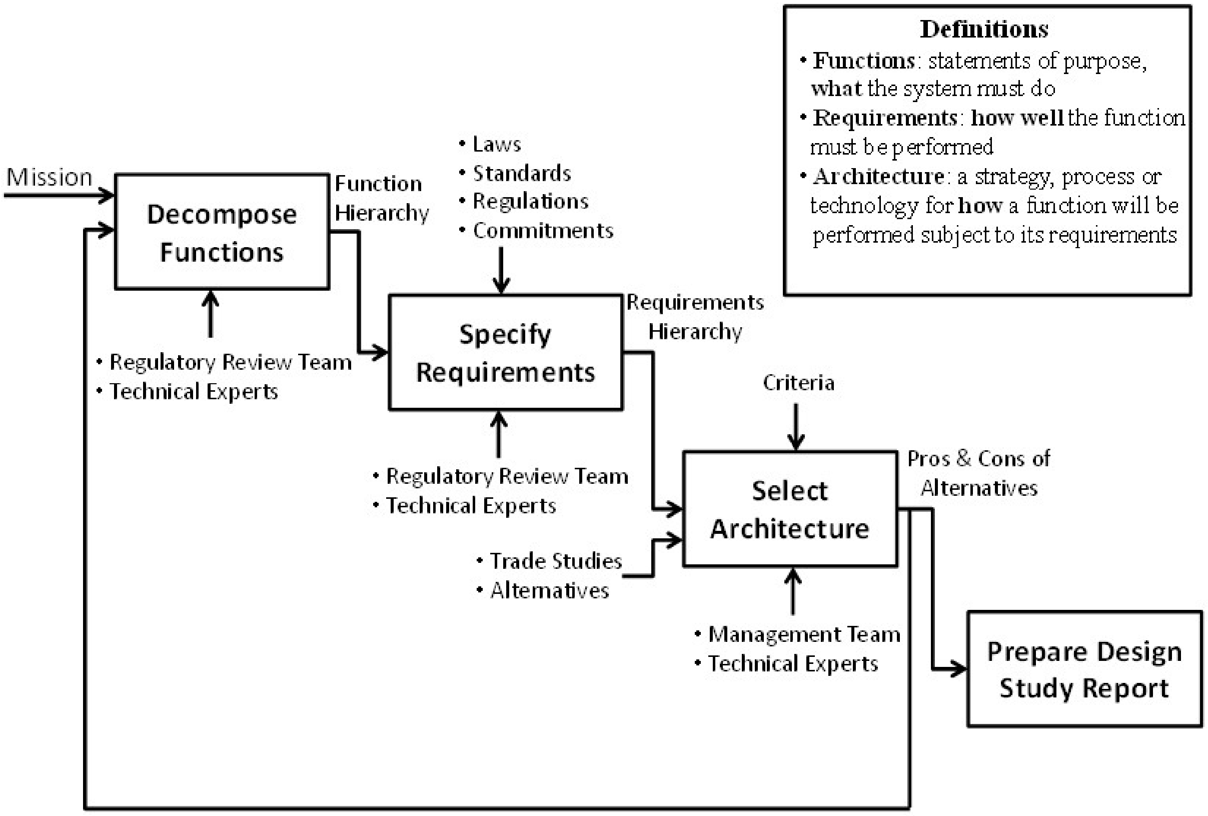
CBI used an Independent Senior Review Team to oversee the work conducted under this Task Order. The members are:

- Buzz Savage – chair (former Deputy Assistant Secretary for Fuel Cycle Technologies, DOE NE)
- Mike Sellman (former CEO, Nuclear Management Co.)
- Tom Isaacs (Lead Advisor to BRC; Former Director, Planning & Special Studies, LLNL)
- Jack Clemmens (Project Director, CB&I)
- Steve Agace (Program Manager - Cask Operations, Holtec)
- Eileen Supko (President, Energy Resources International, Inc.)
- Ray Termini (Mgr., ISFSI Implementation & Support, Exelon)
- John Pfabe (Nuclear Consultant for numerous nuclear utilities)

2.2 Systems Engineering Approach

The CBI team's systems engineering approach transforms the mission need, functions and requirements (F&R's) for an interim storage facility for commercial SNF into alternative concepts which will 'best' satisfy the F&R's contained in the Project Concept discussed above. The CBI Team has perfected application of the F-R-A (functions-requirements-architecture) approach to functional analysis on several large DOE programs (see **Figure 2-1**).

Figure 2-1
Functional Analysis Approach



CBI has applied this hierarchical F-R-A approach to the three Design Studies. This resulted in a decomposition of the top-level functions (i.e., receive SNF, handle SNF, and store SNF) into increasing levels of detail which allowed the team to specify additional necessary requirements (e.g., minimum design criteria, performance requirements, maintenance requirements, and security requirements). It also assisted in the identification of feasible alternatives and the organization of results of engineering analyses in each of the Design Studies. The analyses considered a variety of state-of-the-art technologies for receiving, handling, and storage options that could be implemented effectively. The alternatives were evaluated and compared on the basis of cost, efficiency, schedule, security, and risk and documented within the Design Reviews.

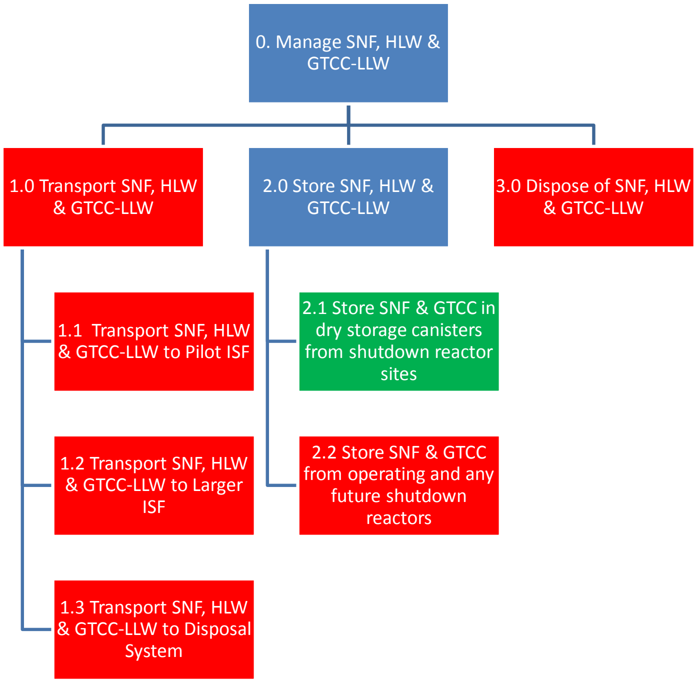
Note that the impacts of potential "retrievability" requirements for a future repository are not evaluated in this study. There may be a future regulatory and/or statutory requirement for waste emplaced in a repository to be retrievable for some period after emplacement. If retrievability were to be undertaken for any reason, the preferred location for such storage is not knowable at this time. It could be stored at the repository site, or back at the ISF, or possibly elsewhere. This contingency is outside the scope of this study, but might need to be addressed as a system requirement at a future date.

A separate and more detailed F-R-A approach was developed for each of these three Design Studies, and is presented in **Sections 3, 4 and 5**.

2.3 Functional Requirements

The starting point in applying CBI's overall systems engineering approach for Task Order 16 is the mission and system level functions and requirements that were developed and documented in the Project Concept document. **Figure 2-2** shows the top-level functions for the overall Waste Management System.

Figure 2-2
Top-Level Functions for Overall Waste Management System



Neither Function 1.0 (*Transport SNF, HLW & GTCC-LLW*) nor Function 3.0 (*Dispose of SNF, HLW & GTCC-LLW*) are within the scope of this task order. However, they are included here because it is important to understand how waste storage will need to be integrated into the overall waste management system. Furthermore, although Function 2.0 (*Store SNF, HLW & GTCC-LLW*) is itself decomposed into Function 2.1 (*Store SNF & GTCC in dry storage canisters from shutdown reactor sites*) and Function 2.2 (*Store SNF & GTCC from operating and any future shutdown reactors*), only Function 2.1 (highlighted in green) is considered at this time.

Figure 2-3 shows how the Pilot ISF will be integrated in the overall Waste Management System.

Figure 2-3
Overall Waste Management Systems

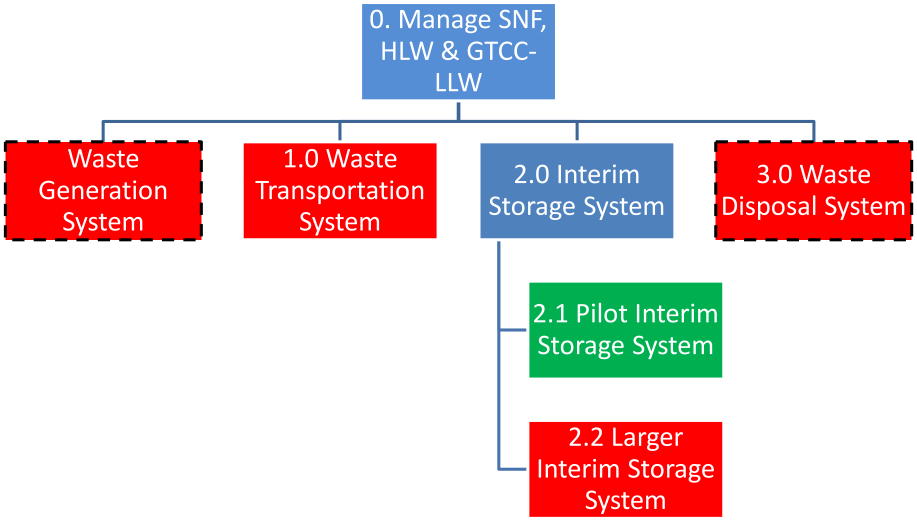
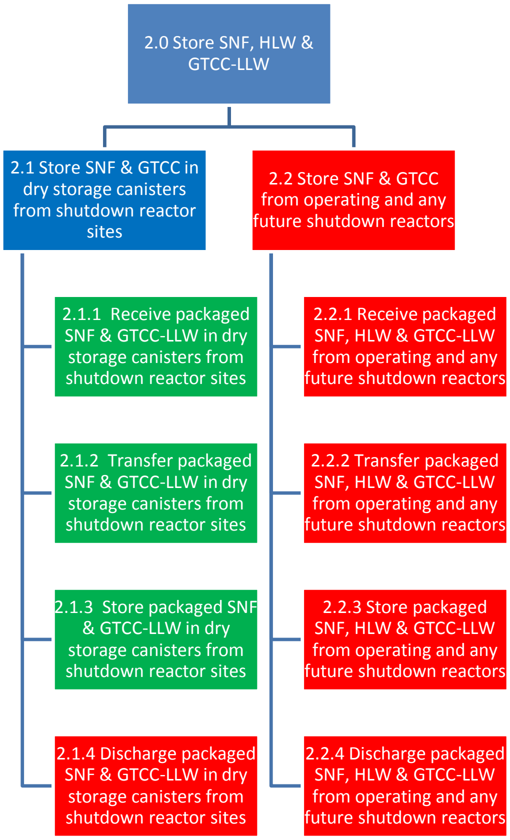


Figure 2-4 shows how Function 2.0 above was further decomposed, resulting in the three important functions that are within the scope of this effort.

Figure 2-4
Top Level Store Functions



Note the three functions, displayed in green, which are within the scope of Task Order 16:

- Function 2.1.1 – Receive packaged SNF & GTCC-LLW in DPCs from shutdown reactor sites
- Function 2.1.2 – Transfer packaged SNF & GTCC-LLW in DPCs from shutdown reactor sites
- Function 2.1.3 – Store packaged SNF & GTCC-LLW in DPCs from shutdown reactor sites

These three functions are further decomposed in **Sections 3, 4 and 5**, to support the various alternatives developed in detail in those sections.

Note that specific requirements governing these functions as they are applied in this report are specified in a variety of source documents, including the Requirements Document and Project Concept Document referenced above, various NRC regulations, etc., in addition to additional design and performance requirements specific to this Task Order. How each requirement is applied to each alternative design option considered is specified in **Sections 3, 4 and 5**.

2.3.1 General Project Requirements

Table 2-2 summarizes the general project requirements from the SOW (Reference 2-1) that were used in preparation of the report.

Table 2-2

General Project Requirements

General Project Requirements
The contractor shall develop generic designs for the interim storage facilities
The contractor shall be knowledgeable of the complete process for taking the commercial spent fuel from its current storage mode and configuration; preparing the fuel for transport to the interim storage facilities site; handling and providing additional packaging, where required; providing storage operations, maintenance of the interim storage facility, and subsequent transportation of SNF to the repository for disposal.
The design reports should not contain company proprietary information; however if proprietary information is relevant, it should be appropriately identified and/or segregated from reports.
The design shall carefully consider the NRC licensing requirements for storage, transportation and packaging, and physical protection/security contained in 10 CRF Parts 72, 71, and 73 respectively and their associated regulatory guides, and applicable industry standards.
Generic design drawings and/or sketches, with related design analyses, and outline specifications shall be prepared to document the new design features and their related design analyses, and establish the engineering baseline for support systems and facilities in a cost-effective manner.
As a minimum, the contractor shall develop the engineering sketches and outline specifications required to adequately depict structures, systems, and components.
The contractor shall provide material flow diagrams necessary to support development of generic design alternatives.
This work element requires a conceptual engineering effort to develop a physical process flow (time/motion) description for onsite transport and emplacement into interim storage (i.e., operational steps, sequences, durations, etc. associated with the movement of spent fuel through the interim storage facility).
Also, the contractor shall determine the number of on-site casks and transporters required to support the receipt rate.
All contract deliverables shall be prepared using applicable NRC regulations and guides and industry standards.
The 90 percent design review is the point where the contractor has completed all the design media for that stage of design and is ready to submit the design package to DOE for review. Further work on any portion of the package should be limited to incorporating comments from DOE's design review and any other wrap-up activities as approved by the DOE technical monitor.
The contractor will provide a briefing at each of these meetings. (i.e., including 90% design review)

General Project Requirements
The Pilot ISF will provide facilities and infrastructure needed to transfer large dry storage canisters (DSC) from transportation casks into dry storage.
Priority would be given to DSCs from the shut-down sites.
This concept includes building and operating a Canister Handling Building, Canister Transfer Facility, a Storage Cask Fabrication Facility, an Administration Building, Visitors Center, and expanded 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.
The mission and system level functions and requirements were developed and documented in the Project Concept document, Section 3.1.1 and 3.1.2. These shall be adopted as the starting point for this task order.
The pilot ISF will accept SNF at shutdown reactor sites.
The pilot ISF design shall be capable of receiving SNF from shut-down sites without the need to open the dry storage canisters or handle bare fuel assemblies.
The pilot ISF design will also be modular, allowing for phased deployment.
The Pilot ISF may provide expanded storage capability such that additional SNF could be handled from other shut-down and/or operating reactors that have Dual Purpose Casks (DPC) and transportable storage casks (TSC) available to ship. This expanded capacity is estimated to hold up to 10,000 MTHM (inclusive of the 5,000MTHM described above).
The contractor shall develop generic designs and conduct alternative studies for the Pilot ISF as described below. (i.e., Study 1, 2, and 3)

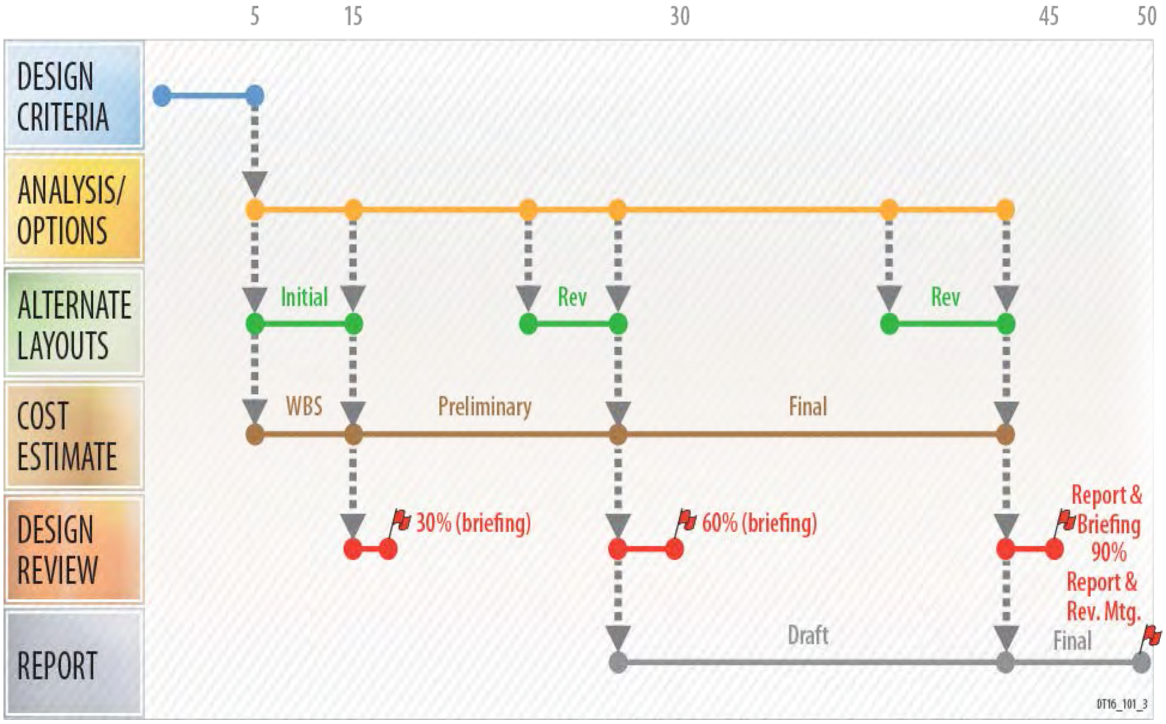
2.4 Overview of Studies

As stated above, the three design studies that were conducted under this Task Order are:

- Design Study #1. Alternative storage systems for commercial DPCs
- Design Study #2. Alternative cask handling methods and configurations
- Design Study #3. Alternative storage systems for standardized dry storage canisters

A number of design alternatives were identified for each of these studies. The approach to identifying and analyzing each design alternative is summarized in **Figure 2-5**.

Figure 2-5
Design Alternatives for Dry Storage of SNF Task Plan



The Process for Optimization of Alternative Variations is summarized below:

1. Explore all Variations
2. Prepare capital cost estimates of feasible variations
    - Compare costs of variations to identify optimum Alternatives
3. Evaluate structures, systems and components (SSCs) performance on optimum alternatives
    - Structural and Seismic
    - Thermal
    - Radiological
    - Design Life, Aging and Maintenance
    - Postulated Accidents
    - Licensing
    - Security
4. Prepare project cost estimates of optimized Alternatives

2.4.1 Design Study #1

Five alternative storage systems for DPCs are investigated and reported in **Section 3**. The DFSSs (or DCSSs) that were evaluated for storage of commercial DPCs at the Pilot ISF and the expanded ISF are as follows:

1. Commercial DPCs using above ground storage (currently deployed and licensed above grade vertical and horizontal storage systems associated with each DPC design). Report abbreviation: **“C-PAD”**
2. Commercial DPCs using standardized overpacks (storage of DPCs in a single universal overpack could reduce the design and operation variables and permit a more simplified process at the ISF). Report abbreviation: **“C-STD”**
3. Commercial DPCs using underground storage (DPCs placed underground in a below grade cylindrical vertical storage silo with a closure lid, which may provide better radiation shielding, and structural and security protection). The primary feature of this option is the use of DPCs that are a component of the typical SNF DFSSs employed at most commercial power reactor sites. Underground storage may offer improvements in security and safety. Report abbreviation: **“C-UGS”**
4. Commercial DPCs using a below grade vault (DPCs 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). The storage spaces would be designed to accept all currently licensed DPC configurations. Report abbreviation: **“C-BGV”**
5. Commercial DPCs using an above grade vault (similar to the below grade vault). Report abbreviation: **“C-AGV”**

These five alternatives are specified in the SOW, but are not new considerations. In fact, alternatives such as these have been studied by DOE as early as the 1990s. In November 1992, DOE (Office of Civilian Radioactive Waste Management, OCRWM) published “Monitored Retrievable Storage Facility Conceptual Design Report” (Reference 2-11), which examined a similar set of design concepts:

- Dry transfer and vertical concrete cask storage (reference design concept)
- Wet transfer and storage
- Dry transfer and vault storage
- Dry transfer and horizontal module storage
- Dry transfer and metal cask storage
- Dry transfer an transportable storage cask storage

The five dry transfer options above closely resemble the five alternatives being examined in this report. Further, there are many other similarities between the overall approach envisioned twenty five years ago and today's approach, including:

- Starting with a small facility and basing options analysis and cost analysis on that initial small facility, capable of storing 5,000 MTHM of SNF.
- Design flexibility, to enable changes and additional features to be added as the facility expands.
- Deferring final selection of the design concept to be used for the facility (e.g., concrete cask, horizontal module, vault storage) until after the host site is identified. This allows for collaboration with the host site on design decisions, considering the specific site characteristics, local infrastructure, and other factors that might impact optimum design.
- A strong focus on protecting public health and safety and the environment, and on minimizing worker dose and safety, throughout the design process. A strong commitment to quality assurance throughout the design process.
- Similar supporting infrastructure and services, including cask handling and maintenance facilities, rail and transportation systems, cranes, security systems, utilities, etc.

In accordance with the SOW, this study evaluates the following for each alternative:

- Identify and include the minimum design criteria for each alternative DCSS evaluated.
- Identify items that are common, or generic, to all facilities regardless of site location and DCSS concept.
- Consider and include (as appropriate) the facility design, fabrication, construction, testing, maintenance, and performance requirements for SSCs important to safety (e.g., consideration for seismic criteria, given that facilities could be "East or West of the Rocky Mountain Front" as defined in 10 CFR Part 72 and will be subject to the 10 CFR Part 72 design criteria for such locations).
- Evaluate the ability of the system to operate over extended periods of time (e.g., 40, and 80, 120 and 200 years), and provide an estimation of the total life cycle costs for the 40 and 80 year lifetimes.
- Develop the total estimated cost (TEC), total project cost (TPC), and annual operating and maintenance (O&M) costs.
- Develop a concept of operations, including assessments of the time and motion required for transferring the fuel from the transport casks to the storage configurations and the anticipated worker dose for each alternative DCSS system evaluated.

- Identify equipment maintenance requirements.
- Assess the licensability of each alternative DCSS system evaluated.
- Provide a schedule to the start of operations.
- Assess differing security requirements and include an appropriate description of the ISF security requirements which shall include a description of the NRC physical protection requirements and their application for such a facility and equipment including staffing, operating procedures, identification of federal organizational responsibilities, plans for evaluating carrier readiness, and those other items that will be utilized to support security operations, communications, and monitoring requirements such as testing, maintenance, and safeguards functions.

2.4.2 Design Study #2

Successful implementation of the Pilot ISF will require more than selecting the best storage system. Equally important is careful consideration of various cask handling methods for various SNF receipt rates. State-of-the-art technologies in automation, handling equipment, etc., must be evaluated to ensure that optimum operations are matched with the optimum storage system.

The objective for Design Study #2 is to examine alternative cask handling methods and configurations given a range of DPC receipt rates to determine which alternative methods improve time and motion for each process step in handling DPCs.

Cask handling operation activities at the ISF are envisioned to be performed in a facility such as a Cask Handling Building (CHB) that receives incoming transport casks and uses the appropriate transfer cask to transfer the DPC to a storage configuration. This process can be optimized to improve efficiency, reduce cost, and reduce exposure. For example, if CHB operations were conducted remotely in a shielded facility, exposure rates would be reduced, but might increase costs. Trade-offs such as this are examined, using time and motion studies and other means.

The range of DPC receipt rates considered in this study includes 1,500 MTHM/year, 3,000 MTHM/year, and 4,500 MTHM/year. The study also considers modular concepts or other methods that could increase receipt rates and improve canister processing throughput.

The alternative cask handling configurations and methods that were evaluated under this study are as follows:

1. Current canister transfer using the system-specific transfer cask. Report abbreviation: **“C-OPS”**
2. Automated canister transfer using a fixed-movement standard transfer cask. Report abbreviation: **“A-OPS”**
3. Remote canister transfer using a shielded facility without a transfer cask. Report abbreviation: **“R-OPS”**
4. Simplified Cask Handling Operations that would not require a CHB. Report abbreviation: **“S-OPS”**

To address various operational issues identified in the SOW, this study performs the following for each DPC handling approach evaluated:

- Identify and include the minimum design criteria for each alternative DCSS handling alternative.
- Identify items that are common, or generic, to all facilities regardless of site location and DCSS storage concept.
- Consider and include (as appropriate) the facility design, fabrication, construction, testing, maintenance, and performance requirements for SSCs important to safety (e.g., consideration for seismic criteria, given that facilities could be “East or West of the Rocky Mountain Front” as defined in 10 CFR Part 72 and will be subject to the 10 CFR Part 72 design criteria for such locations).
- Develop the TEC, TPC, and annual operating costs.
- Develop a concept of operations, including assessments of the time and motion required for transferring SNF from the transport casks to the storage configurations and the anticipated worker dose for each alternative DCSS handling system evaluated.
- Assess the licensability of each alternative cask handling concept evaluated.
- Identify equipment maintenance requirements.

2.4.3 Design Study #3

The BRC report and the DOE Strategy (Refs 2 and 3) placed renewed emphasis on standardization of storage and transportation systems. This is a challenge, given the high degree of diversity among current on-site storage systems at NPPs. However, an orderly transition to standardization, focused on optimizing systems and operations at the ISF, could reap benefits as SNF is shipped and ultimately placed in a permanent geologic repository.

Design study #3 will assist in this standardization effort by evaluating storage system alternatives that rely on standard SNF canisters. This study evaluates the dry storage methods for standard SNF canisters that may be received at the ISF or loaded at the ISF. Since repository requirements are not yet determined, design alternatives include various disposal container sizes, including the following "Standard Transport Aging and Disposal" or STAD canisters:

- Small: 4 Pressurized Water Reactor (PWR)/9 Boiling Water Reactor (BWR) assemblies,
- Medium: 12PWR/32BWR assemblies, and
- Large: 21PWR/44BWR assemblies.

The study utilizes information from the 2008 report, "TAD Canister System Performance Specification" (Reference 2-12), two 2013 IDIQ Task Order 12 reports (References 2-13 and 14), and the 2014 Report "Performance Specification for Small and Medium STAD Canister Systems (Reference 2-15).

Alternatives evaluated in this study for storage of standardized canisters at an ISF are as follows:

1. Standard canisters using above ground storage systems similar to the currently deployed above ground vertical and horizontal DCSSs. Report abbreviation: **"S-PAD"**
2. Below grade storage. Standard canisters would be placed into a below ground storage module consisting of a below grade cylindrical vertical storage cavity and closure lid that provides radiation shielding and structural protection during storage. Underground storage may offer savings in security and safety. Report abbreviation: **"S-UGS"**
3. Vault System below grade. Standard canisters would be placed into a below-grade vault system. The primary feature of below grade vault storage is a hardened reinforced concrete structure with an above grade structure providing an operating area for canister placement, storage, and removal via floor plugs. Natural ventilation would cool the SNF during storage, if necessary. Report abbreviation: **"S-BGV"**
4. Vault System above grade. Standard canisters would be placed in an above grade vault similar to the below ground alternative. Report abbreviation: **"S-AGV"**

In accordance with the SOW, this study evaluates the following for each alternative:

- Identify and include the minimum design criteria for each alternative standard canister storage system evaluated.
- Identify items that are common or generic to all facilities regardless of site location and storage concept.
- Consider and include as appropriate the facility design, fabrication, construction, testing, maintenance, and performance requirements for SSCs important to safety.

- Develop the TEC, TPC, and annual operating costs.
- Develop a concept of operations, including assessments of the time and motion required for transferring SNF contained in standard canisters from the transport casks to the storage configurations and the anticipated worker dose for each alternative storage system evaluated.
- Identify equipment maintenance requirements.
- Assess the licensability of each alternative storage system evaluated.
- Assess differing security requirements and include an appropriate description of the ISF security requirements which shall include a description of the NRC physical protection requirements and their application for such a facility and equipment.

2.5 References

1. Scope of Work (SOW) “Task Order 16: Generic Design Alternatives for Dry Storage of Used Nuclear Fuel,” The Department of Energy – Office of Nuclear Energy, March 2014

2. Report to the Secretary of Energy by the Blue Ribbon Commission on America’s Nuclear Future, January 2012 http://brc.gov/sites/default/files/documents/brc_finalreport_jan2012.pdf

3. Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste (“the Strategy”), January 2013 http://energy.gov/downloads/strategy-management-and-disposal-used-nuclear-fuel-and-high-level-radioactive-waste

4. *Final Report, Task Order No. 11, Development of Consolidated Storage Facility Design Concepts*, Shaw Environmental & Infrastructure, Inc., January 31, 2013.

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

6. *Task Order 11, Development of Consolidated Storage Facility Design Concepts*, Energy Solutions, February 1, 2013.

7. “Used Fuel Management System Architecture Evaluation, Fiscal Year 2012, FCRD-NFST-2013-000020, Revision 0”, October 2012.

8. “A Project Concept for Nuclear Fuels Storage and Transportation” FCRD-NFST-2013-000132, Revision 1, April 2013.

9. “Preliminary Evaluation of Removing Used Nuclear Fuel from Nine Shut-down Sites” FCRD-NFST-2012-000613, September 2013.

10. “Nuclear Fuels Storage and Transportation Planning Project Inventory Basis”, FCRD-NFST-2013-0000263 Revision 0, August 2013.

11. “Monitored Retrievable Storage Facility Conceptual Design Report” CRWMS M&O Document No. TSO.92.0323.0257, prepared by TRW Environmental Safety Systems, Nov. 30, 1992.

12. Transportation, Aging, and Disposal Canister System Performance Specification, Rev.1 / ICN 1, Doc ID WMO-TADCS-000001, DOE/RW-0585, March 2008

13. “Standardized Transportation, Aging and Disposal Canister Feasibility Study,” IDIQ Task Order 12, Energy Solutions, June 2013

14. “Standardized Transportation, Aging, and Disposal Canister Feasibility Study,” IDIQ Task Order 12, AREVA, June 2013

15. “Performance Specification for Small and Medium Standardized Transportation, Aging, and Disposal Canister Systems,” FCRD-NFST-2014-000579, July 2014.

3.0 STUDY 1 – ALTERNATIVE STORAGE SYSTEMS FOR DRY STORAGE CANISTERS

3.1 Background

The purpose of Design Study #1 is to investigate a range of alternative storage systems that can be used for dry storage of dual purpose canisters (DPCs). The canister storage systems that are evaluated are listed below, along with the abbreviation used for each in this report:

- C-PAD: The currently deployed and licensed above grade vertical and horizontal storage systems associated with each DPC design.
- C-STD: DPC standardized storage overpack. Currently the concept is to store each DPC within its licensed storage overpack or module. Use of a single universal overpack could reduce the design and operation variables and permit a more simplified process.
- C-UGS: DPC below grade storage. DPCs would be placed into a below ground storage module consisting of a below grade cylindrical vertical storage cavity and closure lid that provides radiation shielding and structural protection during storage. Underground storage may offer savings in security and safety.
- C-BGV: Vault System below grade. The primary feature of this option is below grade vault storage designed as a hardened reinforced concrete structure with an above grade structure, providing an operating area for canister placement, storage, and removal via floor plugs. Natural ventilation would cool the SNF during storage. The storage spaces would be designed to accept all currently licensed canister configurations. Variations on this alternative include options for an integral cask handling building (CHB) or a separate CHB, with each of these variations allowing for either all canisters stored vertically or vertical canisters stored vertically and horizontal canisters stored horizontally.
- C-AGV: Vault System above grade. An above grade vault would be similar to the below grade alternative, with the same four variations (integral or separate CHB; vertical only storage or vertical and horizontal storage).

For each of these alternatives, the SOW requirements shown in **Table 3-1** were performed for Design Study #1.

Table 3-1
SOW Requirements for Design Study #1

SOW Requirements for Design Study #1
Identify and include the minimum design criteria for each alternative Dry Cask Storage (DCS) system evaluated.
Identify items that are common, or generic, to all facilities regardless of site location and DCS concept.
Consider and include (as appropriate) the facility design, fabrication, construction, testing, maintenance, and performance requirements for Structures, Systems, and Components (SSCs) important to safety. The contractor shall consider that the initial facilities could be “East or West of the Rocky Mountain Front” as defined in 10CFR72 and will be subject to the Part 72 design criteria for such locations.
Evaluate the ability of the system to operate over extended periods of time (e.g., 40, 80, 120 and 200 years), and provide an estimation of the total life cycle costs for the 40 and 80 year lifetimes.
Develop the total estimated cost (TEC), total project cost (TPC), and annual operating and maintenance (O&M) costs.
Develop a concept of operations, including assessments of the time and motion required for transferring the fuel from the transport casks to the storage configurations and the anticipated worker dose for each alternative DCS system evaluated.
Identify equipment maintenance requirements.
Assess the licensability of each alternative DCS system evaluated.
Provide a schedule to the start of operations.
Assess differing security requirements and include an appropriate description of the ISF security requirements which shall include a description of the NRC physical protection requirements and their application for such a facility and equipment including staffing, operating procedures, identification of federal organizational responsibilities, plans for evaluating carrier readiness, and those other items that will be utilized to support security operations, communications, and monitoring requirements such as testing, maintenance, and safeguards functions.

Section 3.2 below provides the detailed systems engineering approach utilized in this study. That process, along with expanded guidance provided by DOE led to a number of variations to the five basic alternative designs listed above. This expanded list of alternatives, with thirteen “variations” follows below:

1. C-PAD, Current Commercial Storage on Concrete Pad (Base Case)
2. C-STD, Pad Storage using a Standardized Storage Overpack
   a. C-STDa, using Single Vertical Standard Storage Overpack
   b. C-STDb, using Single Horizontal Standard Storage Overpack
   c. C-STDc, using both Vertical & Horizontal Standard Storage Overpacks
3. C-UGS, Underground Storage
4. C-BGV, Below Grade Vault
   a. C-BGVa, using Integral CHB, Vertical Storage
   b. C-BGVb, using Integral CHB, Vertical and Horizontal Storage
   c. C-BGVc, using Separate CHB, Vertical Storage
   d. C-BGVd, using Separate CHB, Vertical and Horizontal Storage
5. C-AGV, Above Grade Vault
   a. C-AGVa, using Integral CHB, Vertical Storage
   b. C-AGVb, using Integral CHB, Vertical and Horizontal Storage
   c. C-AGVc, using Separate CHB, Vertical Storage
   d. C-AGVd, using Separate CHB, Vertical and Horizontal Storage

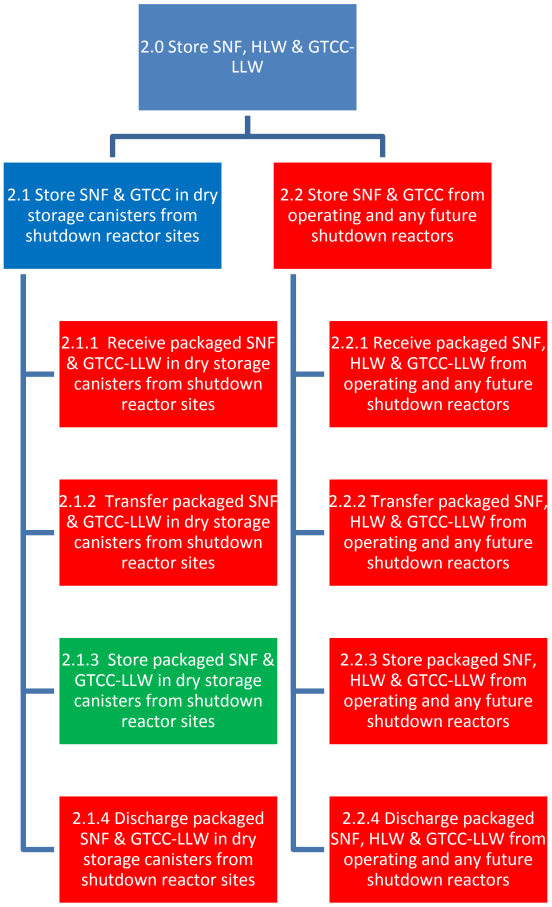
3.2 Design Criteria for Design Study #1

The objective for Design Study #1 is to evaluate various alternative storage methods that could be used to store transportable canister-based dry fuel storage systems currently used at commercial plant sites at an Interim Storage Facility (ISF). The study is focused first on evaluating storage alternatives for a Pilot ISF sized to store up to 5,000 MTHM of SNF from shut down plant sites and second on evaluating storage alternatives for the Expanded ISF sized to store an additional 5,000 MTHM of SNF from other nuclear plant sites. These sites could consist of operating plants as well as newly shut down plant sites.

3.2.1 Functional Requirements

The “*Nuclear Fuel Storage and Transportation Requirements Document (NFST)*” developed a number of system level functions applicable to the overall Waste Management System. **Figure 3-1** shows the top-level function (2.1.3) that applies to this Design Study #1 effort.

Figure 3-1
Study #1 Top Level Functions



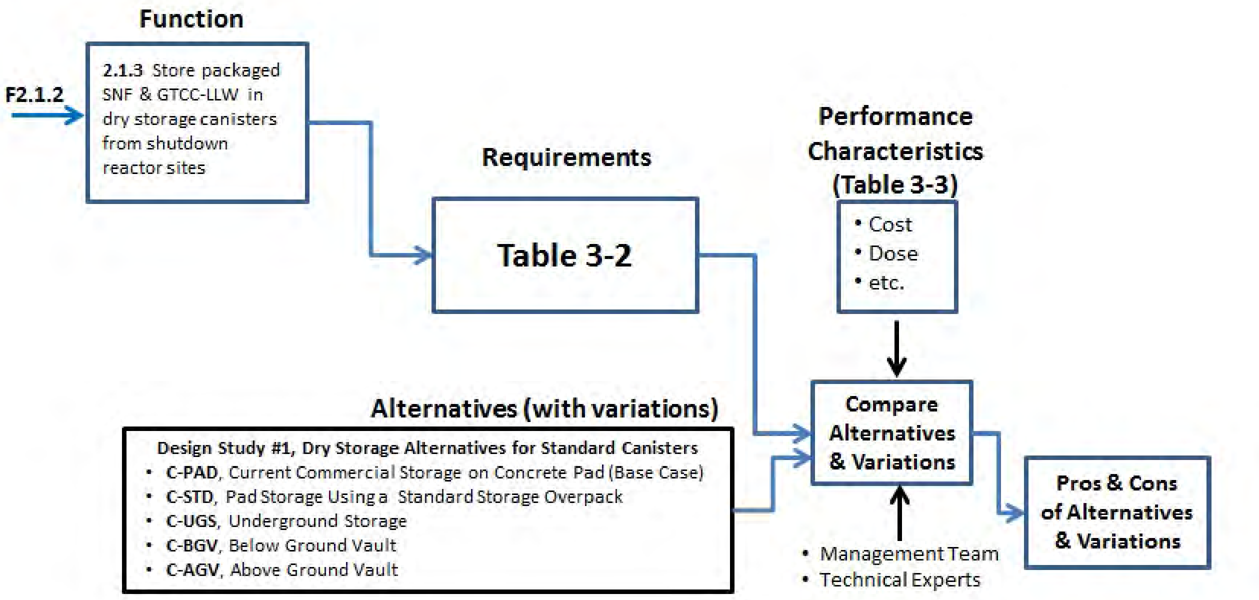
The systems engineering approach used for Study 1 is a structured process, based on hierarchical decomposition that transforms the mission need for long-term management of commercial SNF into a range of storage concepts from which DOE can select the one that best satisfies the need. The basic approach was to apply the functions-requirements-architecture (F-R-A) process as shown in **Figure 3-2**. Functions define what the system must do, requirements specify how well it must be done, and architecture (at the top levels of the hierarchy) identifies the preferred strategy for accomplishing it. The F-R-A process was applied to the one function encountered over the lifecycle of the Study #1 Alternatives: “2.1.3 Store packaged SNF & GTCC-LLW.”

This systematic approach ensured the following:

- The identified storage function is both necessary and sufficient to contribute to satisfaction of the mission.
- Important requirements associated with the storage function were specified.

- Specific strategies, technologies, and systems for performing the storage function subject to its requirements were formulated and consistently evaluated; and the pros and cons of each alternative were established.
- The eventual preferred concept will be a well-integrated system.

Figure 3-2
Systems Engineering Approach to the Evaluation of Canister Storage Alternatives



Specific design requirements from the TO16 SOW and referenced documents that are applicable for the Study #1 effort are shown in **Table 3-2**.

Table 3-2
Evaluation of Commercial Canister Storage Alternatives

Requirements from *Nuclear Fuel Storage and Transportation Requirements Document* (FY2014)
R 0.1.1 The pilot ISF will accept commercial SNF stored in dry storage canisters from shutdown reactor sites.
R 0.1.4The pilot ISF and expanded ISF will accept GTCC-LLW
R 0.2The WMS shall be capable of handling canisters in use by the commercial nuclear industry and the federal government as currently defined in the latest revision of *Dry Storage of Used Fuel Transition to Transport*, FCRD-UFD-2012-000253.

R 0.4 The WMS shall be capable of accommodating SNF, HLW and GTCC- LLW at the annual acceptance rates specified in this Table.

Year	Pilot ISF	
	Shutdown Reactor Sites	
	SNF	GTCC- LLW
1	500 MTHM/yr.	TBD
2	1,000 MTHM/yr.	TBD
3	1,500 MTHM/yr.	TBD
4	1,500 MTHM/yr.	TBD

R 0.4.1 The Pilot ISF acceptance rate shall be ramped up over the first three years of operation to 1,500 MTHM/yr.
R 0.6 WMS shall provide a platform for ongoing R&D to better understand how the storage system will perform over time.
R 0.7 The pilot ISF shall begin operations in 2021.
R 0.10 The Storage System shall have a design life of at least 80 years.
R 0.11 The Packaging System infrastructure shall have a design life.
Requirements from *A Project Concept for Nuclear Fuels Storage and Transportation* (June 15, 2013)
3.1.2.1 Design to focus on accepting SNF and GTCC from shutdown reactor sites in dry storage canisters.
3.1.2.1 Design to be generic, within NWPA regulations.
3.1.2.1 Capacity in the range of 5,000 to 10,000 metric ton heavy metal (MTHM).
3.1.2.1 Design receipt rate to accept and store all SNF and GTCC from current shutdown reactor sites within five years (ramping up to 1500 MTHM/year).
3.1.2.1 Capable of receiving, handling, and storing all dry storage canisters currently licensed for storage and transportation in the existing canisters without opening the canisters.
3.1.2.1 Able to obtain the necessary environmental, state and local permits.
3.1.2.1 Licensed by the NRC meeting 10CFR72 requirements.
3.1.2.1 Facility must meet security requirements of 10CFR73.
3.1.2.1 Operational life will be the time to receive and hold SNF until a repository is ready to receive shipments, including the time to ship all stored SNF to a repository. Design life is 100 years.
3.1.2.2 Design will include a "laboratory" to periodically examine some fuel in storage to ensure the long term stability of the materials and performance, especially high burnup fuels. The laboratory may also have the capability to develop and demonstrate any repackaging techniques required to support the repository operations. Other R&D associated with the repository will be performed elsewhere.
3.1.2.2 The design may include a canister repackaging facility (CRF) capable of removing individual assemblies and packaging them in disposal canisters suitable for transport to the repository. Since the repository requirements are not currently known the design will investigate the impact of multiple disposal canister sizes.
3.1.2.1 Flexible design to allow for future expansion.
3.1.2.1 The Pilot shall receive all spent fuel and GTCC waste from currently decommissioned shutdown sites by the time the expanded interim storage facility is ready to receive fuel (expected to be 5 years). Assumes all SNF is in dry storage casks.
NRC Requirements
10 CFR 72, NRC Licensing Requirements For The Independent Storage Of Spent Nuclear Fuel, High-Level Radioactive Waste, And Reactor-Related Greater Than Class C Waste
TO16 SOW Requirements
Pilot ISF storage capacity to hold up to 5,000 MTHM
Average rate of 1,000 MTHM/year
Maximum rate of 1,500 MTHM/year
Pilot ISF will accept SNF from shutdown reactor sites

Pilot ISF capable of receiving SNF from shut-down sites without the need to open the dry storage canisters or handle bare fuel assemblies
Pilot ISF design will be modular, allowing for phased deployment.
The Pilot ISF may provide expanded storage capability such that additional SNF could be handled from other shut-down and/or operating reactors that have Dual Purpose Casks (DPC) and transportable storage casks (TSC) available to ship. This expanded capacity is estimated to hold up to 10,000 MTHM (inclusive of the 5,000 MTHM described above).

3.2.2 Performance Characteristics

Each alternative was evaluated with respect to the requirements in **Table 3-3**. Each feasible alternative was evaluated to estimate its expected performance with respect to the performance characteristics required by the SOW (See **Table 3-2**). The overall project team then deliberated to identify the pros and cons of each alternative, some of which were necessarily based on qualitative evaluations.

This systematic approach ensured the following:

- All performance characteristics referenced in the SOW pertaining to the storage function were specified, verified and considered
- Specific alternatives for performing the storage function subject to its requirements were formulated, consistently evaluated, and explicitly compared

The eventual preferred concept, as selected by DOE, will be well-integrated within the overall waste management system.

Table 3-3
Performance Characteristics for Commercial Canister Storage Alternatives

Requirements Characteristics
Can meet Performance requirements for SSCs important to safety
Ability to operate 40 years
Ability to operate 80 years
Ability to operate 120 years
Ability to operate 200 years
Ability to transfer the fuel from the transport casks to the storage configuration
Schedule to the start of operations
Can meet worker dose limits per 10 CFR 20
Can be licensed under 10 CFR 72
Accommodates equipment maintenance requirements
Can meet Security and physical protection requirements per 10 CFR 73

Notes:

1. Currently, a standardized overpack that can accommodate all DPCs has not been designed or licensed. The existence of several commercial overpacks that would be similar in design that are already licensed gives precedence that a standardized design could meet this performance characteristic.
2. There is only one underground storage system designed for storing a DPC, the Holtec UMAX system, which is currently under review for an NRC license. Once licensed this system will meet this performance characteristic.
3. There is only one vault that has been licensed for storage of commercial fuel in the U.S., Fort St. Vrain (FSV). The fuel at FSV is unique and is not representative of typical commercial fuel characteristics. A vault that could store typical fuel in DPCs has yet to be designed or licensed. It is possible that a vault could meet this performance characteristic but the design and subsequent licensing would need to be vetted to verify this performance characteristic.
4. Several commercial storage systems are designed for 40 years; however, the NRC only licenses systems to 20 years. There have been steps by the NRC to change to a 40 year license period which would validate a 40 year period of performance.
5. Currently, there are no storage systems that are designed to operate 80 years. However, some systems have received a 40 year license extension that gives them a performance period of 60 years. Evaluations for aging management, time-limited aging analyses, and renewal documentation performed per NUREG-1927 methodology requirements could show that this storage alternative can achieve an 80 year performance period.
6. Currently, there are no storage systems that are designed to operate 120 years. It is very likely that to meet this performance period there will need to be an enhanced aging management program that not only maintains components but includes component replacement with longer life materials.
7. Currently, there are no storage systems that are designed to operate 200 years. It is very likely that to meet this performance period there will need to be an enhanced aging management program that not only maintains components but includes component replacement with longer life materials.

3.2.3 TO 16 References, Regulations, Codes and Standards

The TO16 SOW provided a number of specific references to be used for the study effort. In addition, there are several regulations, codes and standards that may be applicable to the ISF design and storage of canisters. The TO 16 references, regulation, codes and standards are listed in **Table 3-4**.

Table 3-4
TO 16 References, Regulations, Codes and Standards

DOE Requirements
FCRD-NFST-2013-000020, “Used Fuel Management System Architecture Evaluation, Fiscal Year 2012,” Argonne National Laboratory (ANL), Savannah River National Laboratory (SRNL), and Oak Ridge National Laboratory (ORNL), Revision 0, October 2012.
FCRD-NFST-2013-000132, “A Project Concept for Nuclear Fuels Storage and Transportation”, Nuclear Fuels Storage and Transportation Planning Project (NFST), Revision 1, April 2013
FCRD-NFST-2012-000613, “Preliminary Evaluation of Removing Used Nuclear Fuel from Nine Shut-down Sites,” Pacific Northwest National Laboratory (PNNL), Savannah River National Laboratory (SRNL), and Sandia National Laboratory (SNL),
FCRD-NFST-2013-0000263, “Nuclear Fuels Storage and Transportation Planning Project Inventory Basis”, Revision 0, August 30, 2013.

"Fuel Cycle Technologies Quality Assurance Program Document, "U.S. Department of Energy, Revision 2, December 2012
Quality Rigor Level 3 guideline No. 1 Study shall be conducted in accordance with the Laboratory's DOE-approved quality assurance program.
Quality Rigor Level 3 guideline No. 2 Deliverables shall receive a technical review as follows:
Quality Rigor Level 3 guideline No. 3 The general requirements specified in FCT QAPD Section 6 shall also be met including:
NRC Regulations
10 CFR 71, "Packaging and Transportation of Radioactive Material," U.S. Nuclear Regulatory Commission
10 CFR 72, "Licensing Requirements For The Independent Storage Of Spent Nuclear Fuel, High-Level Radioactive Waste, And Reactor-Related Greater Than Class C Waste," U.S. Nuclear Regulatory Commission
10 CRF 73, Physical Protection of Plants and Materials U.S. Nuclear Regulatory Commission, Revision 1, July 2010
Regulatory Guide 1.76, "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants," Nuclear Regulatory Commission, Revision 1, March 2007
NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," U.S. Nuclear Regulatory Commission, Revision 1, July 2010
NUREG-1567, "Standard Review Plan for Spent Fuel Dry Storage Facilities," U.S. Nuclear Regulatory Commission, Revision 0, March 2000
NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel," U.S. Nuclear Regulatory Commission, March 2000.
NUREG-0554, "Single-Failure-Proof Cranes for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, May 1979
NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," U.S. Nuclear Regulatory Commission, July 1980
Industry Codes and Standards
ASME III, Division 3, Containment Systems for Spent Fuel and High Level Waste Transport Packaging, American Society of Mechanical Engineers, 2013.
ASME Code Case N-595-4, "Requirements for Spent Fuel Storage Canisters." ASME III, Division 1, American Society of Mechanical Engineers, 2013
ACI 349, "Code Requirements for Nuclear Safety Related Concrete Structures," American Concrete Institute, 2006
ANSI/AISC N690, "Specification for Safety-Related Steel Structures for Nuclear Facilities," American Institute of Steel Construction, 2012
NFPA 70, "National Electric Code," National Fire Protection Association, 2014

3.2.4 Interim Storage Facility Design Criteria

The Pilot and later Expanded ISF design is important as it relates to features for the storage area and DPC processing area. It is assumed that all DPCs will arrive at the ISF in a transport cask via railcar or tractor-trailer. The transport cask is offloaded from the railcar or tractor-trailer in a canister processing facility (e.g., Cask Handling Building). The scope of this study starts at the point of transport cask receipt and includes the activities in the Cask Handling Building, equipment and areas required to remove the transport cask and transfer a DPC from the Transport cask to the storage location.

The Pilot ISF is primarily designed to process and store existing SNF from shutdown plant sites. The Expanded ISF is designed to process and store existing SNF from all remaining plant sites which could include operating reactors as well as newly shutdown reactors.

The design criteria for the Pilot and Expanded ISF are shown in **Table 3-5**.

Table 3-5
Pilot and Expanded ISF Operational Design Criteria

Description	Parameters
Pilot ISF MTHM Capacity	Approx. 5,000 MTHM
Pilot ISF Canister Capacity	Approx. 450 canisters = 1 module
Expanded ISF MTHM Capacity	Approx. 10,000 MTHM
Expanded ISF Canister Capacity	Approx. 900 canisters
Average Ratio of MTHM per Shutdown DPC	11.11
Percentage of PWR Canisters	62%
Percentage of BWR Canisters	38%
Percentage of Vertical System Canisters	59%
Percentage of Horizontal System Canisters	41%
Pilot ISF MTHM Receipt Rate, Yearly	1,500 MTHM
Pilot ISF DPC Receipt Rate, Yearly	135 DPC
Pilot ISF DPC Receipt Rate, Weekly	2.6 DPC
Expanded ISF MTHM Receipt Rate, Yearly	1,500 MTHM (min.) 3,000 MTHM (avg.) 4,500 MTHM (max.)
Expanded ISF DPC Receipt Rate, Yearly	Approx. 135 DPC (min.) Approx. 270 DPC (avg.) Approx. 405 DPC (max.)
Expanded ISF DPC Receipt Rate, Weekly	Approx. 2.6 DPC (min.) Approx. 5.2 DPC (avg.) Approx. 7.8 DPC (max.)
Pilot and Expanded ISF Access	Rail and Truck
ISF Design Life	40 years 80 years
High Seismic Ground Motion Acceleration	0.75g
Low Seismic Ground Motion Acceleration	0.25g
Design Temperature	125° F

3.2.5 Commercial SNF Canister Systems Data

This section provides information on the shutdown plant sites and storage system data for each of the transportable canister-type storage systems that would be stored at the Pilot ISF and Expanded ISF. The storage system data are used for sizing storage alternatives, establishing the canister transfer process, determining dose vs. distance for storage layouts, and sizing the ISF equipment. The storage system data also provides the bases for design of the ISF storage area and storage structures (pad, underground systems and vaults).

3.2.5.1 Shutdown Plant Sites

There are nine shutdown plant sites identified in the TO 16 SOW that utilize dry cask storage systems. The nine sites include Big Rock Point, Haddam Neck (Connecticut Yankee), Humboldt Bay, LaCrosse, Maine Yankee, Rancho Seco, Trojan, Yankee Rowe and Zion.

Since 2013, four more plant sites (Kewaunee, Crystal River, Vermont Yankee and San Onofre) have shut down; and it has been announced that Oyster Creek will join this category in 2019. All of the shutdown plant sites currently have, or will have, SNF stored in storage systems that have canisters that are transportable, i.e., can be shipped to the ISF in a transport cask. Note that there are also shutdown reactors located at operating plant sites (Dresden 1, Indian Point 1, and Millstone 1). However, 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 shutdown reactor sites that are not included in the list because ownership of the SNF is no longer commercial and has been moved to the DOE. These sites include the ISFSIs at Fort St. Vrain and Idaho National Laboratory which houses the Peach Bottom 1 and Three Mile Island 2 SNF. Finally, SNF is stored in a spent fuel pool at Exelon’s Morris site in Illinois.

Some of the canisters contain GTCC waste which is loaded into canisters similar to those used for the SNF and will need to be removed from the reactor site along with the SNF in order to allow for decommissioning of each site. Transport cask designs utilized at these shutdown plant sites have been certified to transport both SNF and GTCC waste.

The total SNF inventory at the nine shutdown plants is about 2800 MTHM. The assumed capacity of the Pilot ISF (5,000 MTHM) conservatively bounds this total. If the SNF inventory from the five additional plant sites is added to this subtotal, the cumulative inventory is about 6700 MTHM. The assumed capacity of the Expanded ISF (10,000 MTHM) conservatively bounds this total. Since the Pilot ISF design will be modular, which specific shutdown nuclear power plants (NPPs) are included in the scope of this study is not critical to the design of the Pilot ISF. The Expanded ISF capacity of 10,000 MTHM bounds the total anticipated capacity requirements from all reactors currently anticipated to be shut down at the time the Pilot ISF would go into operation. Thus, this modular approach would give DOE maximum flexibility to accommodate future policy decisions.

For the purposes of this study, the storage unit numbers will be rounded to large simplified values so that the layout of the storage area in each Storage Alternative can easily be segregated into vertical and horizontal locations. Therefore, the definition for a fully implemented module at the Pilot ISF will be as follows:

- Storage Units per Module = 450
- Vertical Units per Module = 250
- Horizontal Units per Module = 200

3.2.5.2 Dry Fuel Storage System Data

Table 3-6 identifies the characteristics for dry fuel storage systems at the shutdown reactors. **Table 3-7** identifies the characteristics for transportable canister-based dry fuel storage systems currently in use. The purpose for the data is to provide a basis for the storage layouts used throughout this study. Each storage Alternative is affected by storage system dimensions, weight, thermal performance, seismic limitations, etc.

Table 3-6
Characteristics of Dry Fuel Storage Systems Used at the 12 Shutdown Plant Sites

Dry Cask Storage System (DFSS)	Canister				Transport Cask					Storage Overpack				
	Model	Height (in.)	Dia. (in.)	Weight (Loaded) (lbs.)	Model	Height (in.)	Dia. (in.)	Weight (lbs.)	Weight Loaded (lbs.)	Model	Height (in.)	L x W or Dia. (in.)	Weight (lbs.)	Weight Loaded (lbs.)
Fuel Solutions (Big Rock Point)														
SFMS	FS Canister	192	66	81,129	TS-125	210.4	94.1	285,000	366,129	W-150	230	138	253,200	253,200
Holtec International (Trojan and Humboldt Bay)														
TranStor/MPC-24 Series	MPC-24E/EF	190.3125	68.5	90,000	HI-STAR 100	203.125	96	153,710	243,710	HI-STORM 100S Ver. B	210.5	133.875	291,000	270,000
HI-STAR HB	MPC-HB	114	68.5	59,000	HI-STAR HB	122	96	109,984	168,984	Same as transport cask				
NAC International (Connecticut Yankee, Yankee Rowe, LaCrosse, Maine Yankee and Zion)														
NAC-CY-MPC	CY-MPC	151.75	71	51,766	NAC-STC	190.5	99	157,540	209,306	VCC (CY-MPC)	190.6	128	186,000	237,766
NAC-YANKEE-MPC	YANKEE-MPC	122.5	71	45,200	NAC-STC	190.5	99	157,540	202,740	VCC (YANKEE-MPC)	160	128	155,000	200,200
NAC-MPC-LACBWR	MPC-LACBWR	116.3	70.64	54,650	NAC-STC	190.5	99	157,540	212,190	VCC (MPC-LACBWR)	160	128	141,200	195,850
NAC-UMS 24	NAC-TSC	191.75	67	72,900	UMS-T	209.3	92.9	153,500	226,400	VCC (NAC-UMS)	225.88	136	239,700	312,600
NAC-MAGNASTOR	TSC-37	191.8	72	102,000	MAGNATRAN	202	88	113,000	215,000	MAGNASTOR	225	136	321,000	326,000
AREVA TN (Rancho Seco, Crystal River, Kewaunee and San Onofre 1)														
NUHOMS-24PT1	24PT-1-DPC	186.5	67	82,000	MP187	203	92.7	158,580	240,580	AHSM	247	101	320,000	320,000
NUHOMS-32PT Series	32PT DPC	193	67	108,800	MP197HB	208	91.5	148,610	257,410	HSM-102	180	116.4	364,400	364,400
NUHOMS-61BT Series	61BT/61BTH-DPC	196	67	88,930	MP197HB	208	91.5	148,610	237,540	HSM-102	180	116.4	364,400	364,400

Reference: Characteristics of Spent Fuel Storage Casks, http://www.nrc.gov/pbadupws.nrc.gov/docs/ML1025/ML102580285.pdf - 2010-09-26.

Table 3-7
Characteristics of Transportable Canister-Based Dry Fuel Storage Systems

Dry Fuel Storage System (DFSS)	Canister				Transport Cask					Storage Overpack				
	Model	Height (in.)	Dia. (in.)	Weight Loaded (lbs.)	Model	Height (in.)	Dia. (in.)	Weight (lbs.)	Weight Loaded (lbs.)	Model	Height (in.)	LxW or Dia. (in.)	Weight (lbs.)	Weight Loaded (lbs.)
Holtec International														
HI-STAR/HI-STORM MPC-24 Series	MPC-24	190.3125	68.5	90,000	HI-STAR 100	203.125	96	145,726	235,726	HI-STORM 100S Ver. B	210.5	133.875	320,000	410,000
HI-STORM MPC-32 Series	MPC-32	190.3125	68.5	90,000	HI-STAR 100	203.125	96	145,726	235,726	HI-STORM 100S Ver. B	210.5	133.875	320,000	410,000
HI-STAR/HI-STORM MPC-68 Series	MPC-68	190.3125	68.5	90,000	HI-STAR 100	203.125	96	145,726	235,726	HI-STORM 100S Ver. B	210.5	133.875	320,000	410,000
HI-STORM FW MPC-37 Series	MPC-37	182	75.5	116,400	HI-STAR 190	203.125	96	N/A	N/A	HI-STORM FW	207.75	140	228,100	425,700
HI-STORM FW MPC-89 Series	MPC-89	182	75.5	116,400	HI-STAR 190	203.125	96	N/A	N/A	HI-STORM FW	207.75	140	228,100	425,700
NAC International														
NAC-UMS 24	NAC-TSC	191.75	67	72,900	UMS-T	209.3	92.9	161,700	234,600	VCC (NAC-UMS)	225.88	136	239,700	312,600
NAC-MAGNASTOR	NAC-TSC	191.8	72	102,000	MAGNATRAN	202	88	113,000	215,000	MAGNASTOR	225	136	326,000	428,000
AREVA TN														
NUHOMS-24PT1	24PT1-DPC	186.5	67	82,000	MP187	203	92.7	158,580	240,580	AHSM	247	101	320,000	402,000
NUHOMS-24 Series (except PT1)	24P-DPC	186	67	78,129	N/A	N/A	N/A	N/A	N/A	HSM-102	180	116.4	364,400	442,529
NUHOMS-32PT Series	32PT/H-DPC	193	62.2	98,400	MP197HB	208	91.5	154,220	252,620	AHSM	247	101	320,000	418,400
NUHOMS-61BT Series	61BT/H-DPC	196	67	88,930	MP197HB	208	91.5	154,220	243,150	HSM-102	180	116.4	364,400	453,330

References:

1. *HI-STORM 100 Updated Final Safety Analysis Report, Docket Number 72-1014.*
2. *HI-STAR 100 Updated Final Safety Analysis Report, Docket Number 72-1008.*
3. *NAC MAGNASTOR Updated Final Safety Analysis Report, Revision 1, Docket Number 72-1031.*
4. *NAC UMS Updated Final Safety Analysis Report, Revision 9, Docket Number 72-1015.*
5. *AREVA TN NUHOMS HD Updated Final Safety Analysis Report, Docket Number 72-1030.*
6. *AREVA TN Advanced NUHOMS Updated Final Safety Analysis Report, Docket Number 72-1029*
7. *AREVA TN Standardized NUHOMS Updated Final Safety Analysis Report, Revision 10, Docket Number 72-1004.*
8. *HI-STORM FW Updated Final Safety Analysis Report, Docket Number 72-1032.*

3.3 Overview of Alternative Designs

The five alternatives evaluated under Study #1 are evaluated in detail in Appendices A1 through A-5, as follows:

- **Appendix A1:** Alternative 1 - Pad Storage with Current Above Grade Vertical and Horizontal Storage Systems (C-PAD)
- **Appendix A2:** Alternative 2 - Pad Storage with Standardized Storage Overpack System (C-STD)
- **Appendix A3:** Alternative 3 - Below Grade Storage (C-UGS)
- **Appendix A4:** Alternative 4 - Below Grade Vault (C-BGV)
- **Appendix A5:** Alternative 5 - Above Grade Vault (C-AGV)

In addition, **Appendix A6** provides Cost Estimate Details.

Much of the analyses in these five appendices are common or nearly identical for all five alternatives. This is intentional, since a common baseline of assumptions will enable these analyses to highlight the differences in cost, licensing risk, and other critical factors that are specific to each alternative. For example, each Alternative will include nearly identical sets of buildings (Cask Handling Building, Concrete Batch Plant, Administrative Building, etc.). Each Alternative will be evaluated with respect to nearly identical concepts for operation (similar staff organizational approach, similar assumptions regarding shift work/overtime, etc.). Hence, this subsection overviews key elements of the five alternatives that are common to all, in order to make “apples-to-apples” comparisons in the summaries of each Alternative that follow.

3.3.1 Pilot ISF Site: Overview

The Pilot ISF will consist of a number of features and structures that will need to be constructed for the facility to operate. They include:

- ISF Site (with access road and utilities)
- Railroad spur and yard
- Storage area
- Cask Handling Building
- Protected Area (security boundary, cameras, intrusion detection and lighting)
- Overpack fabrication area
- Concrete batch plant
- Administration building

- Security/access control building
- Warehouse/maintenance facilities

The Pilot ISF site is assumed to be placed on approximately one square mile of property (plus, potentially a larger land purchase to serve as a buffer zone). Not all of the land will require construction, only the area for the initial storage area. A portion of this site will be designated an Owner Controlled Area (OCA), likely controlled by a chain link fence. All of the above site features and structures would be within this OCA. A Protected Area (PA) inside this OCA, with additional barriers and security controls, would encompass the ISF rail yard, the cask handling building (CHB) and storage pads/vaults, depending on the Alternative. Facilities that do not require the extra physical and operational security afforded by the PA, such as the Administrative building, warehouse, concrete batch plant, etc. would be outside the PA but inside the OCA.

The expansion of the Pilot ISF to the Expanded ISF would be accommodated by adding additional storage and handling capacity outside the PA but adjacent to it (inside the OCA), and then expanding the boundaries of the PA when the added capacity is ready to be commissioned.

The rail yard would consist of at least four tracks, two tracks to receive inbound trains and two tracks for staging outbound trains. The Storage Area inside the PA is the feature that varies most from Alternative to Alternative and is discussed in more detail in the subsections below.

The purpose of the CHB is threefold; 1) receive SNF shipments; 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 a building cell and transfer canisters from the transport casks to storage overpacks for vertical systems. The building is designed to provide physical protection for the canisters and radiation shielding to the workers. Slight variations in the CHB are required for some of the Alternatives. Significant effort has been made to optimize the size, layout and functionality of the CHB to match the needs of the Pilot ISF, while retaining flexibility to expand its capability to the Expanded ISF. Based on various references cited in the Appendices, the building floorplan is shaped like a large “T” in which shipments are received at the top of the “T” perpendicular to the processing rooms. This proven configuration accommodates long railcars yet minimizes crane spans. The processing area is arranged so that it can be of any length required to process the desired number of canisters. Adequate operating and laydown space, as well as redundancy in rail bays, truck bays, transfer cells, cranes, etc. is provided to accommodate the required throughput, maintenance and testing requirements, etc.

Most Alternatives will require a Concrete Batch Plant and Overpack Fabrication Area, to construct storage overpacks on site.

3.3.2 Concept of Operations

Cask operations vary significantly between vertical and horizontal canisters. About two-thirds of all canisters arriving at the Pilot ISF will be vertical, and one-third horizontal. Vertical casks are upended in the CHB, where the canister is moved from the transport cask to a fabricated storage overpack by using cranes, a transfer cask, adjacent transfer cells, and other equipment as described in the appendices. Vertical storage casks containing these vertical canisters are then moved from the CHB to the storage system unique to that Alternative. Horizontal cask operations are more streamlined in the CHB but more complex on the pad. Horizontal canisters are loaded directly onto a transporter inside the CHB and then moved to the storage area, typically consisting of horizontal storage modules.

There are two phases to ISF operations: Cask Handling Operations and Storage Facility Surveillance and Maintenance Operations. The Cask Handling Operations are the activities necessary to accept SNF packaged in DPCs from nuclear generators and to place the SNF into interim storage on site. This is a temporary activity lasting only as long as necessary to accept the design basis amount of SNF considered in this study; either 5,000 MTU for the Pilot ISF or 10,000 MTU for the Expanded ISF. This activity lasts only a few years and involves the most labor intensive activities experienced at the ISF. Additional Cask Handling Operations will be necessary at the end of ISF life when the stored SNF is repackaged and shipped to its final destination. However, that effort is not within the scope of this study.

The Storage Facility Surveillance and Maintenance Operation is the ongoing activity that spans the entire operational lifetime of the ISF. It consists of all the activities necessary to plan, to monitor the performance and aging of the storage systems used to house and cool the SNF, and to provide for the safeguards and security necessary to protect the facility from unwanted intrusions and/or damage. The Surveillance and Maintenance Operations begin immediately upon the commissioning of the ISF and continue until the last DPC has been removed.

The largest functional activity at the ISF is physical security. The security group needs to actively maintain the security of the site in addition to inspecting all materials coming onto the site. This security function is the largest single group of the organization and is a 24-7 operation.

The ISF operates 24-hours, 7-days a week basis, but cask handling operations are limited to a single 8-hour shift, 40-hour work week. This has been done because the logistics issues associated with delivering a large number of transport casks to the site do not warrant around-clock cask handling operations. In general, the operations required to accommodate the size and annual throughput required for the Pilot ISF do not require shift work. However, this single shift approach provides the ability to accommodate surges of work that might be necessary by the simple expedient of adding additional cask handling crew shifts.

Staffing studies and Time and Motion analyses are performed for each alternative in order to determine the crew size and throughput requirements for each. Results are discussed in **Section 7**. Consistent boundary conditions are established to ensure worker safety, minimize radiation exposure, and assure safe cask operations. For example, no operation involving the movement of a DPC is started during a shift if it could not be completed by the end of that shift. This is necessary because the CHB does not operate continuously, so no load would be left hanging or in some other potentially unstable condition that would jeopardize the integrity of the SNF or its confining structures in the event of a design basis event. Other assumptions ensure consistent bases for analyses, for example – it was assumed that a large supply of transport casks on railcars is staged on the site ready for processing.

The assumption that large supplies of transport casks on railcars are staged to support this throughput is not a trivial one. Extensive planning and preparation (overpack construction, shipping, etc.) of design-specific storage overpacks and/or spacers and shims for standardized storage casks must be undertaken many months in advance and tailored to the transportation plan for each canister shipped from the shutdown NPP sites listed previously. Some alternatives are proven methods with significant operating and licensing history; others lack this background and present more risks. These and other challenges are discussed in the appendices.

Each Alternative is evaluated against a number of performance issues, such as structural and seismic, thermal, radiological exposure, design life/aging/maintenance, postulated accidents, licensing, and security. Most of these issues are summarized in main report **Section 6**, Cross-cutting Issues.

Key conclusions regarding throughput and staffing requirements for each alternative, comparative dose information, etc., are provided in **Section 7**, Results and Conclusions.

3.4 Alternative 1 – Pad Storage with Current Above Grade Vertical and Horizontal Storage Systems (C-PAD)

3.4.1 Description of Storage Alternative

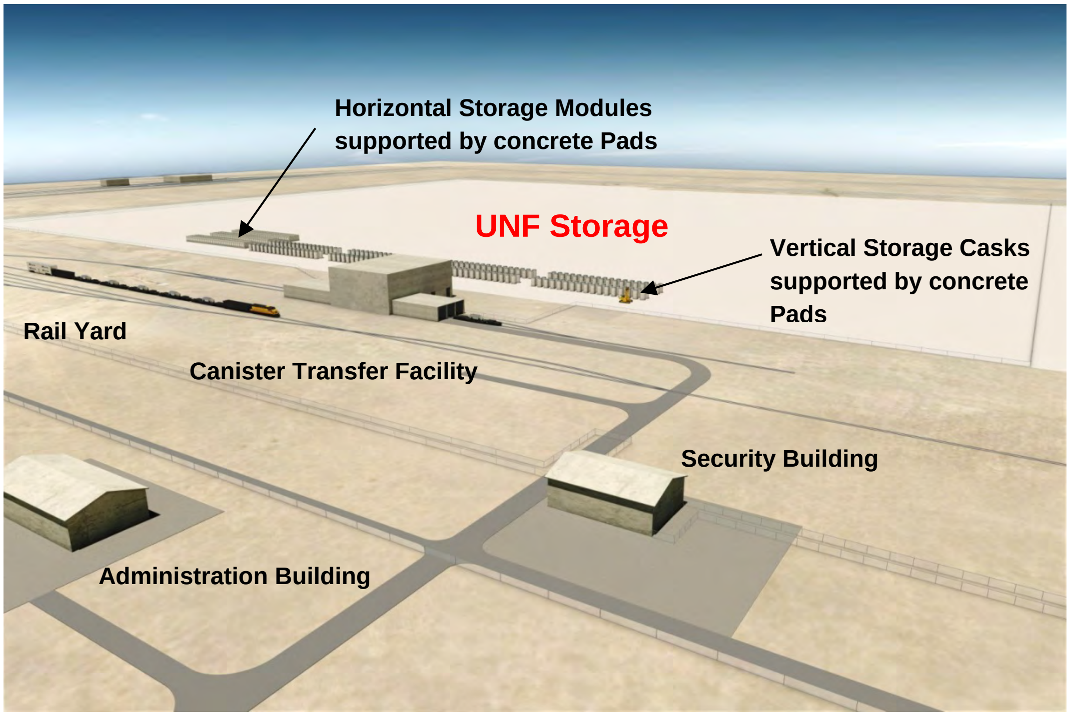
Alternative 1 represents the current method of storage at most of the reactor site ISFSIs. DPCs are stored in a heavily reinforced vertical concrete overpack (large vertical cylindrical cask as shown in **Figure 3-3**) or horizontal storage module (a rectangular prism as shown in **Figure 3-4**). Both 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. See Appendix A1 for details.

Figure 3-3
Vertical Storage Overpacks at the Zion Plant

Figure 3-4
Horizontal Storage Modules at the Rancho Seco Plant

An artist's view of a Pilot ISF using existing storage systems is shown in **Figure 3-5**.

Figure 3-5
Artist's View of a Pilot ISF Using Existing Storage Systems



3.4.2 Concept of Operations

During the Cask Handling Operations, many supporting activities need to be performed by the ISF staff. The most directly related to the Cask Handling Activities is the vertical storage overpack or horizontal storage overpack fabrication function. This is a full-time activity to complete the fabrication of overpacks necessary to support DPC placement activities. The steel components of the storage systems are fabricated by the original vendor or contractors under the original vendor's control and shipped to the site. After receipt inspection to ensure that the components meet specifications, concrete is added to the steel components in accordance with the vendors' specifications to complete the overpack design. Since C-PAD uses the original storage systems, the Overpack Fabrication Crew needs to coordinate closely with the Operations Manager to ensure that the proper vertical storage overpack or horizontal storage overpacks are prepared far enough in advance of DPC placement to permit the concrete to cure properly. As a result, the Overpack Fabrication Crew needs to be operating well ahead of the SNF acceptance process with a minimum of 30-days after the arrival of the steel components from the manufacturer until the overpack is ready to accept SNF.

The procurement activities necessary to support the overpack production must be well ahead of the delivery of the SNF because the lead time for overpack components, delivery and final fabrication is on the order of 24 months. Orders must be placed with the appropriate overpack vendors well ahead of the need in order to ensure that there is time to fabricate and deliver the necessary components. Ideally, the system should support just-in-time delivery of all necessary overpack components so that they can be used directly by the Cask Handling Crews. However, as a practical matter, the system should allow for buffer storage of these components in order to assure that SNF shipments are not held up by the lack of availability of Overpacks. This means that the Supply Chain Management must identify the correct vendor, the correct model of DPC and the schedule for delivery, in order to issue the purchase orders necessary to ensure the flow of material to the site. No shipment of SNF should be undertaken unless there is an appropriate Overpack available on site.

The Cask Handling Operations staff is dedicated to the movement of SNF packages around the site. These operations are carried out by dedicated crews who focus on certain areas of the operation. This way, when multiple DPCs are processed each week, a crew learns specialized skills that will improve efficiency. The crews are: 1) the Railbay crew, 2) the Cask Transfer crew and 3) the Transporter crew.

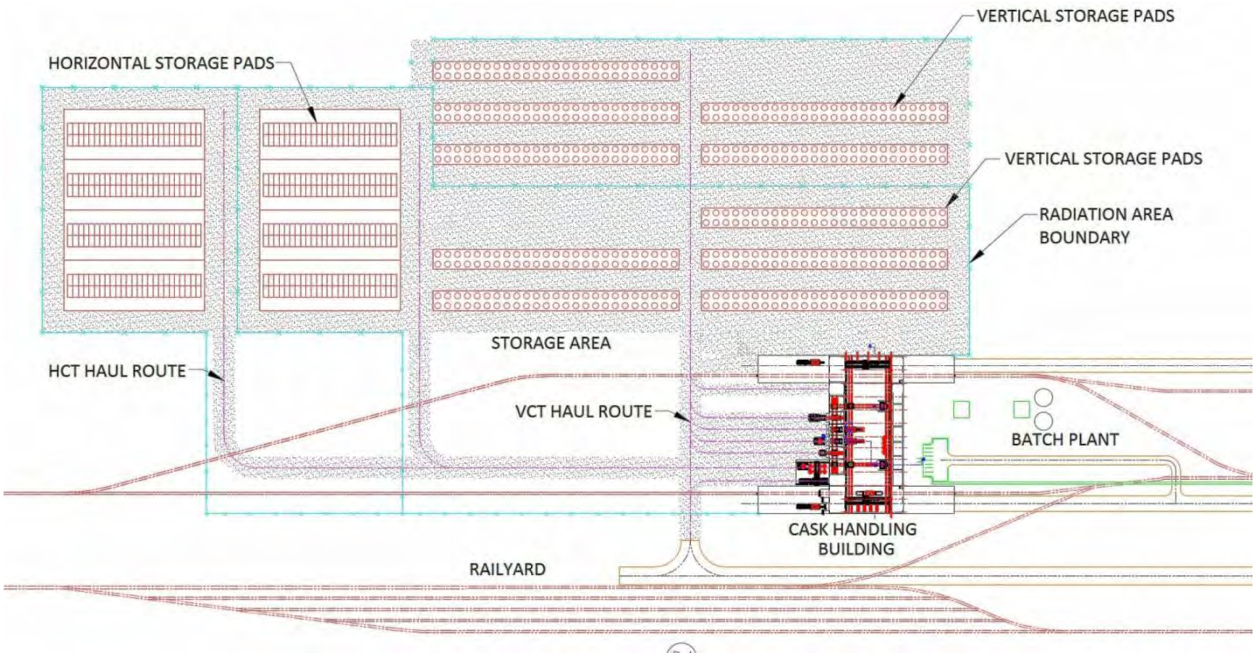
The staffing and time and motion studies in Appendix A1 establish how large the crew sizes need to be to support this alternative, and what the resulting throughput will be. Staffing estimates are approximate since not all crafts are required for an entire shift. Also, some intermediate steps do not require a certain craft, but in reality, they do not disappear. Based on this study, the site organization staff will need to be increased by 47 workers to achieve the desired ISF throughput during the cask handling phase of the facility’s life cycle. This results in a total ISF staff of 196. It was determined that the C-PAD throughput with all of the assumptions is 5 full-sized DPCs placed into storage each week.

The largest operations challenge for the C-PAD alternative is controlling the supply chain to ensure that the proper storage system is available to match the DPC being received from the generator. The licensability of the final SNF package is based on the conformance of the storage system with the original licensed dry storage system. As described above, the preparation time for a storage system is at least a month after receipt of the hardware from the storage system vendor. The lead time for this shipment could be eighteen to twenty four months. Therefore, up to two years ahead of the receipt of the SNF at the site, the supply chain manager needs to place an order for the necessary storage system components. This means that the ISF staff needs to know well in advance of delivery what vendor and what model of DPC system is needed. The coordination of the supply chain for the Overpack Fabrication and the SNF storage operations will be the largest management challenge for this design alternative.

3.4.3 ISF Expansion

Each of the Alternative storage methods was evaluated to determine if there were any additional pros or cons due to the expanded storage area. For Pad Storage, no additional pros or cons were noted for the Expanded ISF. The number of pads and storage units increase proportionally with the number of DPCs. **Figure 3-6** shows the Expanded ISF.

Figure 3-6
C-PAD Pilot ISF / Expanded ISF Layout



3.4.4 Performance of Structures, Systems and Components

Appendix A1 contains detailed evaluations of the C-PAD Alternative against a number of performance issues, including structural and seismic, thermal, radiological exposure, design life/aging/maintenance, postulated accidents, licensing, and security. Since C-PAD is standard technology at ISFSI sites at the nation's NPPs, significant experience already exists on how these performance issues would translate to the Pilot ISF environment. No new issues or problem areas were identified.

3.4.5 Summary; Pros and Cons for This Storage Alternative

Pros

- The C-PAD Alternative is the quickest to implement with minimal effort. All of these storage systems are already designed and licensed either under a General License or a Site Specific License for the location currently used. 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 existing FSARs could be incorporated by reference into the ISF Site Specific license which would greatly streamline the licensing process.
- These systems performance capabilities are well known. There are no unknowns that would need to be studied, designed for, or debated. The NRC has even determined that over several years, with proper maintenance, these storage methods are safe.
- The systems can be implemented over time, reducing their initial capital costs. Nuclear power plants create SNF over a 40 to 60 year typical life span. As it is created, the SNF can be shipped to the Pilot ISF where concrete storage pads and vertical overpacks or horizontal modules housing the DPCs can be installed over several years.

Cons

- Vertical systems require a more extensive DPC transfer process that could 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.
- 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, DPC transfer adapters, transporters, etc. (some of the transport casks are designed for multiple DPCs which could cut down the number of transport casks required). Employing 13 sets of equipment to lift and offload a transport cask, transfer the DPC from the transport cask to a storage overpack or module and move the DPC 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.

- 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 7 different storage overpack or module designs. Onsite fabrication of some sort will need to accommodate all 7 overpack designs.
- Although all of the storage systems are licensed, placing them at a specific location will require some licensing revisions and therefore, prolong the duration required to implement the Pilot ISF to some degree. 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 for the site specific conditions and the NRC review of those analyses will take time and money.

3.5 Alternative 2 - Pad Storage with Standardized Storage Overpack System (C-STD)

3.5.1 Description of Storage Alternative

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 as with Alternative 1.

There are three variations that are evaluated for this Alternative as follows:

- C-STDa, using Single Vertical Standard Storage Overpack
- C-STDb, using Single Horizontal Standard Storage Overpack
- C-STDc, using both Vertical & Horizontal Standard Storage Overpacks

The first two variations would place all DPCs into either a single vertical type overpack or a single horizontal type overpack. Having a single overpack design would greatly simplify overpack fabrication, enabling the ISF to focus on a production mode throughout the fabrication process. A single overpack would simplify the pad design since the pad analysis would only need to consider one universal overpack.

However, there are issues to consider. The first issue is with DPC dimensions. A single overpack would be sized for the largest DPC meaning that all smaller DPCs need to be shimmed in order to meet seismic and stability conditions. Secondly, thermal transmission is derived through stack effect which necessitates certain clearances between the outside wall of the DPC and inside wall of the overpack to efficiently create air flow. A larger clearance may need to be evaluated for heat removal capability from the vertical configuration. Thirdly, both variations have handling or storage issues: horizontal storage type DPCs lack lifting capabilities which requires the use of a lifting cage for vertical storage; vertical DPCs would need additional shielding measures added to the transfer cask for ALARA purposes if they are to be stored horizontally. Further, vertical DPCs are only designed with a shield plug on one end. Some shielding measures would need to be added to the transfer cask for ALARA purposes

The third variation would place all the horizontal type DPCs into a single horizontal storage overpack and all the vertical type DPCs into a single vertical storage overpack. This would resolve many of the “one size fits all” issues above, but would reduce (but not eliminate) the simplicity and cost benefits of standardization. Having a single overpack design for each type of storage system would still simplify the overpack fabrication process even though there would be two types. Two pad designs would be required; one for the horizontal storage module and one for the vertical storage overpack. Having a storage orientation that matches the storage type and license would reduce the potential issues associated with heat removal and canister handling.

Perhaps a fourth variation would be to have each of the four vendors be responsible to design, license and fabricate a standard overpack for their DPCs. This approach would avoid the transfer of proprietary information to another vendor in this highly competitive industry. Clearly four different standard overpacks are not as efficient as one or two standard overpacks but it is better than the current seven available overpacks. Since the purpose of a standard overpack is to simplify the ISF storage and overpack fabrication operations, this hybrid approach would need to be fully investigated to determine if it negated the standardized storage cask benefits.

3.5.2 Concept of Operations

The concept of Operations for the C-STD alternative is almost identical to that for Alternative 1 (C-PAD), with a few added complications. These complications fall into two basic categories:

1. The use of the standardized overpacks for the storage of SNF adds several additional operations to the ISF and may actually cost more than procuring more traditional overpacks from the original vendors. Indeed, the overpacks would need to be large enough to accommodate the largest of all of the commercial DPCs so they would, in general, be larger and more expensive than the legacy storage casks. This coupled with the need to provide inserts/adaptors to ensure the protection of the confinement barrier and heat transfer capability of the original storage system, could increase rather than decrease the cost of the overall system.

2. For variations 2a and 2b, transferring vertical DPCs into horizontal overpacks and transferring horizontal DPCs into vertical overpacks requires modified handling procedures, and may introduce unanalyzed safety and licensing issues. The handling issues and proposed solutions follow.

Horizontal DPCs are not intended to be lifted vertically by their upper end cover plate. Therefore, they cannot be lifted in the same manner as the DPCs designed for vertical storage. So, the universal overpack will be rotated into the horizontal position in a transfer rig. The overpack will have been preloaded with the appropriate lifting frame with adaptors to center and secure the DPC in the oversized standard overpack.[1] The horizontal DPC will be first loaded into a transfer cask, rotated 180° and then pushed into the lifting frame. This is necessary to avoid storing the SNF assemblies upside down. The horizontal DPC is pushed into the overpack by means of a hydraulic ram engaged on a full diameter pressure disk in the transfer cask. This assures that the DPC is pushed straight into the lifting frame without concern about the rigidity of the ram. This transfer cart will share many design features from horizontal cask transporters (HCTs), but will have fewer degrees of motion permitting rapid alignment with the overpack. The universal overpack will then be righted into the vertical orientation and the lid will be installed in the normal manner. The reoriented horizontal DPC in the universal overpack is then ready to be picked off of the transfer rig by the vertical cask transporter (VCT).

Vertical dry shielded canisters do not have a ram grapple ring on the bottom of the canister and therefore cannot be pushed into the horizontal overpack. So, to address this deficiency, the vertical storage canisters are first loaded into an adaptor frame that has been preloaded into a transfer cask and positioned in the vertical transfer receiving cell. This adaptor frame provides a tight fit to the DPC and incorporates a ram grapple ring on the bottom. The transfer cask replaces the transport cask for the final SNF placement enabling the transport cask to be returned to the Railbay Crew for repackaging before the SNF canister is placed into storage. Traditional horizontal SNF storage concepts do not need vertical transfer cells (and indeed is one of the concept’s greatest advantages); however, this variant requires both the vertical transfer cells and the work crew on the pad preparing the horizontal overpack to receive the vertical DPCs. This process requires double handling of the vertical DPCs in order to affix this necessary component onto the canister. The transport cask containing a vertical DPC is placed on the transfer cart and the lifting lug is bolted onto the upper cover. The transport cask is moved into the transfer cell and the shield door is closed. In the receiving cell, the adaptor frame has been positioned inside of a reusable transfer cask that has all of the functionality of a transport cask. The DPC is grappled and lifted into a shielded transfer cask above the transfer cells. The upper transfer cask is repositioned over the receiving cell and the DPC is lowered into the shielded transfer cask. The receiving transfer cask is then moved out of the cell on its transfer cart allowing access for the Cask Transfer Crew to remove the lifting lug from the DPC and to attach the upper cover of the adaptor frame that secures it to the DPC. Then the transfer cask upper lid is installed on the transfer cask. The transfer cask is picked by the overhead traveling bridge (OTB) crane and placed onto a HCT for movement to the pad.

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[1] The lifting frame is necessary to remove the DPC from the Overpack in the future. Without the lifting frame, there could be no means of removing the DPC because the Ram Grapple Ring necessary to remove horizontal DPCs would be inaccessible at the bottom of the vertical overpack

The time and motion studies for Alternative 2 result in a slight increase in staffing requirements. The site organization staff will need to be increased slightly to 201 as compared to 196 for Alternative 1 (C-PAD). The time and motion studies also determined that the C-STD throughput with all of the assumptions is at best 5 full-sized DPCs placed into storage each week (second railbay required).

3.5.3 ISF Expansion

Each of the Alternative storage methods was evaluated to determine if there were any additional pros or cons due to the expanded storage area. For Standard Overpacks, no additional pros or cons were identified. The number of pads and standardized storage units increase proportionally with the number of DPCs. Obviously, the three variations within this alternative result in three very different storage pad configurations – one consisting of only vertical storage casks, one with only horizontal storage modules, and one with a mix of both. In each case, however, the expansion to the expanded ISF would be straightforward, very similar to Alternative 1.

3.5.4 Performance of Structures, Systems and Components

Appendix A2 contains detailed evaluations of the C-STD Alternative against a number of performance issues, including structural and seismic, thermal, radiological exposure, design life/aging/maintenance, postulated accidents, licensing, and security. As expected, since C-STD is similar to standard C-PAD technology in most respects, there are limited new issues introduced by this Alternative. As with the Concept of Operations discussion above, the new issues, which could introduce unanalyzed safety and licensing issues, relate primarily to:

1. The standardized overpacks would need to be large enough to accommodate the largest of all of the commercial DPCs, requiring inserts/adaptors to ensure the protection of the confinement barrier and heat transfer capability of the original storage system.

2. For variations 2a and 2b, transferring vertical DPCs into horizontal overpacks and transferring horizontal DPCs into vertical overpacks.

Since no standardized overpack currently exists that is designed and licensed to store several different DPC types, it would take several years to design and license standard overpacks that could store different canisters. Since the overpack could house a number of different DPC types, the design would need to be analyzed and licensed to demonstrate that various parameters (structural, thermal, radiological) are acceptable under normal, off-normal and accident conditions. Since the sizes and weights of the canisters vary, which would impact the center of gravity of the storage system, structural analyses would need to be performed to demonstrate storage overpack stability for various conditions including seismic, tornado wind/missiles, explosion overpressures that are specific to the ISF. The size of the canisters would affect the flow area in the annulus between the DPC and inner shell of the overpack, so thermal analyses would need to be performed to demonstrate adequate heat removal capability for each different DPC, also considering the maximum permissible decay heat loadings (which could vary) for the different DPCs. Shielding analyses would also need to consider not only DPC design features (thickness of steel shell, bottom plate and closure lid), but also gamma and neutron source strengths of the spent fuel permitted to be stored in the different DPCs, which varies with allowable spent fuel enrichment, burnup and cooling time.

Obtaining a single license could be difficult with the four vendors' proprietary designs since it is unlikely that any of the vendors would be willing to release design information to one of its competitors or even a third party. From a licensing standpoint it might be more prudent to let each vendor develop and license their own standardized overpack which would need to conform to specifications required for the ISF standard overpack (e.g., size and weight) but would be able to store any DPC designed and licensed by that vendor.

Storing vertical DPCs in a horizontal position or horizontal DPCs in a vertical position would require significant analysis and licensing effort. DPC design features would need to be accommodated in different storage positions. 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. Concentrated loads where the canister contacts the rails would need to be analyzed. Thermal analysis would need to be performed to show adequate heat removal from the DPC in the different orientation such that all the SNF and DPC materials remain below design limits. Shielding would need to be reanalyzed for the changed DPC orientation. Dose rates may not be prohibitive when a vertical canister is stored in a horizontal module, and vice versa; however, dose rates would need to be evaluated and documented in the ISF SAR and ER. The analysis and re-licensing efforts could be reduced significantly by use of a single standardized vertical overpack and a single standardized horizontal storage module, so that the DPCs could be placed in the orientation for which they were originally designed and licensed. It is considered that this would be most efficient and avoid unnecessary analyses and licensing review.

3.5.5 Summary; Pros and Cons for This Storage Alternative

In summary, the pros and cons to this alternative, listed from the highest most significant impact to the lowest least significant impact are as follows:

Pros

- A single overpack design would simplify overpack fabrication. Up to 6 overpacks or modules would need to be fabricated in C-PAD yet C-STD 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 23, reducing the analyses, design and licensing time.
- The standardized overpacks and associated pads can be implemented over time, reducing their initial capital costs. As it is created, the SNF can be shipped to the Pilot ISF where concrete storage pads and standardized overpacks housing the DPCs can be installed over several years.

Cons

- 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 DPC 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.
- Vertical systems require a more extensive DPC 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. 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.
- Placing vertical DPCs in a horizontal position or horizontal DPCs in a vertical position requires analysis and licensing time. Performing the new analyses required to store DPCs 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 DPC could release enough heat to keep all the SNF and DPC material below design limits as an active cooling system may be required. 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.

- A one-size-fits-all overpack would have to accommodate 13 different sizes of DPCs. There are also more DPC 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 DPC. This would in turn necessitate design and fabrication provisions for the smaller DPCs 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 DPCs 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.
- 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.

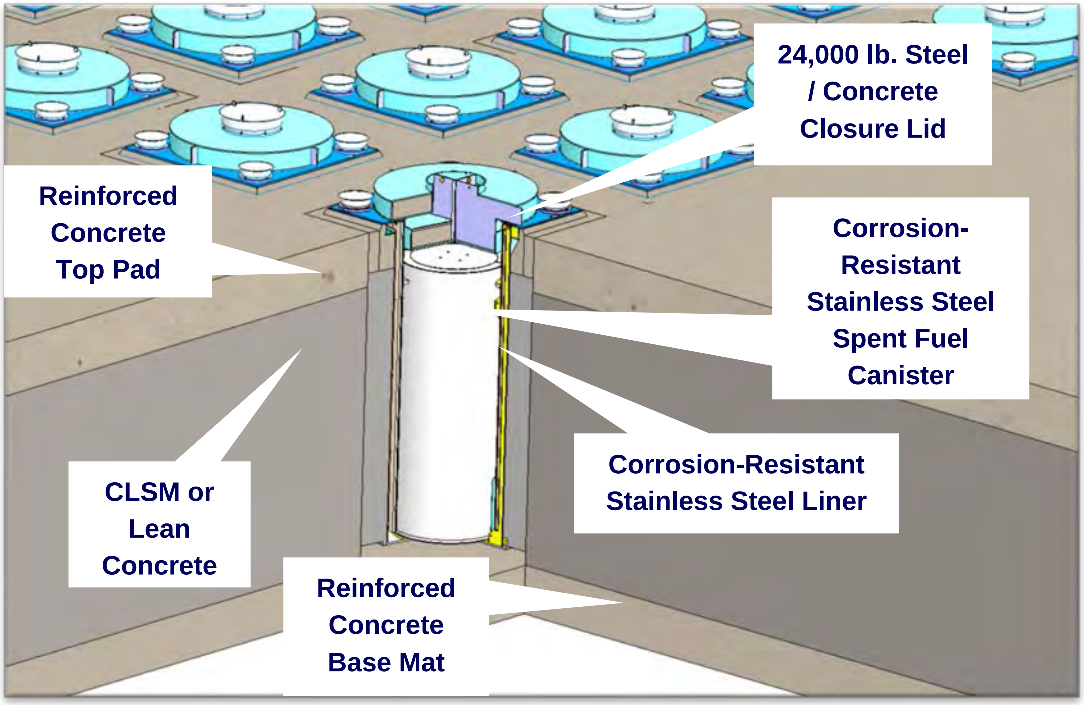
3.6 Alternative 3 – Below Grade Storage (C-UGS)

3.6.1 Description of Storage Alternative

Alternative 3 does away with pad storage altogether and places each DPC into an underground silo. Currently there is only one company that provides an underground storage system, Holtec International. The Holtec UMAX system utilizes this type of storage method and is in the process of being licensed by the NRC. No ISFSIs are currently in operation to prove the merits of this system but there are two ISFSIs under development using the UMAX system that are expected to be operational in the next 1-3 years. The Callaway nuclear plant is completing construction of the first UMAX system, and San Onofre units 2 and 3 have ordered a UMAX system. Like Alternative 2, this storage alternative creates a single overpack that stores all the DPCs.

An artist's view of a Pilot ISF using an underground storage system is shown in **Figure 3-7**.

Figure 3-7
Holtec UMAX Storage System



The UMAX storage system is an underground SNF storage concept that consists of a thick monolithic block of concrete with embedded thick walled 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.

The VVM are shown before the installation of the concrete in **Figure 3-8**. The completed UMAX installation at the Callaway ISFSI is shown on **Figure 3-9**.

Figure 3-8

Holtec UMAX VVM set on the Base Mat at the Callaway ISFSI

Figure 3-9
Holtec HI-STORM UMAX, Completed Pad Construction, Callaway ISFSI

Obviously, the Holtec system at Callaway is optimized for that plant's needs, and uses standardized welded metal canisters sized for Callaway's SNF. Application of this concept at the ISF would entail designing the VVM to accommodate the largest anticipated canisters and using spacers or adaptor frames to permit storage of different vertical and horizontal DPC designs in the silos, similar to how Alternative 2 (C-STD) would accommodate varying sizes.

3.6.2 Concept of Operations

C-UGS is a straightforward application of the Holtec HI-STORM UMAX system for SNF storage. This is a new SNF storage technology but it has only been proposed for vertical storage canisters. The C-UGS alternative will propose an approach that will broaden the applicability of this concept to accept both vertical and horizontal DPCs.

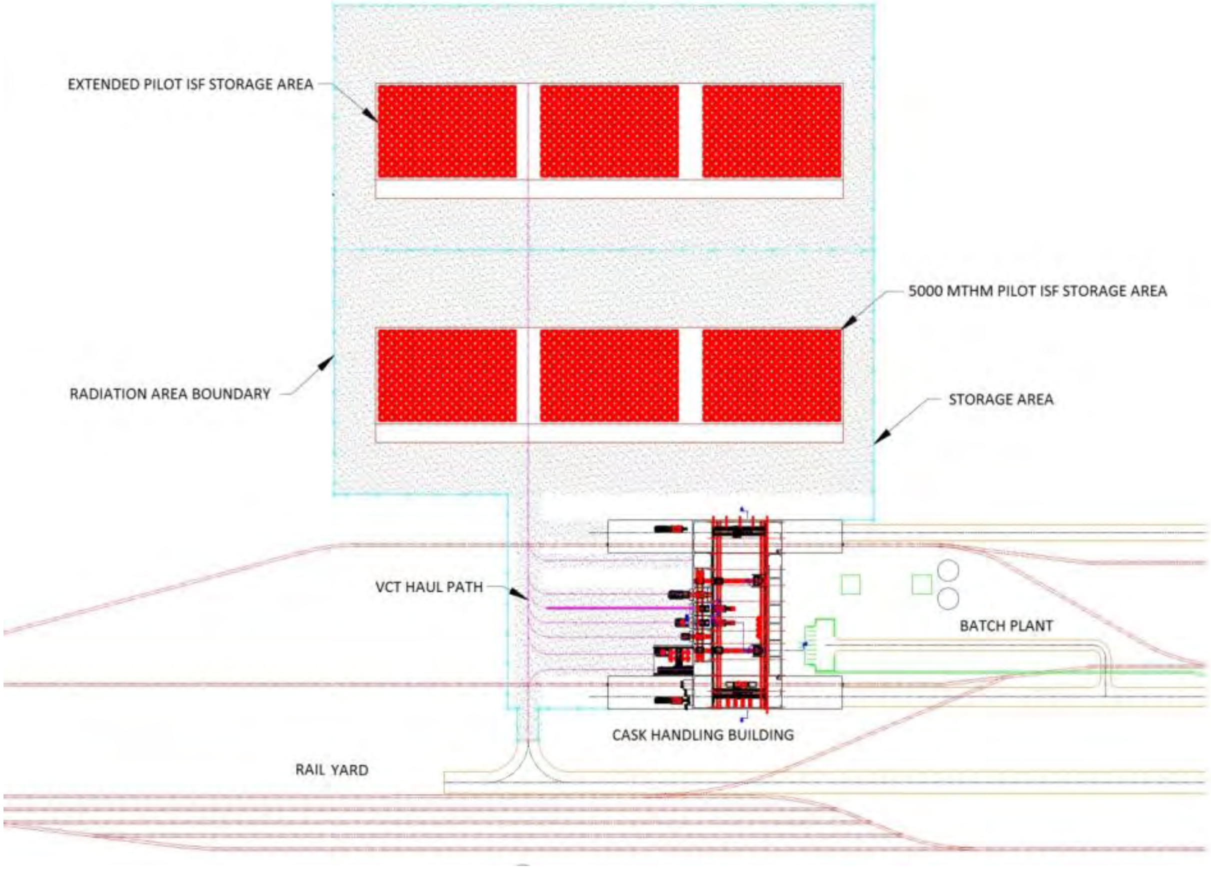
During the Cask Handling Operations, various inserts and adaptors will be provided to enable the legacy DPCs to fit properly in the cavity enclosure containers. Also, Horizontal Cask Lifting Frames for the legacy horizontal DPCs cavity enclosure containers need to be produced in order to place horizontal DPCs in the C-UGS system. The inserts/adaptors/lifting frames will be designed by the legacy DPC vendor to meet the design envelope of the C-UGS VVM.

Time and motion studies indicate that the total staffing requirements for the C-UGS Alternative will be a total ISF staff of 185, significantly better than C-PAD and C-STD. Time and motion studies also verified that the C-UGS throughput with all of the assumptions is 5 full-sized DPCs placed into storage each week.

3.6.4 ISF Expansion

Each of the Alternative storage methods was evaluated to determine if there were any additional pros or cons due to the expanded storage area. For Underground Storage, no additional pros or cons were identified. The number of underground storage units increases proportionally with the number of DPCs. Since the UMAX concept involves construction of a large number of cells (CECs) at a time, the implementation of this concept would likely consider a phased approach, in which 450 UMAX CECs could be divided into three sections of 150 CECs each to enable faster phased deployment. If needed, the 450 CECs could be divided into six or nine sections to further help expedite deployment. The Expanded ISF is shown in **Figure 3-10**.

Figure 3-10
C-UGS Pilot ISF Layout, Expanded ISF



3.6.3 Performance of Structures, Systems and Components

Appendix A3 contains detailed evaluations of the C-UGS Alternative against a number of performance issues, including structural and seismic, thermal, radiological exposure, design life/aging/maintenance, postulated accidents, licensing, and security. This work reveals limited new issues introduced by this Alternative. Experience with the Callaway project, including the detailed design, licensing and construction effort, has reduced the potential issues with C-UGS. As with the Concept of Operations discussion above, the new issues, primarily related to unanalyzed licensing issues, are:

1. The VVMs would need to be large enough to accommodate the largest of all of the commercial DPCs, requiring inserts/adaptors to ensure the protection of the confinement barrier and heat transfer capability of the original storage system.
2. Transferring horizontal DPCs into vertical VVMs.

Unlike the manner in which these issues impact the risks with Alternative #2 (C-STD) this alternative benefits from the fact that the basic design has been developed, licensed and constructed. Appendix C identifies no fundamental problems in designing the spacers which smaller DCSs would need for SNF placement in the VVMs. These spacers would be designed by the canister manufacturers according to standard VVM interface specifications, eliminating any potential issues that canister manufacturers might raise relative to releasing design information to competitors.

Storing horizontal DPCs in a vertical position could be somewhat problematic. This issue would require some analysis and licensing effort, but probably less than would be the case for C-STD. This is because of the better seismic and radiological performance of the C-UGS design and the elimination of tip-over as an issue. A structural analysis would need to be performed to determine how a horizontal canister responds to an earthquake when stored in a vertical position. Thermal analysis would need to be performed to show adequate heat removal from the DPC in the different orientation such that all the SNF and DPC materials are below design limits.

3.6.4 Summary; Pros and Cons for This Storage Alternative

Pros

- Removes the possibility of overpack tipover or sliding caused by an earthquake since the DPC is locked into position within the ground.
- Greatly reduces direct radiation from the sides of the DPC by using the earth as a shield. The distance to the Owner Controlled Area boundary could be reduced due to the reduction in direct and skyshine radiation.
- Minimizes security concerns since the DPCs 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.
- The UMAX is licensed which will enable the SAR to be referenced into a Site Specific license reducing the overall licensing duration.
- Depending on their size and layout, the underground storage blocks could be implemented over time, reducing their initial capital costs. Implementation would not be as flexible as C-OPS or C-STD but could be constructed in smaller blocks to suit the forecasted storage needs.

Cons

- 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.
- A canister transfer facility would be required to offload transport casks perform vertical canister transfer from the transport cask to a transfer cask and to re-package the horizontal canisters into a lifting cage. This large facility would increase the cost of the Alternative.
- 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 DPC sizes. The underground silo would need to be constructed for the largest DPC. This would in turn necessitate design and fabrication provisions for the smaller DPCs such as shims or spacers to ensure they would not be battered around during an earthquake or ducting to insure adequate heat removal.
- Horizontal DPCs 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 DPCs in a vertical position would require additional analyses. New thermal, structural and shielding analyses would need to be performed to show the horizontal DPCs could be placed in the vertical position without adverse effects.

3.7 Alternative 4 – Below Grade Vault (C-BGV)

3.7.1 Description of Storage Alternative

Alternative 4 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. These systems require more up front capital investment but are cost effective if the total storage capacity is fixed and known during the design process. In the USA, air-cooled vaults have been used or proposed to store non-LWR SNF. Most recently, an air-cooled vault design has been chosen to house the SNF from the decommissioned Fort St. Vrain (FSV) High Temperature Gas Cooled Reactor.

In this concept, 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 sliding and tipping 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 direct cool outside air into the vaults. This natural draft system provides bulk cooling to remove the decay heat from the SNF. **Figure 3-11** is a photograph of the FSV facility.

There are four variants of this alternative:

4. a. Below Grade Vault, with Integral CHB storing DPCs vertically, C-BGVa

4. b. Below Grade Vault, with Integral CHB storing DPCs vertically and horizontally, C-BGVb

4. c. Below Grade Vault, with Separate CHB storing DPCs vertically, C-BGVc

4. d. Below Grade Vault, with Separate CHB storing DPCs vertically and horizontally, C-BGVd.

Typically, air-cooled vaults used for the storage of nuclear SNF have stored individual fuel assemblies in vertical storage locations. The ISF air-cooled vaults will need to accommodate DPCs that house many fuel assemblies and it will need to accommodate DPCs designed to be stored both vertically and horizontally. There are two ways of accomplishing this:

1. The horizontal DPCs can be loaded into lifting frames that enable the horizontal DPCs to pick up and stored vertically.

2. The horizontal DPCs can be stored horizontally in a dedicated storage area.

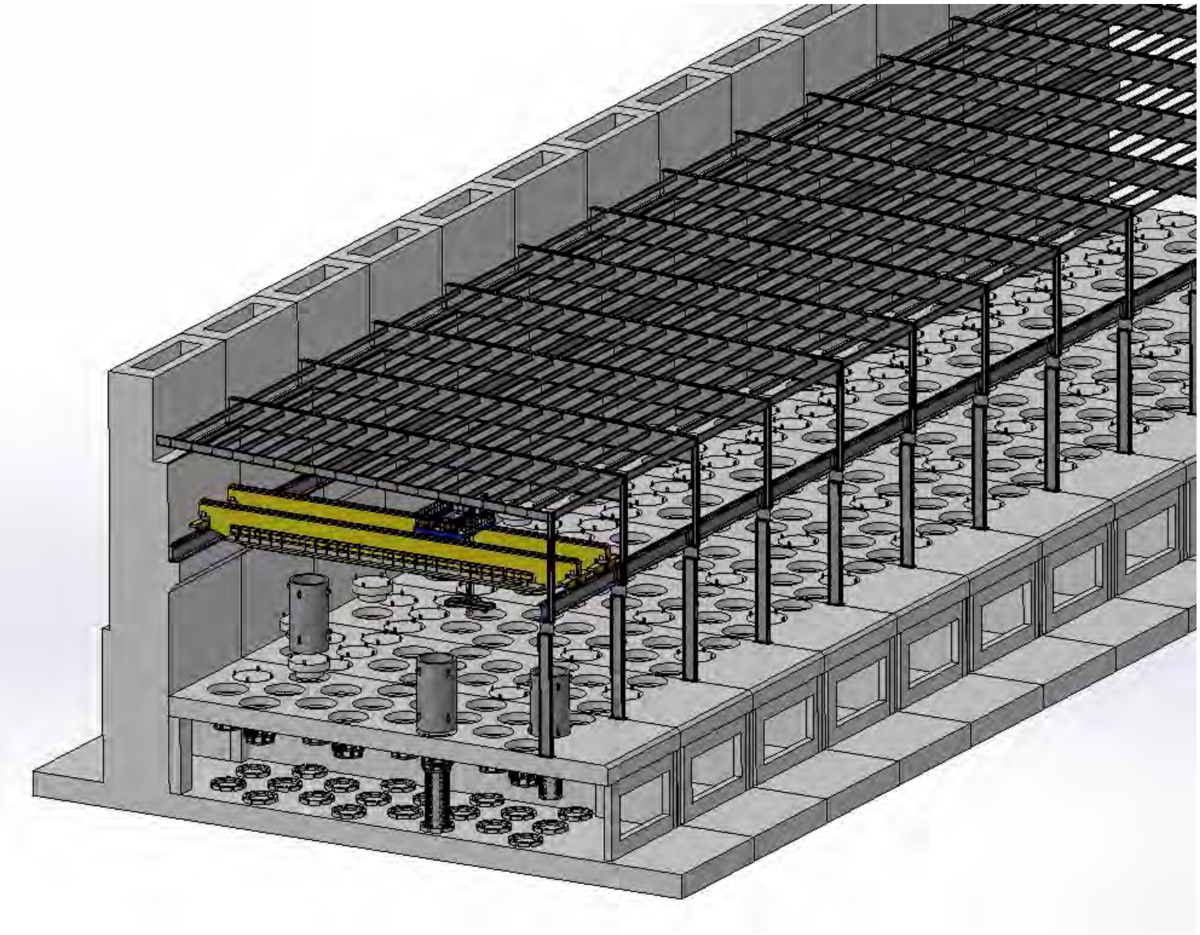
Both of these approaches have disadvantages. The first requires additional handling steps and components and results in the fuel being stored upside down. The second requires a novel approach to air-cooled vaults that is unprecedented in the industry. Horizontal storage would require active ventilation, which would require a change to the NRC regulations – one that NRC may not be willing to consider. Therefore, this study determined that horizontal storage of DPCs would be unacceptable, due to the need for active cooling and DPC retrieval difficulties.

Another variation considered in this study is the location of the Cask Handling Building (CHB). The CHB can be integral to the storage vault or it can be a separate, standalone structure. The benefit of an integral CHB is that it simplifies operations and eliminates transferring casks between buildings. The disadvantage is that in the event of a need to expand the ISF, the CHB will need to be part of each new vault constructed. This will increase cost and involve not only duplicating the CHB hardware, but also reconfiguring the rail lines on the site to be able to interface with the new CHB location. A standalone CHB eliminates these issues at the cost of an increase in labor, and equipment necessary to transfer DPCs between the CHB and the storage vaults.

Figure 3-11
Fort St. Vrain ISFSI Vault Storage System

A model of the vault bays showing the crane, storage positions, and the chimney used to passively cool the DPCs is shown in **Figure 3-12**.

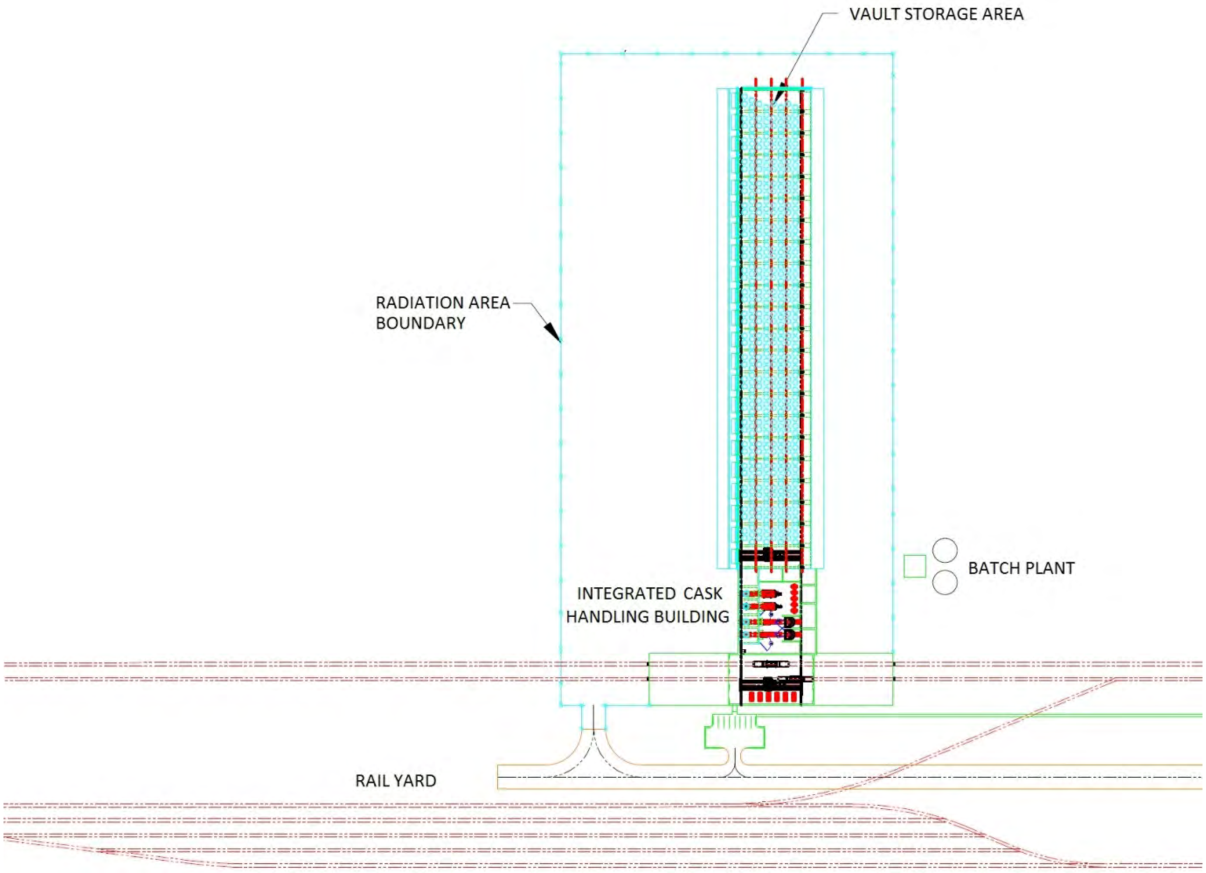
Figure 3-12
Vault Bays for Commercial DPC Storage



3.7.2 Concept of Operations

The Below Grade Vault alternative has four variants with integral or standalone CHBs and with all vertical or vertical and horizontal storage. **Figure 3-13** shows the Below Grade Vault overall site layout with the first variant (integral CHB).

Figure 3-13
Conceptual Overall Site Plan of Below Grade Vault with Integral CHB



For the second variant of the concept, the CHB is centrally located between the different vaults. **Figure 3-14** shows the two configurations of the vault area with integral CHB: BGVa is on the left and BGVb is on the right. It is obvious that BGVb is larger and more complex than BGVa. This is because the horizontal storage layout is much less space efficient than the vertical layout.

Figure 3-14
Conceptual Plan of the Below Grade Vault with Integral CHB

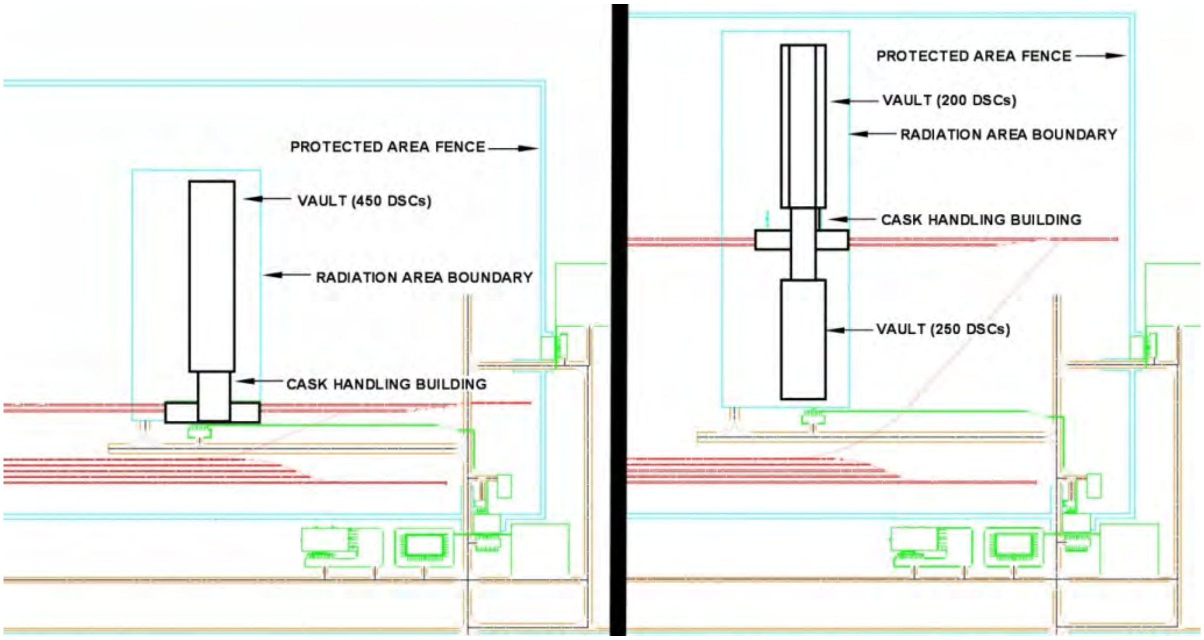


Figure 3-15 shows the ISF site layout for below grade vaults with standalone CHB. As can be seen, the only difference in the layout of the site is the position of the CHB relative to the storage vault. It is also clear that because of the layout, the capital CHB can have two rail bays and independent OTB cranes.

Figure 3-15
Conceptual Overall Site Plan of Below Grade Vault with Standalone CHB

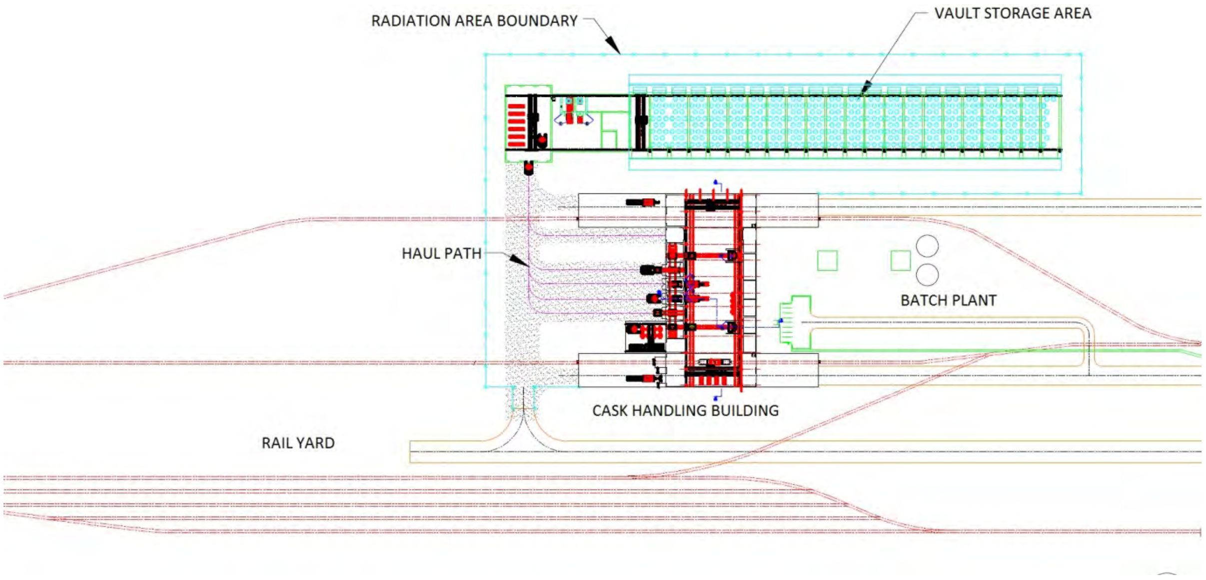
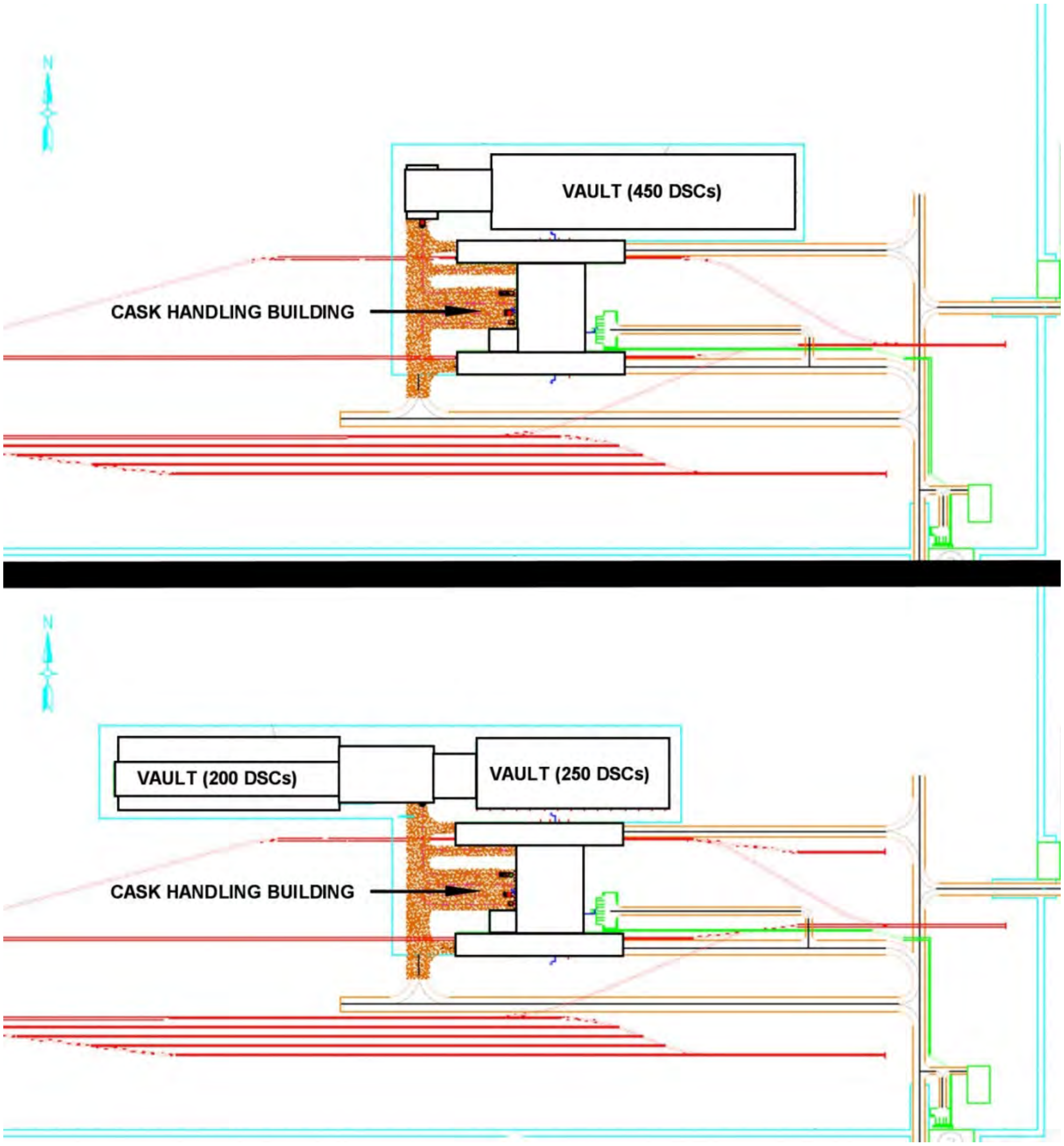


Figure 3-16 shows the two configurations of the vault area with standalone CHB. BGVc is on the top; BGVd is on the bottom. It can be seen from these layouts that the expansion of the site is simplified by this approach and a wide variation of vault configurations could be added giving these variants broad capabilities for expansion.

Figure 3-16
Conceptual Plan of the Below Grade Vaults with Standalone CHB



The designs of the BGVc/BGVd variants are significantly impacted by how the DPC is delivered to the Vault Building from the CHB. A simplistic approach is to move the transport cask directly from the CHB to the Vault Building where the DPC can be unloaded directly into the appropriate transfer device. This has several drawbacks. First, the cycle time of the ISF is determined by how rapidly the transport cask can be unpacked, emptied, and repackaged for shipment back to the generators. Moving the transport cask to the Vault Building delays the repackaging for shipment and thereby reduces the achievable throughput for the facility. In addition, there are several potential activities that must be performed in order to assure that the DPC is properly placed in storage. Lifting frames and adapters, as appropriate, must be installed on the DPC after it is removed from the transport cask. If the transport cask is moved directly from the railbay to the Vault Building, these activities would need to be performed in the vault building. This would require significant material handling capabilities be designed into the Vault Building which would duplicate many of the functions in the CHB. The result would be the construction of a standalone CHB and a CHB in each Vault Building.

For this reason, this study has assumed the use of a shielded transfercask to transfer the DPC to the Vault Building with whatever adaptor/insert/lifting frame necessary for placement of the DPC into storage. This adds several complex and heavy components to the ISF inventory but it significantly increases the throughput possible. It also concentrates most of the DPC preparation activities in the CHB. This allows for better utilization of the work crews by segregating the types of work into the appropriate buildings.

Time and motion studies indicate that the total staffing requirements for the C-BGV Alternative will be a total ISF staff of 162 for variants BGVa and BGVb (integral CHB), and 185 for variants BGVc and BGVd (standalone CHB), both significantly better than C-PAD and C-STD. However, time and motion studies verified that the C-BGV throughput for both integral CHB variants, with all of the assumptions, is 2.5 full-sized DPCs placed into storage each week – half that of the other alternatives. A throughput of 5 DPCs can be achieved for both Standalone CHB options.

3.7.3 ISF Expansion

Each of the Alternative storage methods was evaluated to determine if there were any additional pros or cons due to the expanded storage area. For Below 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 DPCs 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. **Figure 3-17** shows the vault storage layout with integral canister transfer for the Expanded ISF. **Figure 3-18** shows the vault storage layout with a standalone CHB for the Expanded ISF. **Figure 3-19** shows the vault cross section of the storage layout and Transfer Sleeve.

Figure 3-17
Expanded ISF Vault Storage Layout with Integral Canister Transfer

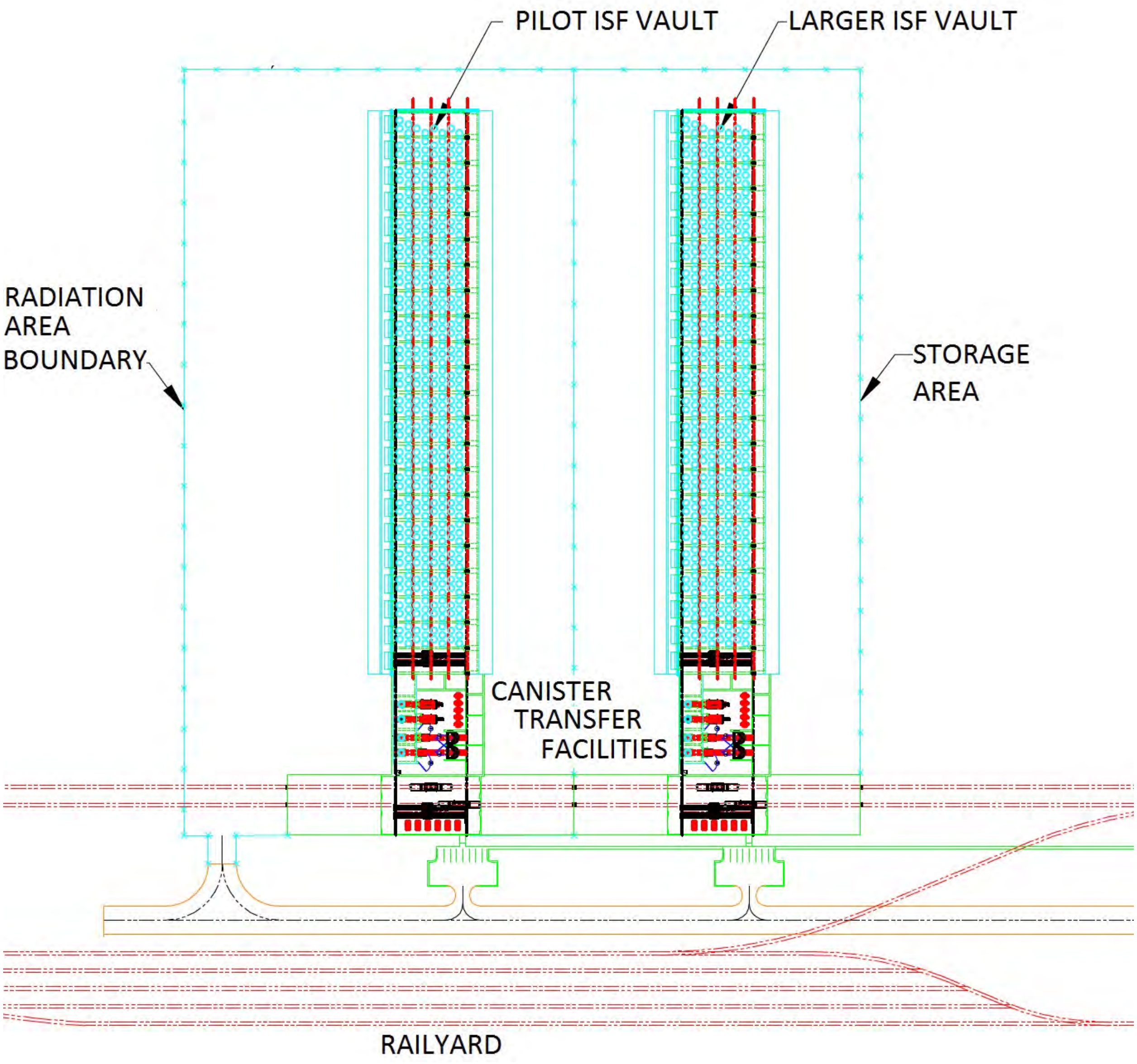


Figure 3-18
Expanded ISF Vault Storage Layout with Standalone Canister Transfer

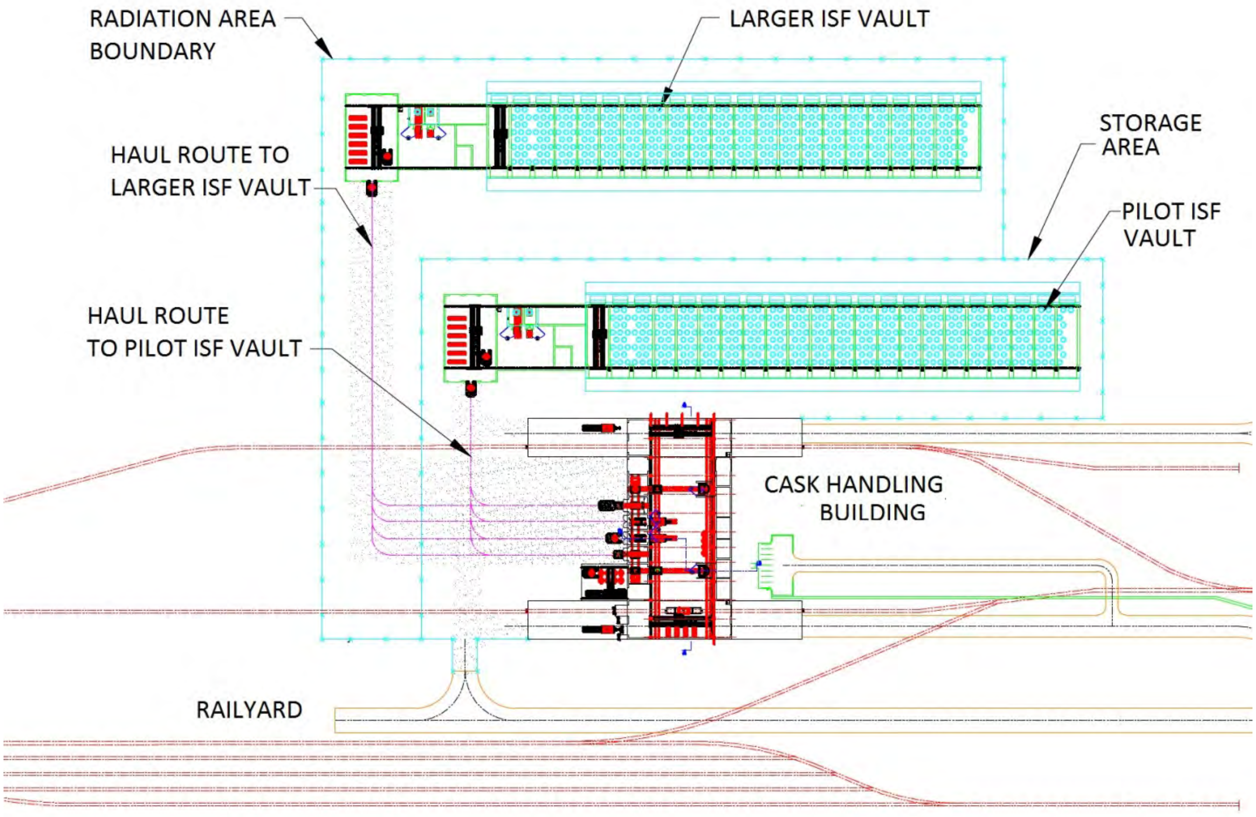
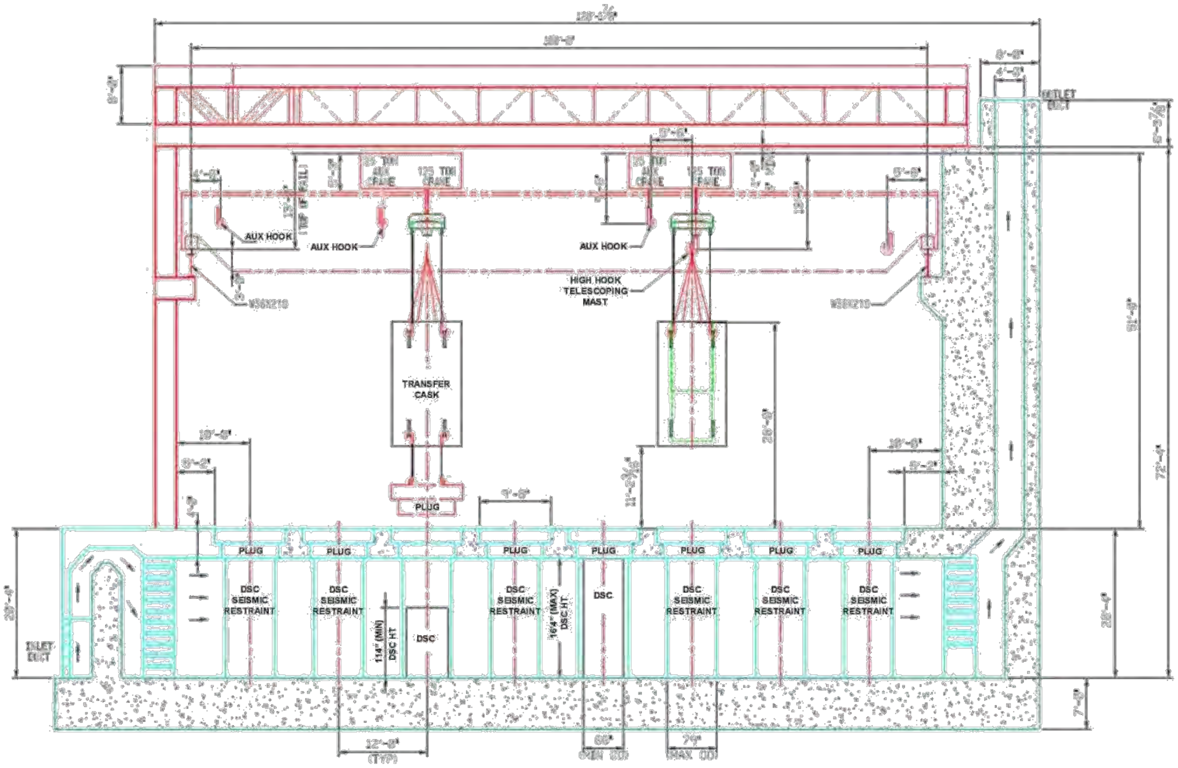


Figure 3-19
Cross-Section of the Storage Vault



3.7.4 Performance of Structures, Systems and Components

Appendix A4 contains detailed evaluations of the C-BGV Alternative against a number of performance issues, including structural and seismic, thermal, radiological exposure, design life/aging/maintenance, postulated accidents, licensing, and security. A number of issues were identified, as discussed above.

There are significant licensing challenges with Alternative 4. Design and licensing tasks would be extensive and involve significantly more time than the other storage methods. The NRC has never licensed a vault system for storing large commercial DPCs. The performance characteristics of a vault would need to be licensed as part of the Pilot ISF Specific License which would require considerable development in the ISF SAR, costing more NRC review time. As with Alternatives 2 and 3, this vault storage method would involve obtaining a single license for systems owned by four different spent fuel storage system vendors. Therefore, the use of this method could incur proprietary conflicts that could be difficult to resolve, possibly involving legal issues.

Vault storage for large commercial DPCs is still conceptual, unlike other storage methods. In order to store 450 DPCs, a vault 100 ft. in width would need to be about 800 ft. long, increasing the complexity of the structure. The canisters (fuel storage containers) at FSV are much smaller (only 18 inches in diameter), and have a much lower heat release rate than LWR DPCs, so FSV experience is not entirely transferable.

As with Alternatives 2 and 3, the horizontal DPCs cannot be lifted by the lid and would require some type of lifting cage to lift and place into a vertical position. The lifting cage for handling horizontal DPCs in a vertical orientation would need to be addressed in the licensing documentation (i.e., ISF SAR).

3.7.5 Summary; Pros and Cons for This Storage Alternative

Pros

- Since the DPC storage is effectively indoors, the vault alternative may provide a more controlled environment than other alternatives. The DPCs 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 DPCs. The DPCs 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 with an integral CHB. Once the railcar enters the facility there are no outdoor operations unless a separate CHB concept is used.
- A vault shields DPCs from view, easing security concerns. Also, since the DPCs are stored within a secured building, they are more protected from design basis explosions or unauthorized intrusions. In addition, security staff can observe the entire storage area since the system is all internal to the C-BGV building.
- The below grade vault positions the DPCs so that direct radiation from the sides of DPCs is shielded by the ground.
- Removes the possibility of DPC tipover caused by an earthquake or other postulated accidence since the DPCs are locked into position within the vault.
- Below grade vaults with integral CHBs have inherently lower throughputs than vaults with standalone CHBs, but accomplish this at a significant reduction in capital and operating costs during the cask handling phase of the project. If the throughput is acceptable based on the ability to deliver DPCs to the site, and if expansion of the Pilot ISF is not desired, these designs offer a lower cost approach to storing SNF in vaults. If, on the other hand, it is determined that expansion of the Pilot ISF is appropriate, the follow-on concepts are not forced to follow the same design. In other words, a below grade vault with standalone CHB

can be added to the site at a later date to increase throughput or to expand the capacity of the site.

Cons

- Unlike other storage methods, vault storage for large commercial DPCs is still conceptual. Canisters stored in existing vaults do not have the increased performance issues such as weight and thermal loading characteristic of commercial DPCs. 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 DPCs, 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 Fort St. Vrain (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 DPCs. 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.
- Most DPCs 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 DPCs with hotter SNF may not be able to be adequately cooled in a vault which would require longer pool cooling prior to storage.
- Like C-STD and C-UGS, 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 DPC sizes. Each floor opening would likely be the same diameter which would require some means to keep smaller DPCs secure. This would necessitate design and fabrication provisions for the smaller DPCs such as shims or spacers to ensure they would not be battered around during an earthquake.
- Like C-STD and C-UGS, the horizontal DPCs 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.

- Placing horizontal DPCs in a vertical position would require additional analyses. New thermal, structural and shielding analyses would need to be performed to show the horizontal DPCs could be placed in the vertical position without adverse effects.
- In order to store an additional 5,000 MTHM of spent fuel, an entire new vault would need to be constructed attached to the cask handling building. If more than 10,000 MTHM of spent fuel storage is required beyond the expanded ISF, a completely separate vault structure with CHB would need to be constructed.

3.8 Alternative 5 – Above Grade Vault (C-AGV)

3.8.1 Description of Storage Alternative

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. The four variants are identical to C-BGV:

5. a. Above Grade Vault, with Integral CHB storing DPCs vertically, C-AGVa

5. b. Above Grade Vault, with Integral CHB storing DPCs vertically and horizontally, C-AGVb

5. c. Above Grade Vault, with Separate CHB storing DPCs vertically, C-AGVc

5. d. Above Grade Vault, with Separate CHB storing DPCs vertically and horizontally, C-AGVd.

As was the case for the below grade vault, this study determined that horizontal storage of DPCs would be unacceptable, due to the need for active cooling and DPC retrieval difficulties.

3.8.2 Concept of Operations

The concept of operations for this alternative is identical to that of Alternative 4, Below Grade Vault. The layout drawings for the four variations displayed above in **Section 3.7** are applicable to the Above Grade Vault Alternative.

Time and motion studies indicate that the total staffing requirements for the C-AGV Alternative will be identical to the C-BGV Alternative: a total ISF staff of 162 for variants AGVa and AGVb (integral CHB), and 185 for variants AGVc and AGVd (standalone CHB), both significantly better than C-PAD and C-STD. However, time and motion studies verified that the C-AGV throughput for both integral CHB variants, with all of the assumptions, is 2.5 full-sized DPCs placed into storage each week – half that of the other alternatives. A throughput of 5 DPCs can be achieved for both Standalone CHB options.

3.8.3 ISF Expansion

Each of the Alternative storage methods was evaluated to determine if there were any additional pros or cons due to the expanded storage area. For Above Grade Vaults, additional storage at vaults creates some difficulties. Vaults nearly 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. 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 DPCs 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.

3.8.4 Performance of Structures, Systems and Components

Appendix A5 contains detailed evaluations of the C-AGV Alternative against a number of performance issues, including structural and seismic, thermal, radiological exposure, design life/aging/maintenance, postulated accidents, licensing, and security. A number of issues were identified, as discussed above.

There are significant licensing challenges with Alternative 5, all of which are described above for Alternative 4. The above grade configuration adds additional challenges because of its height, e.g., seismic design and licensing.

3.8.5 Summary; Pros and Cons for This Storage Alternative

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 DPCs. The walls of the structure itself would need to be thick enough to shield the DPC 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 DPCs may need to be designed to provide adequate radiation shielding and withstand a design basis explosion since they are not protected by the ground as in the below grade vault.

4.0 STUDY 2 – ALTERNATIVE CASK OPERATIONS METHODS & CONFIGURATIONS INTRODUCTION

4.1 Background

The purpose of Design Study #2 is to evaluate canister processing operations at the interim storage facility (ISF). These operations begin at receipt of a transport cask carrying a dual purpose canister (DPC) through DPC transfer to a storage configuration and end at the final storage location. Design Study #2 evaluates operational alternatives to reduce the complexity, cost, and personnel exposure associated with cask operations at the ISF.

A cask handling building at the ISF is envisioned to be a facility that receives transport casks and uses the appropriate transfer methods to transfer the DPC to a storage configuration. It may be more efficient and reduce personnel exposure if, for example, these operations were conducted remotely in a shielded facility. This study examines alternative cask handling methods and configurations, considering a range of DPC receipt rates to include 1,500 MTHM/year, 3,000 MTHM/year, and 4,500 MTHM/year; and evaluates alternative methods to improve time and motion for each process step in handling dry storage canisters, including modular concepts for increasing receipt rate and other methods to improve throughput.

For each DCS handling approach evaluated in this task, this study:

- Identifies and includes design criteria for each alternative DCS handling alternative.
- Identifies items that are common, or generic, to all facilities regardless of site location and DCS storage concept.
- Considers and includes (as appropriate) the facility design, fabrication, construction, testing, maintenance, and performance requirements for SSCs important to safety. The study considers that the facilities could be "East or West of the Rocky Mountain Front" as defined in 10CFR72 and will be subject to 10CFR71 design criteria for such locations.
- Develops total estimated costs (TEC), total project costs (TPC), and annual operating costs.
- Develops a concept of operations, including assessments of the time and motion required for transferring the fuel from the transport casks to the storage configurations and the anticipated worker dose for each alternative DCS handling system evaluated.
- Assesses the licensability of each alternative cask handling concept evaluated.
- Identifies equipment maintenance requirements.

The following alternatives are evaluated in Study #2:

1. C-OPS, Current Canister Processing Operations (Base Case)
2. A-OPS, Automated Canister Handling Operations
3. R-OPS, Remote Canister Handling Operations
4. S-OPS, Simplified Cask Handling Operations

Cask handling operation activities at the ISF for Alternatives 1, 2, and 3 are envisioned to be performed in the Cask Handling Building (CHB) that receives incoming transport casks and uses the appropriate transfer cask to transfer the DPC to a storage configuration. Alternative 4 considers the option of doing away with the CHB (or initiating cask handling operations prior to completion of CHB construction), and conducting cask handling operations at the ISF in a manner similar to how they are done at some operating nuclear plant sites today. For each of these alternatives, both vertical and horizontal storage system operations are considered.

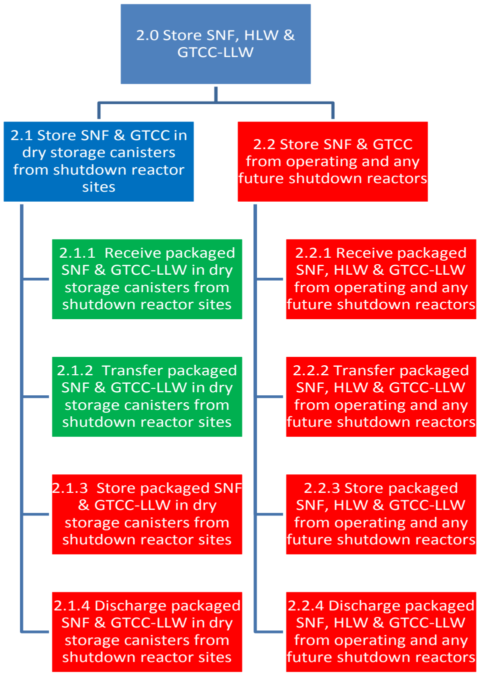
4.2 Design Criteria for Study 2

The objective for Design Study #2 is to examine alternative cask handling methods and configurations, given a range of DPC receipt rates, to determine which alternative methods improve time and motion and/or dose rates for each process step in handling dry storage canisters. The range of DPC receipt rates includes 1,500 MTHM/year, 3,000 MTHM/year, and 4,500 MTHM/year. The study must also consider modular concepts or other methods that could increase receipt rates and improve canister processing throughput.

4.2.1 Functional Requirements

The "*Nuclear Fuel Storage and Transportation Requirements Document (NFST)*" developed a number of system level functions applicable to the overall Waste Management System. **Figure 4-1** shows the top-level functions (2.1.1 and 2.1.2) that apply to this Design Study 2 effort.

Figure 4-1
Study 2 Top–Level Functions

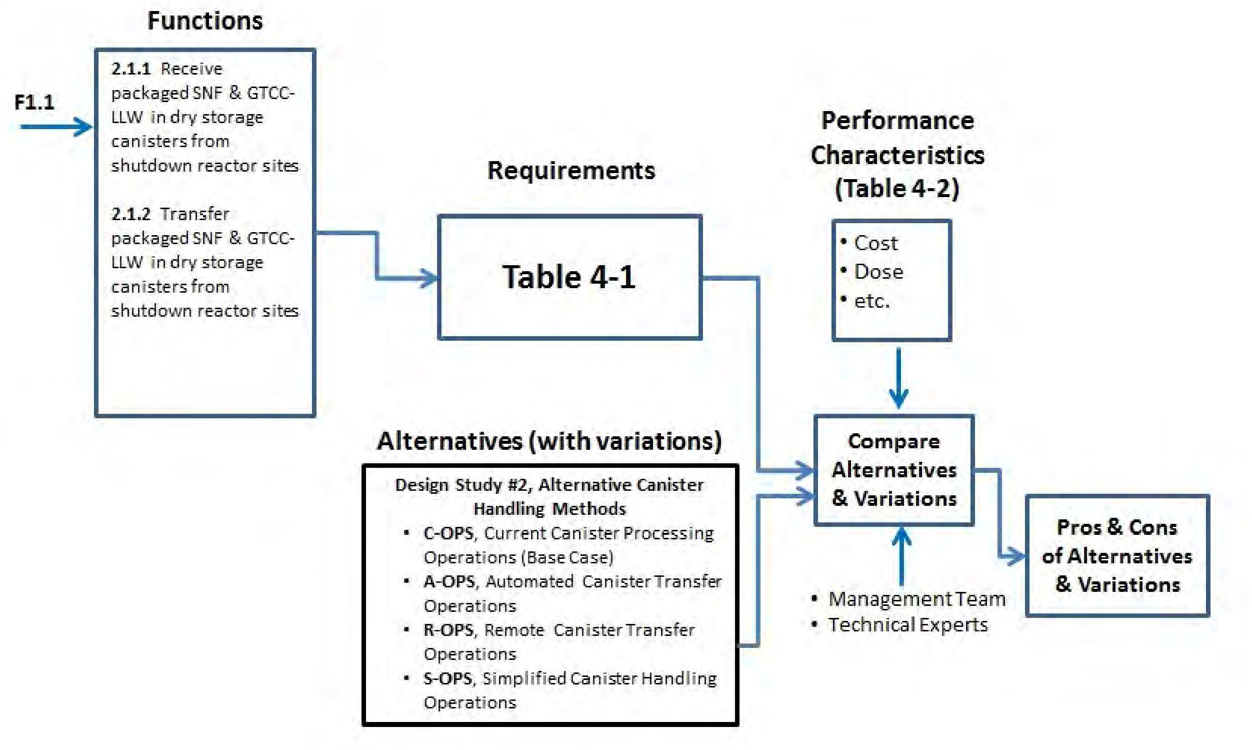


The systems engineering approach used for Study 2 is a structured process, based on hierarchical decomposition that transforms the mission need for long-term management of commercial SNF into a preferred cask handling concept which best satisfies the need. The basic approach was to apply the functions-requirements-architecture (F-R-A) process as shown in **Figure 4-2**. Functions define what the system must do, requirements specify how well it must be done, and architecture (at the top levels of the hierarchy) identifies the preferred strategy for accomplishing it. The F-R-A process was applied to each of the functions encountered over the lifecycle of the Study 2 Alternatives.

This systematic approach ensured the following:

- All cask handling functions that are both necessary and sufficient to contribute to satisfaction of the mission were identified.
- Important requirements associated with each cask handling function were specified.
- Specific strategies, technologies, and systems for performing the cask handling functions subject to their requirements were formulated and consistently evaluated; and the pros and cons of each alternative were established.
- The eventual preferred concept will be a well-integrated system.

Figure 4-2
Systems Engineering Approach to Evaluation of Canister Handling Alternatives



Specific design requirements from the TO16 SOW that were applicable to the Design Study #2 effort are shown in **Table 4-1**.

Table 4-1
Design Study #2 Design Requirements

<table>
<tr><th>Requirements from Nuclear Fuel Storage and Transportation Requirements Document (FY2014)</th></tr>
<tr><td>R 0.1.1 The pilot ISF will accept commercial SNF stored in dry storage canisters from shutdown reactor sites.</td></tr>
<tr><td>R 0.1.4 The pilot ISF and larger ISF will accept GTCC-LLW</td></tr>
<tr><td>R 0.2 The WMS shall be capable of handling canisters in use by the commercial nuclear industry and the federal government as currently defined in the latest revision of <i>Dry Storage of Used Fuel Transition to Transport</i>, FCRD-UFD-2012-000253.</td></tr>
<tr><td>R 0.4 The WMS shall be capable of accommodating SNF, HLW and GTCC- LLW at the annual acceptance rates specified in this Table.
<table>
<tr><td>Year</td><td colspan="2">Pilot ISF</td></tr>
<tr><td></td><td colspan="2">Shutdown Reactor Sites</td></tr>
<tr><td></td><td>SNF</td><td>GTCC- LLW</td></tr>
<tr><td>1</td><td>500 MTHM/yr.</td><td>TBD</td></tr>
<tr><td>2</td><td>1,000 MTHM/yr.</td><td>TBD</td></tr>
<tr><td>3</td><td>1,500 MTHM/yr.</td><td>TBD</td></tr>
<tr><td>4</td><td>1,500 MTHM/yr.</td><td>TBD</td></tr>
</table></td></tr>
<tr><td>R 0.4.1 The Pilot ISF acceptance rate shall be ramped up over the first three years of operation to 1,500 MTHM/yr.</td></tr>
<tr><td>R 0.6 WMS shall provide a platform for ongoing R&D to better understand how the storage system will perform over time</td></tr>
<tr><td>R 0.7 The pilot ISF shall begin operations in 2021.</td></tr>
<tr><td>R 0.11 The Packaging System infrastructure shall have a design life</td></tr>
<tr><th>Requirements from <i>A Project Concept for Nuclear Fuels Storage and Transportation</i> (June 15, 2013)</th></tr>
<tr><td>3.1.2.1 Design to focus on accepting SNF and GTCC from shutdown reactor sites in dry storage canisters.</td></tr>
<tr><td>3.1.2.1 Design to be generic, within NWPA regulations.</td></tr>
<tr><td>3.1.2.1 Design receipt rate to accept and store all SNF and GTCC from current shutdown reactor sites within five years (ramping up to 1500 MTHM/year).</td></tr>
<tr><td>3.1.2.1 Capable of receiving, handling, and storing all dry storage canisters currently licensed for storage and transportation in the existing canisters without opening the canisters.</td></tr>
<tr><td>3.1.2.1 Able to obtain the necessary environmental, state and local permits.</td></tr>
<tr><td>3.1.2.1 Licensed by the NRC meeting 10CFR72 requirements.</td></tr>
<tr><td>3.1.2.1 Facility must meet security requirements of 10CFR73.</td></tr>
<tr><td>3.1.2.1 Operational life will be the time to receive and hold SNF until a repository is ready to receive shipments, including the time to ship all stored SNF to a repository. Design life is 100 years.</td></tr>
<tr><td>3.1.2.2 The design may include a canister repackaging facility (CRF) capable of removing individual assemblies and packaging them in disposal canisters suitable for transport to the repository. Since the repository requirements are not currently known the design will investigate the impact of multiple disposal canister sizes.</td></tr>
<tr><td>3.1.2.1 Operational life will be the time to receive and hold SNF until a repository is ready to receive shipments, including the</td></tr>
</table>

time to ship all stored SNF to a repository. Design life is 100 years.
3.1.2.1 Flexible design to allow for future expansion.
3.1.2.1 The Pilot shall receive all spent fuel and GTCC waste from currently decommissioned shutdown sites by the time the larger interim storage facility is ready to receive fuel (expected to be 5 years). Assumes all SNF is in dry storage casks.
NRC Requirements
10 CFR 72, NRC Licensing Requirements For The Independent Storage Of Spent Nuclear Fuel, High-Level Radioactive Waste, And Reactor-Related Greater Than Class C Waste
TO16 SOW Requirements
Pilot ISF throughput - average rate of 1,000 MTHM/year
Pilot ISF throughput - maximum rate of 1,500 MTHM/year
Pilot ISF will accept SNF from shutdown reactor sites
Pilot ISF capable of receiving SNF from shut-down sites without the need to open the dry storage canisters or handle bare fuel assemblies
The Pilot ISF may provide expanded storage capability such that additional SNF could be handled from other shut-down and/or operating reactors that have Dual Purpose Casks (DPC) and transportable storage casks (TSC) available to ship. This expanded capacity is estimated to hold up to 10,000 MTHM (inclusive of the 5,000MTHM described above).

4.2.2 Performance Characteristics

Trade studies were performed on each feasible alternative to estimate its expected performance with respect to the performance characteristics required in **Table 4-2**. The project team then deliberated to identify the pros and cons of each alternative, some of which were necessarily based on qualitative evaluations.

This systematic approach ensured the following:

- All performance characteristics pertaining to the cask handling function were specified, verified, and considered
- Specific alternatives for performing the cask handling function subject to its requirements were formulated, consistently evaluated, and explicitly compared

Table 4-2
Performance Characteristics for Cask Handing Alternatives

Performance Characteristics
Receipt rate of 1,500 MTHM/year
Receipt rate of 3,000 MTHM/year
Receipt rate of 4,500 MTHM/year
Alternative methods to improve time and motion and improve throughput
Performance requirements for SSCs important to safety

Performance Characteristics
Total estimated cost (TEC) ($)
Total project cost (TPC) ($)
Annual operating and maintenance (O&M) costs ($/year)
Concept of operations, including assessments of the time and motion required for transferring the fuel from the transport casks to the storage configurations (hours)
Anticipated worker dose (mr/hr.)
Licensability
Equipment maintenance requirements

4.2.3 TO 16 References, Regulations, Codes and Standards

The TO16 project provided a number of specific references to be used for the study effort. In addition, there are several regulations, codes and standards that may be applicable to the ISF design and storage of canisters. The TO 16 references, regulation, codes and standards are listed in **Table 4-3**.

Table 4-3
TO 16 References, Regulations, Codes and Standards

DOE Requirements
FCRD-NFST-2013-000020, “Used Fuel Management System Architecture Evaluation, Fiscal Year 2012,” Argonne National Laboratory (ANL), Savannah River National Laboratory (SRNL), and Oak Ridge National Laboratory (ORNL), Revision 0, October 2012.
FCRD-NFST-2013-000132, “A Project Concept for Nuclear Fuels Storage and Transportation”, Nuclear Fuels Storage and Transportation Planning Project (NFST), Revision 1, April 2013
FCRD-NFST-2012-000613, “Preliminary Evaluation of Removing Used Nuclear Fuel from Nine Shut-down Sites,” Pacific Northwest National Laboratory (PNNL), Savannah River National Laboratory (SRNL), and Sandia National Laboratory (SNL),
FCRD-NFST-2013-0000263, “Nuclear Fuels Storage and Transportation Planning Project Inventory Basis”, Revision 0, August 30, 2013.
“Fuel Cycle Technologies Quality Assurance Program Document, ”U.S. Department of Energy, Revision 2, December 2012
Quality Rigor Level 3 guideline No. 1 Study shall be conducted in accordance with the Laboratory’s DOE-approved quality assurance program.
Quality Rigor Level 3 guideline No. 2 Deliverables shall receive a technical review
Quality Rigor Level 3 guideline No. 3 The general requirements specified in FCT QAPD Section 6 shall also be met

NRC Regulations
10 CFR 71, "Packaging and Transportation of Radioactive Material," U.S. Nuclear Regulatory Commission
10 CFR 72, "Licensing Requirements For The Independent Storage Of Spent Nuclear Fuel, High-Level Radioactive Waste, And Reactor-Related Greater Than Class C Waste," U.S. Nuclear Regulatory Commission
10 CRF 73, Physical Protection of Plants and Materials U.S. Nuclear Regulatory Commission, Revision 1, July 2010
Regulatory Guide 1.76, "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants," Nuclear Regulatory Commission, Revision 1, March 2007
NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," U.S. Nuclear Regulatory Commission, Revision 1, July 2010
NUREG-1567, "Standard Review Plan for Spent Fuel Dry Storage Facilities," U.S. Nuclear Regulatory Commission, Revision 0, March 2000
NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel," U.S. Nuclear Regulatory Commission, March 2000.
NUREG-0554, "Single-Failure-Proof Cranes for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, May 1979
NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," U.S. Nuclear Regulatory Commission, July 1980
Industry Codes and Standards
ASME III, Division 3, Containment Systems for Spent Fuel and High Level Waste Transport Packaging, American Society of Mechanical Engineers, 2013.
ASME Code Case N-595-4, "Requirements for Spent Fuel Storage Canisters." ASME III, Division 1, American Society of Mechanical Engineers, 2013
ACI 349, "Code Requirements for Nuclear Safety Related Concrete Structures," American Concrete Institute, 2006
ANSI/AISC N690, "Specification for Safety-Related Steel Structures for Nuclear Facilities," American Institute of Steel Construction, 2012
NFPA 70, "National Electric Code," National Fire Protection Association, 2014

4.2.4 Canister Processing Facility Design Criteria

Design Study #2 centers around alternative cask handling methods and configurations involved in receiving and removing the transport cask from a rail car or truck and transferring the canister from the transport cask to the storage overpack. Most of these operations are likely to occur in a canister processing facility which has the equipment to facilitate the process. The canister processing facility, which could also be called a canister transfer building or cask handling building, will contain a rail and truck access point, large cranes, radiological shielded cells and other features that enable the canister processing.

The design criteria for the Canister Processing Facility are shown in **Table 4-4**.

Table 4-4
Canister Processing Facility Operational Design Criteria

Description	Parameters
Pilot ISF Capacity, MTHM	Approx. 5,000 MTU
Pilot ISF Canister Capacity	Approx. 450 canisters
Percentage of Vertical System Canisters	59%
Percentage of Horizontal System Canisters	41%
Pilot ISF MTHM Receipt Rate, Yearly	1,500 MTHM
Pilot ISF DPC Receipt Rate, Yearly	Approx. 135 DPC
Pilot ISF DPC Receipt Rate, Weekly	Approx. 2.6 DPC
Canister Processing Receipt Rates to consider, MTHM / Yr	1,500 MTHM (min.) 3,000 MTHM (avg.) 4,500 MTHM (max.)
Canister Processing Receipt Rate, DPC / Yr	Approx. 135 DPC (min.) Approx. 270 DPC (avg.) Approx. 405 DPC (max.)
Canister Processing Receipt Rate, DPC / Wk	Approx. 2.6 DPC (min.) Approx. 5.2 DPC (avg.) Approx. 7.8 DPC (max.)
Canister Processing Facility Design Life	40 years 80 years
High Seismic Ground Motion Acceleration	0.75g
Low Seismic Ground Motion Acceleration	0.25g
Design Temperature	125° F

The major equipment that is assumed required for canister processing is shown in **Table 4-5**.

Table 4-5
Canister Processing – Major Equipment

Equipment	Operation
200 ton Overhead Crane or Gantry Crane	Offload and move Transport Casks
50 ton Mobile Crane	Lift HSM Door
Lifting Yoke	Lift Transport Cask and Transfer Cask
Transfer Cask	Means to Transfer Canisters
Cask Mating Adapter for Canister Transfer	Connecting Vert. Sys. Casks
Vertical Cask Transporter (VCT)	Vert. Sys. Cask Transport
Horizontal Cask Transporter (HCT)	Horiz. Sys. Cask Transport

4.3 Alternative 1 – Current Canister Transfer Operations (C-OPS)

4.3.1 Description of Operation Alternative

Alternative 1 examines the use of cask handling methods currently in use today at operating and decommissioned nuclear plants in the USA that could be employed at the ISF. Commercial Operations, or C-OPS, is a simple extrapolation of current industry practices applied directly to the ISF. The methods described are thoroughly demonstrated and proven, and while small improvements are being developed all the time, these cask handling approaches are the best-understood of all of the alternatives discussed in this study.

For this study, all of the spent nuclear fuel (SNF) received at the ISF is packaged in canister-based systems. Canister-based systems use a dual purpose canister (DPC). The DPC is a welded sealed metal container in which SNF assemblies are placed. The DPC is placed in different overpacks or casks for transport, storage or transfer between the transport cask and storage overpack. A typical PWR canister will hold 24 to 37 PWR SNF assemblies and a typical BWR canister will hold 61 to 89 BWR SNF assemblies. These systems fall into one of two categories: vertical or horizontal type systems. These methods for cask handling use existing storage system and nuclear plant infrastructure to be deployed and therefore offer the opportunity for a "standard" option for the ISF. Using this alternative for cask handling will enable the ISF to start operations with a well-known supporting infrastructure. The two major steps of cask handling consist of unloading the transport cask and canister transfer into a storage overpack.

For the vertical systems, the study considers the stack-up method used by all vertical systems for canister transfer. The general steps to unload and transfer a vertical DPC from a transport cask to a storage overpack are as follows:

1. Removing the transport cask from the railcar, up-righting it and placing it on the floor in a vertical orientation
2. Placing a transfer cask on top of the transport cask
3. Lifting the DPC out of the transport cask and up into the transfer cask
4. Securing the DPC in the transfer cask
5. Removing the transfer cask from the transport cask
6. Placing the transfer cask on the storage overpack
7. Lowering the DPC down into the storage overpack
8. Removing the transfer cask
9. Securing the storage overpack lid
10. Transporting the storage overpack to the storage location on the pad using a vertical cask transporter (VCT)
11. Reconfiguring the transport cask on the railcar for shipment off-site.

For horizontal systems, the study considers the NUHOMS methodology of canister transfer. The general steps to unload and transfer a horizontal DPC from a transport cask to a storage overpack are as follows:

1. Removing the transport cask from the railcar
2. Placing the transport cask onto a horizontal cask transporter (HCT)
3. Transferring the transport cask to a horizontal storage module (overpack) on the pad
4. Preparing the storage overpack to receive the DPC
5. Aligning the HCT so that the DPC will slide smoothly into the storage overpack
6. Pushing the DPC into the storage overpack using a hydraulic ram
7. Securing the storage overpack lid
8. Returning the empty transport cask to the rail siding
9. Reconfiguring the transport cask on the railcar for shipment off-site.

C-OPS only considers existing licensing configurations for these systems where the original overpack design is employed to house the DPCs at the ISF. This eliminates any infrastructure complexities.

Typical canister transfer operations are shown in **Figure B1-1 through Figure B1-7** in Appendix B1. Two of those examples are shown in **Figure 4-3** and **Figure 4-4**.

Figure 4-3
AREVA TN NUHOMS Horizontal Canister Transfer Using a TN Transport Trailer

Source: NMC Duane Arnold Energy Center

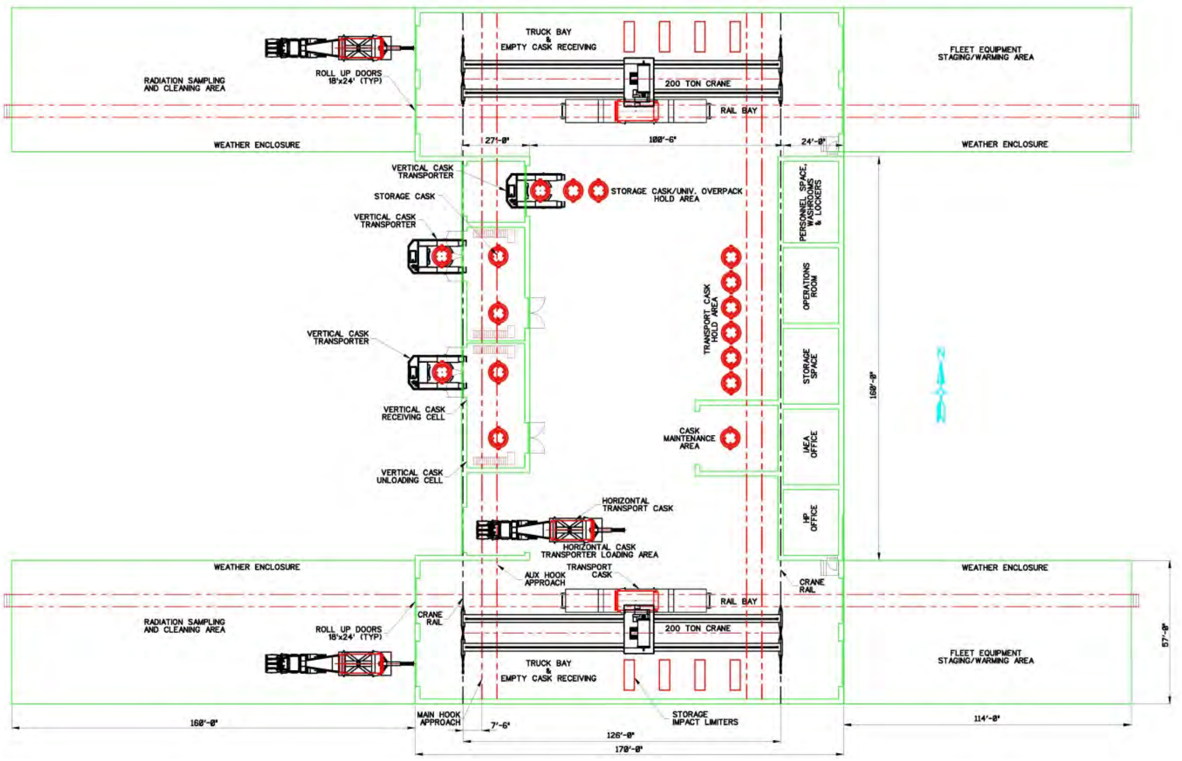
Figure 4-4
Holtec International HI-STORM “Stack-up” Vertical Canister Transfer

Source: Holtec International

For C-OPS, the ISF utilizes a cask handling building (CHB) with capabilities similar to that found at a commercial NPP. The purpose of the CHB is threefold; 1) receive SNF shipments (railcar and transport cask) in an environmentally controlled 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 building would be designed to provide physical protection for the canisters and radiation shielding to the workers.

Based on extensive research as described in Appendix B1, a reference CHB has been proposed that optimizes operations such that sufficient throughput can be achieved to satisfy DOE's requirements for the ISF. This CHB is shown in **Figure 4-5** below.

Figure 4-5
C-OPS Alternative – Cask Handling Building



This CHB design concept incorporates many of the characteristics of previous structures, with innovations that improve throughput and operation using typical storage system transfer equipment and methodology. The building consists of two sets of rail/truck bays and 2 vertical type canister transfer cells. The building is 274 feet long x 170 feet wide x 72 feet high.

Weather enclosures on either side of the rail/truck bays are added for shipment prep work. The CHB has two dedicated 200 ton single-failure-proof overhead traveling bridge (OTB) 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. It was determined that a single rail/truck bay and two transfer cells could accommodate the required throughput of 1,500 MTHM. The second rail/truck bay was added for redundancy so that any one equipment failure would not jeopardize the required throughput. However, this redundant rail/truck bay would also enable a higher throughput. For horizontal type systems, either of the rail/truck bays is used for transferring the transport casks onto a horizontal cask transporter. The design of the CHB with two sets of rail/truck bays can accommodate a throughput that will enable five DPCs to be placed into storage each week using one shift per day. This translates into an annual throughput of 260 DPCs placed into storage per year (approximately 3,000 MTHM per year) which is double the required throughput for the Pilot ISF.

4.3.2 Concept of Operations

Appendix B1 describes the concept of operations for both vertical and horizontal canisters in great detail, including material handling flow details (production of storage overpacks at the ISF using steel structures shipped to the site by the vendors).

The largest operations challenge for the C-OPS alternative is controlling the supply chain to ensure that the proper storage system and its various components are available to match the DPC being received from the generator. The licensability of the final DPC is based on the conformance of the storage system with the original licensed dry storage system. Concrete takes at least 30-days to cure, so the minimum time required before the vertical overpacks can be placed into service would be one month. However, practicalities of such a large material receipt and fabrication process would suggest that a 60-day period would be a better basis for planning. The lead time for delivery of these material components and fabrication of the initial overpacks is estimated to be 6 to 12 months. Therefore, up to a year ahead of the receipt of the SNF at the site, the supply chain manager needs to place an order for the necessary storage system components. Well in advance of delivery of specific DPCs from generator sites, the ISF staff needs to know what vendor-specific components are needed for the DPC being delivered. The coordination of the supply chain for the Overpack Fabrication and the SNF storage operations will be the largest management challenge for this design alternative.

Cask handling operations are a series of heavy lifts and heavy equipment movements that move the SNF in sealed DPCs from the rail head to the storage pad. The C-OPS alternative is an exact reproduction of the approaches used at nuclear facilities so no extrapolations were required. The only variation to the existing commercial operational sequence is the limitation of a single 8-hour shift per day, five days a week. It should be noted that this is essentially a three shift exercise regardless of the original storage concept used (vertical vs. horizontal).

4.3.3 Performance

Appendix B1 contains detailed time and motion analyses, as well as structural, radiological, and licensing evaluations. No major obstacles were identified for the C-OPS Alternative.

It was determined that the C-OPS can process an average of five horizontal DPCs placed into storage every week. This assumes that there are two railbays, with two OTB cranes and four operating HCTs. However, the vertical DPCs can only average half of that number per week. This is because the OTB crane is required for most of the steps associated with the stack-up process. Therefore, it cannot be freed up to enable the unpacking of the next Transport Cask. The attractiveness of this concept is that it is linear. Two heavy lift cranes in the CHB coupled with two cask transporters of each type result in 5 DPCs every week.

The disadvantage of this approach is that it is labor intensive. In addition, it increases the radiation exposure necessary for each activity slightly over the more remote techniques. In addition, one crane is tied-up because the vertical DPCs are limited to a series operation so that the crane is required for the DPC transfer processes.

The horizontal DPCs would appear to have an advantage because the crane is available to unpackage the next transport cask while the HCT is delivering the DPC to the overpack on the pad. However, a problem arises when HCT returns with the empty transport cask. The transport cask on the railcar will be completely unpacked but will need to be positioned so that the crane can pick the emptied transport cask off of the HCT and place it on its railcar. So, a conservative sequence does not try to take advantage of the down time of the crane by staggering the processing of two railcars at the same time.

4.3.4 Summary

C-OPS is the typical means of cask handling at commercial nuclear plants and therefore an extremely predictable alternative that would serve the ISF well.

This alternative can process a vertical DPC in 4 shifts and a horizontal DPC in 3 shifts or an overall average of five horizontal DPCs placed into storage every week resulting in an overall throughput of approximately 3,000 MTHM per year. This throughput can be attained providing the CHB has two rail/truck bays and two overhead cranes. A higher throughput can be established by utilizing more shifts per day.

The average overall dose to workers is 391 mrem processing a vertical DPC and 203 mrem processing a horizontal DPC.

In summary, the pros and cons to this alternative, listed from the highest most significant impact to the lowest least significant impact are as follows:

Pros

- The C-OPS process is used at most of nuclear power plants and therefore very predictable. A wealth of operation procedures are available that have evolved over 25 years to address almost every conceivable issue using the equipment in this alternative.
- All of the operation steps in C-OPS and transfer casks and ancillary equipment have been reviewed by the NRC and licensed. Normal, off-normal and accident scenarios are well understood. The Pilot ISF Site Specific license under 10CFR72 (Reference B1-18) can utilize all the existing operational information which will streamline the licensing process.

Cons

- C-OPS uses a cask handling building to perform transport cask offloading and vertical canister transfer operations. This facility is a large structure that increases the cost of this alternative.
- C-OPS relies on a number of manual steps that increases transfer time and personnel radiation dose.
- There are 13 different systems that need to be accommodated. Currently, each system has been designed to use its own specific equipment. The C-OPS alternative would likely use transfer casks and ancillary equipment designed and licensed for all 13 storage systems. Processing multiple systems will require space to store all the equipment, multiple procedures, and a variety of equipment that can introduce the potential for errors. Employing 13 sets of equipment to lift and offload a transport cask, transfer the DPC from the transport cask to a storage overpack could be burdensome. The creation of equipment that could be used for multiple systems would improve the process.

4.4 Alternative 2 – Automated Cask Handling Operations (A-OPS)

4.4.1 Description of Operation Alternative

Alternative 2 evaluates the impact of improving the cask handling operations by increasing the automation of the DPC transfer operations. In the current cask handling operations study (C-OPS), 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 DSC transfer operation to some degree and vertical DSC transfer operations to a larger degree. Horizontal DSC transfers are already automated by the operation of the horizontal cask transporters (HCTs) but there is room for improvements, some of which are already being implemented in the industry.

Vertical DPC transfers traditionally have been nuclear plant dependent where equipment and space are limited. In addition, few power plants are designed similarly so the vertical transfer process is more of an adaptive arrangement tailored to suit plant conditions.

In Study 1, all of the alternative storage concepts use the Cask Handling Building (CHB) for all cask handling activities except where integrated into the vault designs. While the concept employs some systems that simplify the canister transfer process compared to the current seismic/stack-up approach used at the operating nuclear plants, the systems are all expected to be operated manually with visual and other unsophisticated means of achieving the transfers necessary. A-OPS will examine the benefits of automating these processes as follows:

<u>Horizontal systems</u>

- Reduce overall canister transfer duration
- Reduce overall worker radiation dose
- Streamline alignment process of the HCT to the storage module
- Replace tractor trailer with self-propelled HCT that is easier to position
- Add shielding to the transport cask once on the HCT
- Install fixtures on the HCT or on mobile equipment that can enhance the transfer process
- Add manipulators at the railbay to assist in trunnion removal of the horizontal transport cask

<u>Vertical systems</u>

- Reduce overall canister transfer duration
- Reduce overall worker radiation dose
- Replace all DPC system transfer casks with a track mounted shielded transfer sleeve to automate canister transfer and eliminate crane time to perform canister transfer
- Add cask transfer carts that can move transport casks and storage overpacks in and out of the canister transfer cells to a set location

- Install jib cranes at canister transfer cell entrances to improve cask preparation time and reduce overhead crane time
- Add horizontal canister transfer fixture and hydraulic cask upend fixture to place horizontal DPC in lifting cage for storage alternatives that use vertical only storage (C-STDa, C-UGS, C-BGVa and C-AGVa)

Figure 4-6 shows a fairly new innovative HCT by Wheelift that employs the first four improvements listed above for horizontal systems. The Wheelift HCT is self-propelled and can move in any direction including forward-backward, lateral, diagonal, and rotational. This enables the unit to move laterally down a narrow apron between rows of NUHOMS modules and directly in front of a storage module. Current tractor-trailer HCTs require 50’ to 70’ of apron width to facilitate the backup movements necessary to place the trailer in front of a module. In addition, the unit is remotely operated eliminating the need for a worker to sit for long hauls in close proximity to the transport cask receiving radiation doses.

Figure 4-6
Wheelift Horizontal Cask Transporter for AREVA TN Systems

Source: Doerfor Companies

Figure 4-7 shows an existing innovation used at some nuclear power plants aimed at reducing large radiation doses caused by the use of low weight horizontal transfer casks. Low weight transfer casks are used at plants where the overhead crane capacity is lower than 125 tons. The weight is lessened by removing cask wall thickness which removes shielding. This same principle can be used on horizontal transport casks once they are loaded on the HCT to lower radiation doses to workers throughout the transport and canister transfer process.

Figure 4-7
Removable Radiation Shielding on an AREVA TN Transfer Cask

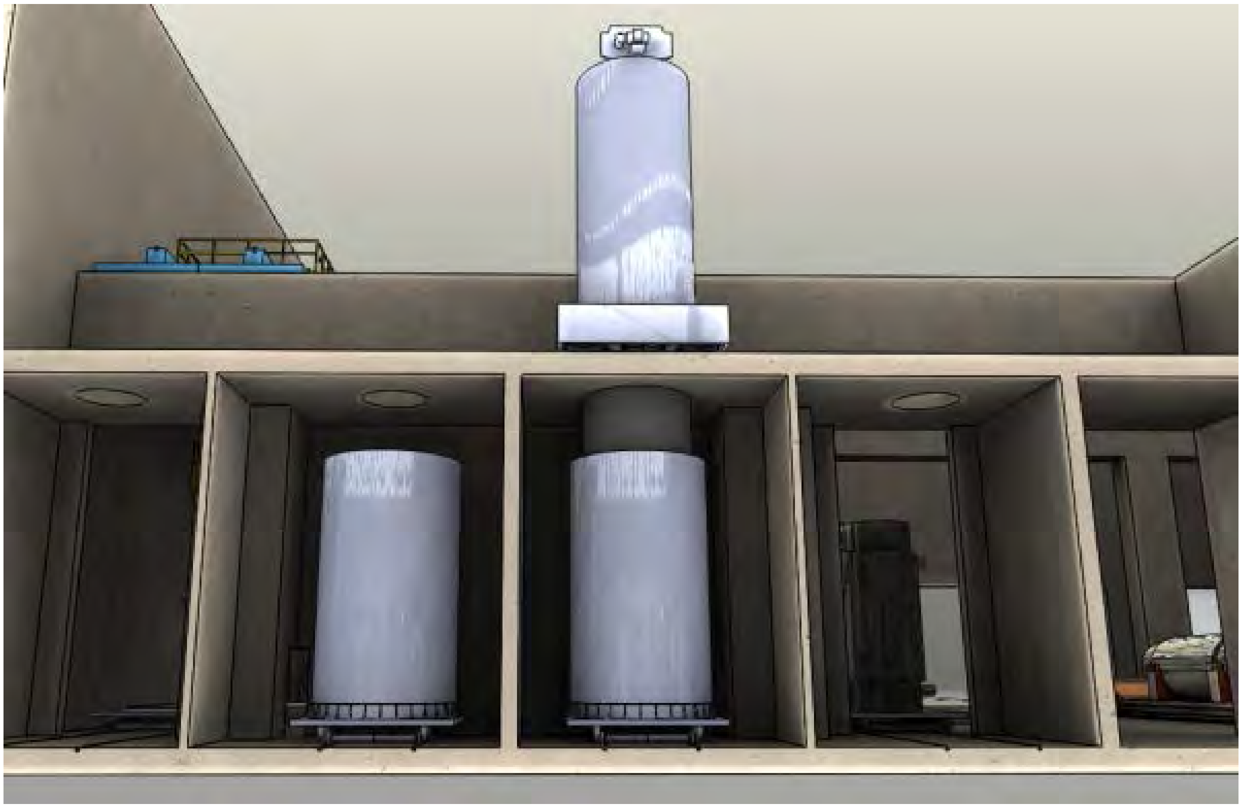
Source: Omaha Public Power District

Improvements can be made during the horizontal canister operation. Some of the highest dose operations occur when the transport cask lid is removed before the HCT has docked up to the storage module and before the storage module lid is installed once the DPC has been transferred into the storage module and the HCT has moved away from the module. Currently a mobile stick crane is used to lift these lids so that workers can position the lids to the transfer cask or storage module. This process can be made more automated with fixtures hug by the mobile stick crane so that allow the lids to be swung back into place with minimal worker involvement.

Lastly, installing one or more manipulators at the railbay to assist in removal/attachment of trunnions on the horizontal transport casks. The NUHOMS transport casks require removal of their trunnions for shipment in order to stay within rail clearance requirements. The trunnions are secured to the cask with large bolts. This operation consumes some time and can add a significant dose to workers. Since the ISF will experience several shipments every year, it is necessary to institute ALARA measures to reduce doses so that each cask handling operation does not contribute significantly to the overall facility doses. The manipulators could be fitted with stud tensioners and grapples that lifted the heavy trunnions out of the way rather than using the overhead crane.

Figure 4-8 shows a conceptual 3D cutaway view of the canister transfer cell inside the CHB and transfer sleeve. For vertical-type systems, processing several different DPC systems would be cumbersome at best. Rather than employ individual transfer casks, lifting yokes, and associated handling equipment from each system, the shielded transfer cask would perform the canister transfer operation for all storage systems processed through the CHB.

Figure 4-8
3D Conceptual Cutaway View of the Canister Transfer Cell and Transfer Sleeve



Since the overhead crane would not be used for canister transfer operations, it frees the overhead crane for offloading impact limiters, placing the incoming transport casks onto the cask transfer carts, and transferring horizontal transport casks onto the HCT.

The shielded transfer sleeve, which is open on top and bottom, would be positioned on a floor above the transfer cell on tracks and designed to be positioned over an opening located directly above the transport cask and storage overpack. The transfer sleeve would be rail-guided and operate remotely. It would be constructed with a steel and lead gamma shield and neutron shield, like any other transfer cask, so as not to preclude personnel from being near it when it contains a DPC. But it could operate remotely to vastly reduce radiation doses to workers during canister transfer operations. Since the ISF would be performing canister transfers every week, it is essential that the canister transfer radiation doses are mitigated to the maximum extent possible.

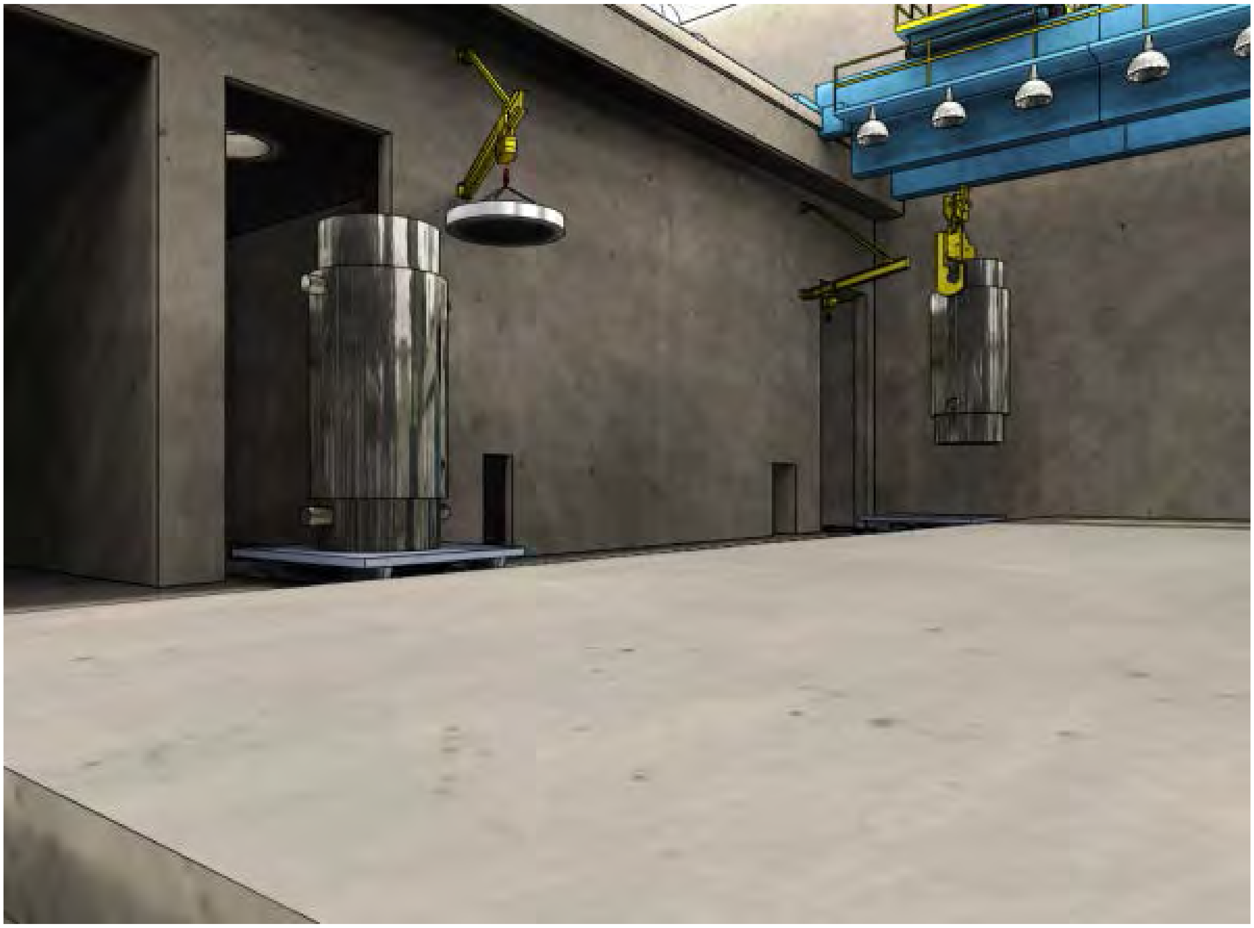
To prevent radiation streaming as the DPC is passing up or down through the floor opening, shielding could be placed around the openings or a shielding collar could be used to fit each cask.

The use of the transfer sleeve would eliminate the cask “stack-up” configuration, in which the transfer cask is placed on top of a storage or transport cask to facilitate canister transfer between the casks. In addition, stacked cask stability during a seismic event is eliminated with use of a transfer sleeve. The installation of seismic struts to prevent a tip-over event, which take time to install or remove and subject workers to radiation doses, is eliminated. A single-failure-proof hoist would be mounted to the top of the shielded transfer sleeve to raise and lower the DPCs removing any need for overhead crane time.

Another innovation is the use of cask transfer carts that would be used to move both the transport cask and storage overpack in and out of the canister transfer cell. After the overhead crane unloads the transport cask, it would place the cask onto a transfer cart. The transfer cart would move the transport cask to a set position, directly under and fully aligned with the floor opening below the transfer sleeve. Likewise, a vertical cask transporter (VCT) would place a storage overpack onto a second transfer cart. This cart would move the storage overpack to a set position under a second floor opening. Once in place the transfer sleeve could retrieve the DPC from the transport cask, roll into position above the storage overpack and lower the DPC into the overpack. The transfer carts enable the canister transfer cell to be closed during the transfer to limit radiation dose exposure yet allow workers to enter the cell if there is a problem.

A third innovation is the use of a wall-mounted jib crane to enable removal of the transport cask lid prior to entry into the canister transfer cell. **Figure 4-9** shows the jib cranes in relation to the canister transfer cell door. The figure also shows the transport cask on a transfer cart. The jib crane would be sized for the lid weight. Once the lid was unbolted and secured by the jib crane, the lid could be swung out of way and then back again for reinstalling after the transport is returned from the canister transfer cell. The storage overpack lid would be removed and supported by the VCT that brought the overpack to the CHB. This is an innovation that came out of the dry cask industry and has proven to be a time saver. Removing both lids keeps the canister transfer cell free from lids, which consume valuable floor space.

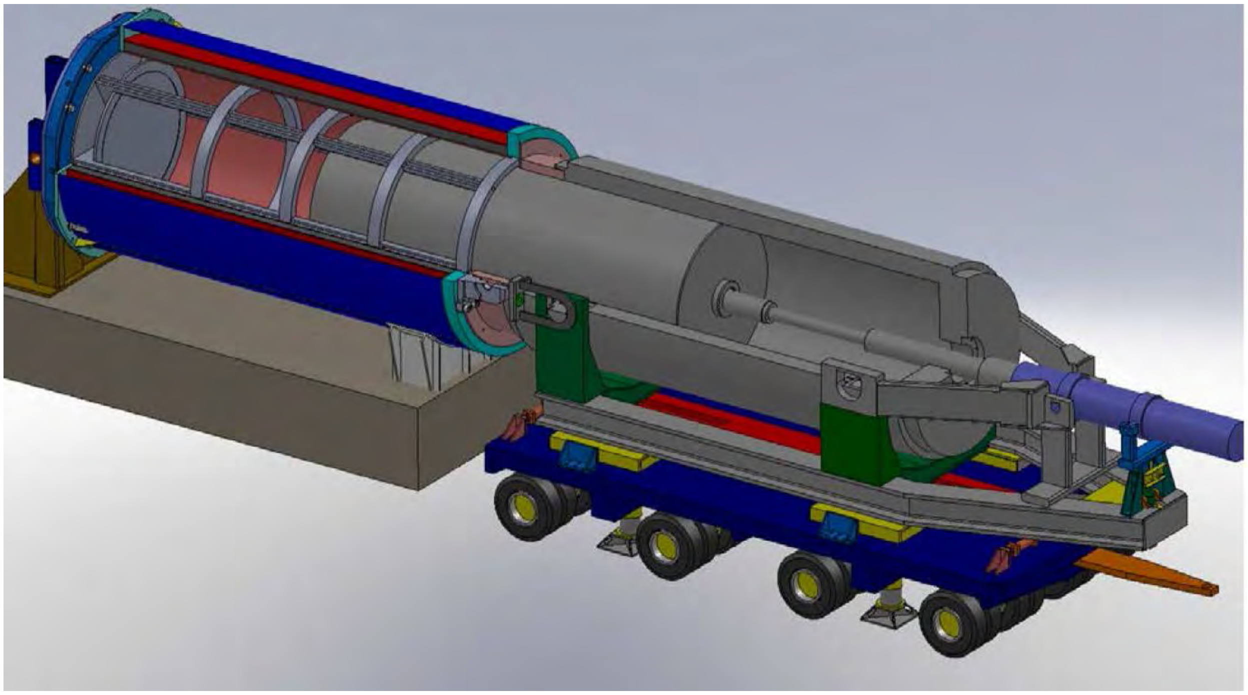
Figure 4-9
3D Conceptual View of Jib Cranes for Securing the Transport Cask Lids



Lastly, the CHB could be designed with bays to facilitate a horizontal canister transfer fixture and hydraulic cask upend fixture. The fixtures would only be necessary for storage alternatives that use vertical only storage (C-STD-all vertical storage, C-UGS, C-BGV and C-AGV).

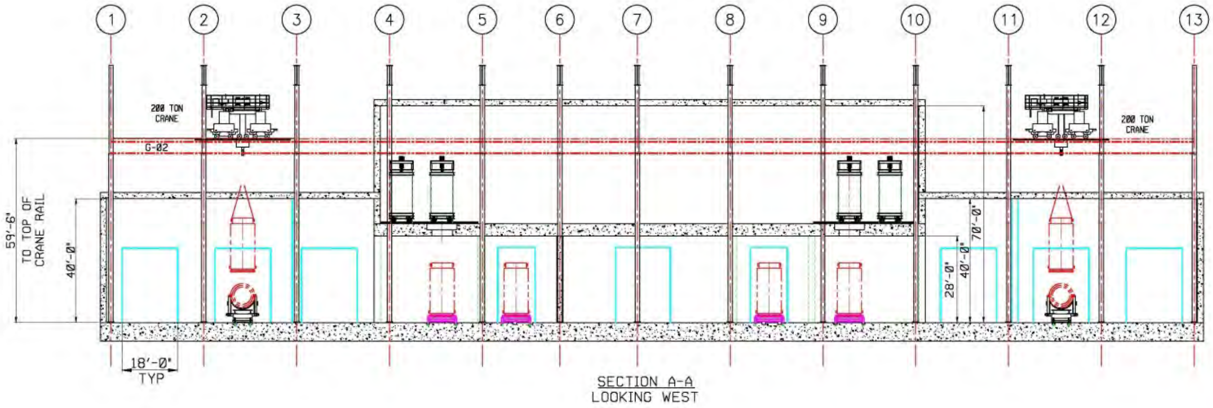
The horizontal transport canister would be offloaded from the railcar and placed on a HCT. The HCT would then move to this bay, align with the horizontal canister transfer fixture and the DPC pushed from the transport cask into the horizontal canister transfer fixture (See **Figure 4-10**). After the DPC is transferred, the horizontal canister transfer fixture would be upended using the hydraulic cask upend fixture. Once in the vertical position, the lifting cage with horizontal DPC cage would either be hoisted up into the transfer sleeve, moved over a standardized storage overpack (C-STD) or picked up by the VCT and transported to the underground storage system (C-UGS) or to a vault (C-BGV or C-AGV).

Figure 4-10
3D Conceptual View of Horizontal Canister Transfer Fixture



The CHB for alternative A-OPS incorporates all of the automation features to improve throughput and operation as well as reduce worker doses. The building consists of two sets of a rail bay and truck bay servicing 2 vertical type canister transfer cells. This floor plan also includes two bays for moving a horizontal DPC into a lifting cage which is required for storage alternatives without horizontal storage since the horizontal DPCs have no means for vertical lifting. Appendix B2 provides additional details.

Figure 4-11
Cask Handling Building with automated design features



4.4.2 Concept of Operations

A-OPS evaluates labor-saving automated systems to improve the transfer of the DPC from the transport cask into the storage overpack. Instead of using riggers as spotters and a local crane operator to conduct the transfers, the A-OPS alternative uses remote sensors, and automated transfer carts and shielded transfer sleeves.

Appendix B2 describes the concept of operations for both vertical and horizontal canisters in great detail. It concludes that the A-OPS alternate canister transfer system would represent a small improvement in ISF throughput and a slightly larger reduction to the exposures to workers involved with C-OPS. Most of that reduction was achieved by the reduction in the size of the Cask Handling Crew. Fewer workers associated with DPC transfers spending less time in the radiation area resulted in less worker exposures. However, overall it did not represent a significant savings in overall dose reduction or in the overall time to put a vertical DPC into storage. While some marginal improvement may be possible over C-OPS, the vertical DPCs could only be processed at a rate of four per week. This is an improvement over the C-OPS rate of 2.5 per week, but it is not as much as other alternatives considered in this study. The impact on horizontal DPCs was negligible and the throughput of horizontal DPCs at the ISF would remain at about five DPCs per week.

The crew size needed to process vertical DPCs is reduced by about ten FTEs over the Base Case. The resultant reduction in cost would be the major improvement of this approach. The radiation exposures are also reduced slightly, which is a benefit, but the real tangible benefit of this approach is a reduction in the necessary Cask Handling Crew size from an average of 49 in the Base Case to an average of 39 for the A-OPS alternative. The crew size for the processing of horizontal DPCs is unchanged from the base case

The largest operations challenge for the A-OPS alternative is controlling the supply chain to ensure that the proper storage system is available to match the DPC being received from the generator. The licensability of the final SNF package is based on the conformance of the storage system with the original licensed dry storage system. Concrete overpacks are fabricated on site at the ISF; or the final concrete addition to prefabricated steel frames is completed on site. The preparation time for an overpack is at least a month after receipt of the hardware from the storage system vendor. The lead time for this shipment could be six to twelve months. Therefore, up to a year ahead of the receipt of the SNF at the site, the supply chain manager needs to place an order for the necessary storage system components. This means that the ISF staff needs to know well in advance of delivery what vendor and what model of DPC system is needed. The coordination of the supply chain for the Overpack Fabrication and the SNF storage operations will be the largest management challenge for this design alternative. The correct DPC overpack needs to be staged in the receiving cell of the canister transfer cell or horizontal storage area prior to the beginning of the transfer process.

4.4.3 Performance

Appendix B2 contains detailed time and motion analyses, as well as structural, radiological, and licensing evaluations. No major obstacles were identified for the A-OPS Alternative. The A-OPS alternative will be somewhat more difficult to license than C-OPS because it employs a number of features that have not been previously licensed. However, most of the innovations use equipment that has been licensed in some form.

4.4.4 Summary

A-OPS introduces a number of innovations that automate the canister transfer process which reduces the time workers need to be near the DPC and therefore worker doses

This alternative can process a vertical DPC in 2½ shifts and a horizontal DPC in 3 shifts or an overall average of five horizontal DPCs placed into storage every week resulting in an overall throughput of approximately 3,000 MTHM per year. This throughput can be attained providing the CHB has two rail/truck bays and two overhead cranes. A higher throughput can be established by utilizing more shifts per day.

The average overall dose to workers is 251 mrem processing a vertical DPC and 198 mrem processing a horizontal DPC.

In summary, the pros and cons to this alternative, listed from the highest most significant impact to the lowest least significant impact are as follows:

Pros

- The operation steps in A-OPS improve consistency, reliability, worker safety and reduce worker doses.
- A-OPS standardizes canister transfer equipment that would be designed to process all 13 different systems that need to be accommodated. This is a major advantage over C-OPS since it eliminates equipment required for multiple systems.

Cons

- A-OPS uses an enhanced cask handling building from C-OPS to perform transport cask offloading and canister transfer operations. This facility is a large structure that increases the cost of this alternative.

- A-OPS does not affect the major SNF handling activity at the ISF: unpacking and repacking the transport cask. Two of the three shifts necessary to process DPCs in the C-OPS are associated with these activities. Therefore, A-OPS has little impact on these activities and does not make a significant difference to the throughput of the ISF.

4.5 Alternative 3 – Remote Cask Handling Operations (R-OPS)

4.5.1 Description of Operation Alternative

Alternative 3 evaluates the impact of remotely handling the dual purpose canister (DPC) to accomplish the transfer operations. The evaluation will consider only the vertical DPC transfer operations because the horizontal DPC transfers are made on horizontal cask transporters (HCTs) and there are essentially no transfer activities that can be performed remotely.

The C-OPS alternative uses the Cask Handling Building (CHB) for all cask and DPC handling activities. While the concept employs many systems that simplify the canister transfer process compared to the current seismic/stack-up approach used at the operating nuclear plants, the systems rely on a transfer cask to extract the DPC from the transport cask and to transfer it to the storage overpack in an adjoining shielded cell. R-OPS will examine the benefits of performing this transfer remotely in a shielded "hot cell."

R-OPS examines the benefits of a remote vertical canister transfer process as follows:

Horizontal systems

- No change from A-OPS. Use advanced HCT and additional shielding added in A-OPS

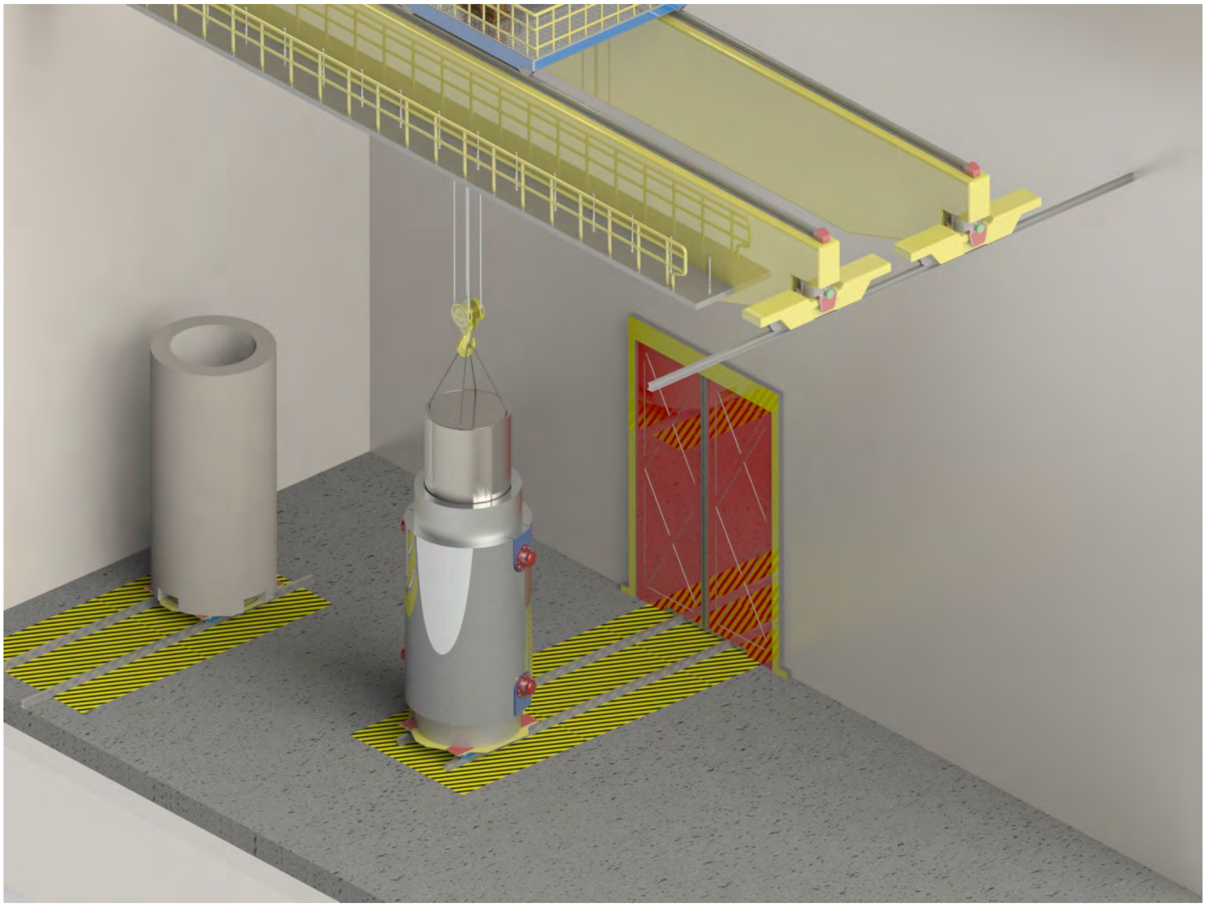
Vertical systems

- Streamline the canister transfer process by eliminating the transfer cask.
- No other changes. Use cask transfer carts, jib cranes and transfer fixtures added in A-OPS

Figure 4-12 shows a 3D conceptual view of a remote canister transfer cell.

Typical vertical canister transfer activities utilize a transfer cask that serves as a temporary container and means of transfer for the DPC between the spent fuel pool, transport cask or storage overpack. The transfer cask also provides a means of lifting the DPC and radiation shielding during the transfer. The DPC is constructed of a thin metal shell which only provides containment of the SNF assemblies. Without the transfer cask, the DPC radiation dose rates could reach between 2,000 to 10,000 Rem/hr., a lethal dose to humans in a very short time.

Figure 4-12
3D Conceptual View of a Remote Canister Transfer Cell



The use of the transfer cask involves a number of operations, many of which are eliminated by remote operation. **Table 4-6** provides a comparison of major canister transfer steps between C-OPS, A-OPS, R-OPS and S-OPS. Clearly it can be seen that fewer steps are required for A-OPS than C-OPS or S-OPS and even fewer steps are required for R-OPS. The R-OPS alternative shows time saved without a transfer cask and advantages over the other alternatives.

Table 4-6
Comparison of Major Canister Transfer Operational Steps

Major C-OPS steps	Major A-OPS steps	Major R-OPS Steps	Major S-OPS Steps
Transporter removes lid and moves storage overpack into transfer cell.	Transporter removes lid and moves storage overpack into transfer cell.	Transporter removes lid and moves storage overpack into transfer cell.	Transporter removes lid and moves storage overpack to rail siding.
Overhead crane places transport cask into transfer cell	Overhead crane places transport cask onto transfer cart.	Overhead crane places transport cask onto transfer cart.	Gantry crane places transport cask on hard stand
Overhead crane removes transport cask lid	Jib Crane removes transport cask lid	Jib Crane removes transport cask lid	Gantry crane removes transport cask lid
	Transfer Cart moves transport cask into cell	Transfer Cart moves transport cask into cell	Transport Cask is secured seismically to hard stand
Transfer cell doors are closed	Transfer cell doors are closed	Transfer cell doors are closed	
Mating adapters are mounted to top of transport cask and storage cask.			Mating adapters are mounted to top of transport cask and storage cask.
Overhead crane places transfer cask on transport cask.	Transfer sleeve is located over transport cask		Overhead crane places transfer cask on transport cask.
Seismic/stack-up struts are attached to transfer cask.			Seismic/stack-up struts are attached to transfer cask.
Transfer cask is bolted to mating adapter.			Transfer cask is bolted to mating adapter.
Overhead crane raises DPC from transport cask up into transfer cask.	Transfer sleeve hoist raises DPC from transport cask into transfer sleeve.	Dedicated cell crane raises DPC from transport cask	Gantry crane raises DPC from transport cask up into transfer cask.
Transfer cask is unbolted from mating adapter.			Transfer cask is unbolted from mating adapter.
Seismic/stack-up struts are removed from transfer cask.			Seismic/stack-up struts are removed from transfer cask.
Overhead crane moves transfer cask from transport cask to storage overpack.	Transfer sleeve is moved from transfer cask position to storage overpack position.		Gantry crane moves transfer cask from transport cask to storage overpack.
Seismic/stack-up struts are attached to transfer cask.			Seismic/stack-up struts are attached to transfer cask.
Transfer cask is bolted to the mating adapter.			Transfer cask is bolted to the mating adapter.
Overhead crane lowers DPC from transfer cask to storage overpack.	Transfer sleeve hoist lowers DPC from transfer sleeve to storage overpack.	Dedicated cell crane lowers DPC into storage overpack.	Gantry crane lowers DPC from transfer cask to storage overpack.
Seismic/stack-up struts are removed from transfer cask.			Seismic/stack-up struts are removed from transfer cask.

Major C-OPS steps	Major A-OPS steps	Major R-OPS Steps	Major S-OPS Steps
Transfer cask is unbolted from mating adapter.			Transfer cask is unbolted from mating adapter.
Transfer cask is removed and placed back into storage location.			Transfer cask is removed and placed back into storage location.
Mating adapters are removed from storage and transport casks.			Mating adapters are removed from storage and transport casks.
Outside doors are opened	Outside doors are opened	Outside doors are opened.	
VCT drives into transfer cell	Transfer cart moves storage overpack outdoors.	Transfer cart moves storage overpack outdoors.	VCT maneuvers onto hard stand
VCT attaches to storage overpack	VCT attaches to storage overpack	VCT attaches to storage overpack	VCT attaches to storage overpack
Storage overpack lid is bolted on.	Storage overpack lid is bolted on.	Storage overpack lid is bolted on.	Storage overpack lid is bolted on.
VCT takes storage overpack to pad.	VCT takes storage overpack to pad.	VCT takes storage overpack to pad.	VCT takes storage overpack to pad.

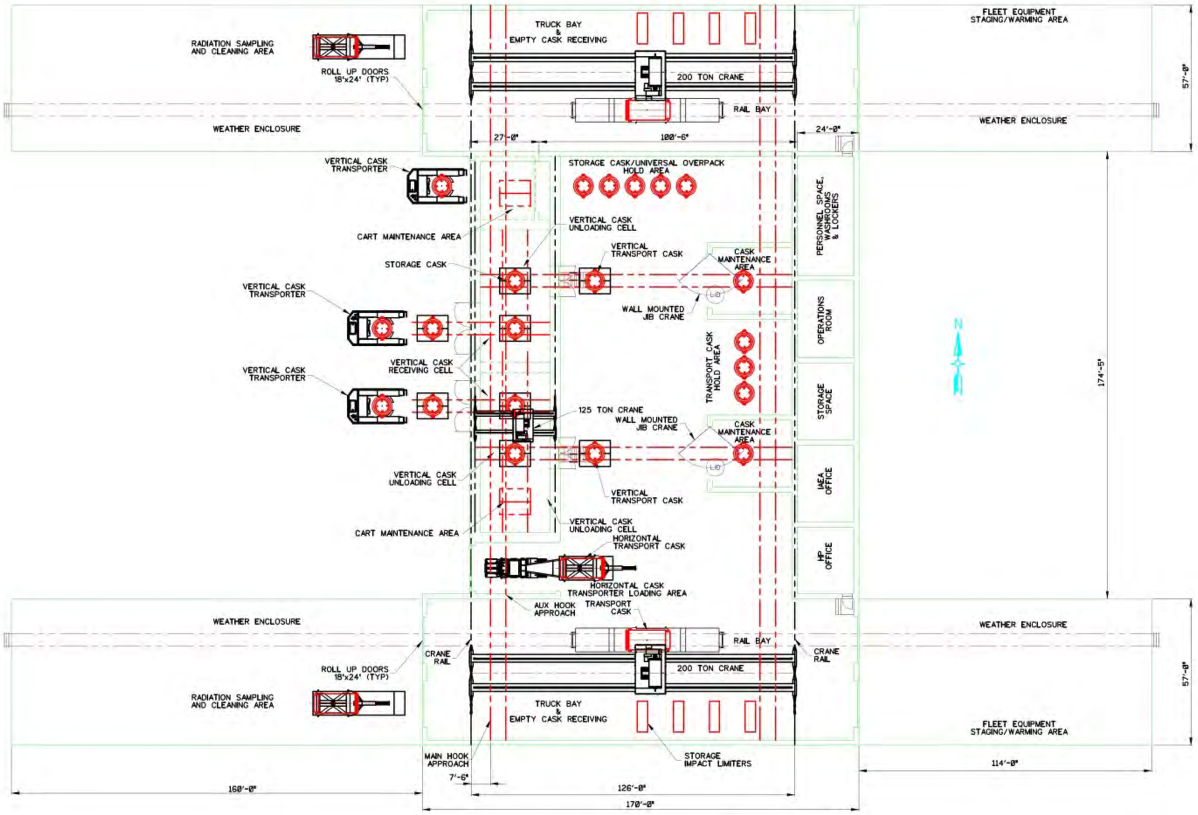
Vertical canister transfers must be performed every week; therefore eliminating the transfer cask would reduce operation time and reduce radiation doses for workers that would otherwise be in close contact with the DPC. R-OPS also eliminates the prospect of having to employ 13 different individual transfer casks, lifting yokes, and associated handling equipment from each system. In addition, this alternative eliminates the seismic issues associated with cask “stack-up” configuration since no stack-up occurs.

A major impact to this alternative is that when the DPC is removed from either the transport cask or storage overpack it emits a very high radiation dose in the cell. This means that no workers can enter the cell during the transfer. Essentially, the cell becomes a “hot cell” environment. The walls of the cells would need to be thick enough to attenuate the radiation from the DPC. The ceiling over the cells would also need to be thick reinforced concrete. There could be no streaming paths around the cell and doors would need special seals. Each cell would need to be sealed off from all other cells. Oil filled or leaded windows could be used for operators to observe canister transfer activities. Closed circuit TV cameras could also be used to ensure that the alignment of the DPC is accurate so that the DPC never impacts the wall of the casks during movements. A-OPS frees the overhead crane from transfer activities, however, it requires a dedicated overhead crane of approximately 100 tons inside each of the canister transfer cells.

Lastly, even though R-OPS is optimal, it would require remote equipment failure mitigation strategies. Workers could not enter the cell if a failure of the dedicated cell crane occurred with the DPC outside of a cask. Therefore, each cell would need to be designed so that the crane could manually lower the DPC back in a cask or to the floor and the crane winched into a safe area where workers could resolve the crane problems.

The R-OPS ISF would utilize a cask handling building (CHB). The purpose of the CHB is threefold; 1) receive SNF shipments (railcar and transport cask) in an environmentally controlled 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 building would be designed to provide physical protection for the canisters and radiation shielding to the workers. For this alternative, the Cask Handling Building is laid out with all the features discussed above as shown in **Figure 4-13.**

Figure 4-13
R-OPS Alternative – Cask Handling Building (Plan View)



The CHB for alternative R-OPS incorporates all of the automation features incorporated in A-OPS to improve throughput and operation as well as reduce worker doses. The building consists of two sets of a rail / truck bay servicing two vertical type canister transfer hot 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. The building also has two 125 ton dedicated canister hot cell overhead cranes.

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. However, this redundant set of cells and bays would also enable a higher throughput. This design of the CHB can accommodate a throughput that will enable 5 DPCs to be placed into storage each week using 1 shift per day. This translates into an annual throughput of 260 DPCs placed into storage per year (approximately 3,000 MTHM per year) which is double the required throughput for the Pilot ISF.

The R-OPS CHB is designed to provide radiation shielding during canister transfer operations. All four vertical type canister transfer cells would be shielded with thick reinforced concrete walls to shield workers from very high dose operations and oil filled or leaded glass windows and cameras to enable workers to observe transfer operations.

4.5.2 Concept of Operations

Appendix B3 describes the concept of operations for vertical canisters only, in great detail. This alternative replaces the complexity of multiple steps to transfer the DPC first into a Transfer Cask and then into a storage overpack with a simple pick and place using a crane in a shielded hot-cell. Instead of using riggers as spotters and a local crane operator to affect the transfers, the R-OPS alternative uses a remote viewing system and an overhead traveling bridge crane in a hot-cell to affect the DPC transfer. The DPC transfer requires a revision to the CHB in the Base Case to replace the transfer vaults with a two story hot-cell with a dedicated overhead traveling bridge crane. This would be an atmospheric hot-cell with shield doors. No inerting is required.

As with other Alternatives, the largest operations challenge for the R-OPS alternative is controlling the supply chain to ensure that the proper storage system and its various components are available to match the DPC being received from the generator.

Appendix B3 concludes that the R-OPS alternate canister transfer system would represent a small improvement in ISF throughput and a slightly larger reduction to the exposures to workers involved in C-OPS. Most of that reduction was achieved by the reduction in the size of the Cask Handling Crew. Fewer workers associated with DPC transfers spending less time in the radiation area resulted in less worker exposures. However, it did not represent a significant savings in overall dose reduction or in the overall time to put a vertical DPC into storage. While some marginal improvement may be possible, it was considered that the throughput of the ISF would remain at about five DPCs per week.

4.5.3 Performance

Appendix B3 contains detailed time and motion analyses, as well as structural, radiological, and licensing evaluations. A few potential issues were identified.

The hot-cells are structural elements that add strength to the CHB structure, but that also add complexity to the design as well. The need to be able to address maintenance and equipment failures in the hot-cell adds cost and complexity to the design. In addition, the extra height of the structure needs to be carefully integrated into the design to avoid interferences with the Railbay Overhead Traveling Bridge (OTB) cranes. However, generally speaking, the layout of the hot-cells does not present a significant design change to the CHB layout or operation.

The R-OPS alternative will be significantly more difficult to license than C-OPS because it involves the use of hot cells. Although hot cells may have been previously licensed, they involve dangerous levels of radiation that would require significant NRC review to ensure that all normal, off-normal and accident conditions are thoroughly reviewed and shown to be safe for workers. The dedicated cell cranes will also require significant review, not because of the crane design, which would be in accordance with well proven crane codes, but for the failure mitigation strategies that must show how any failure can be safely resolved.

4.5.4 Summary

R-OPS introduces the use of a hot cell environment to reduce the number of steps in the canister transfer process which reduces the overall operational time and worker doses.

This alternative can process a vertical DPC in 2½ shifts and a horizontal DPC in 3 shifts or an overall average of five horizontal DPCs placed into storage every week resulting in an overall throughput of approximately 3,000 MTHM per year. This throughput assumes that the CHB has two rail/truck bays, two overhead cranes and two hot cell overhead cranes. A higher throughput can be established by utilizing more shifts per day.

The average overall dose to workers processing a vertical DPC is 248 mrem.

In summary, the pros and cons to this alternative, listed from the highest most significant impact to the lowest least significant impact are as follows:

Pros

- The operation steps in R-OPS reduce canister transfer steps and worker dose.
- R-OPS eliminates the transfer equipment that would be required to process all 13 different systems that need to be accommodated. Storage requirements from R-OPS are totally eliminated because the transfer equipment is not required.

Cons

- R-OPS performs canister transfer in essentially “hot cells” which are costly, involve very high radiation doses, and require failure mitigation strategies to safely handle the DPC when equipment fails.
- R-OPS introduces the use of a hot cell environment to reduce the number of steps in the canister transfer process which reduces the overall operational time and worker doses. In summary, the pros and cons to this alternative, listed from the highest most significant impact to the lowest least significant impact are as follows:

4.6 Alternative 4 – Simplified Cask Handling Operations (S-OPS)

4.6.1 Description of Operation Alternative

Alternative 4 examines the use of cask handling methods that are more simplified compared to those currently in use today at operating and decommissioned nuclear plants that could be employed at the Interim Storage Facility (ISF). Essentially, this method would do away with a cask handling building to greatly reduce the capital costs of the Pilot ISF. Simplified Operations, or S-OPS, is a simple extrapolation of current industry practices applied directly to the ISF. Some of the methods described are used at a few nuclear power plants and therefore are demonstrated and proven on limited quantities of operations.

These methods require the least infrastructure to be deployed and therefore offer the opportunity for a “quick start” option for the ISF. Using these methods for cask handling operations will enable the ISF to start operations with a minimum of supporting infrastructure. All that is needed is some standard equipment and a hard surface near a rail line.

For the vertical systems, the study considers the stack-up method used by all vertical systems for canister transfer. The general steps to unload and transfer a vertical DPC from a transport cask to a storage overpack are as follows:

1. Removing the transport cask from the railcar, up-righting it and placing it on the floor in a vertical orientation
2. Placing a transfer cask on top of the transport cask
3. Lifting the DPC out of the transport cask and up into the transfer cask
4. Securing the DPC in the transfer cask
5. Removing the transfer cask from the transport cask
6. Placing the transfer cask on the Storage Overpack
7. Lowering the DPC down into the overpack
8. Removing the transfer cask
9. Securing the overpack lid
10. Transporting the overpack to the storage location on the pad using a vertical cask transporter (VCT)
11. Repackaging the transport cask on the railcar.

For horizontal concepts, the standard methodology of canister transfer is considered. The general steps to unload and transfer a horizontal DPC from a transport cask to a storage overpack are as follows:

1. Removing the transport cask from the railcar
2. Placing the transport cask onto a horizontal cask transporter (HCT)

3. Transferring the Transport cask to a horizontal storage overpack on the pad
4. Preparing the overpack to receive the DPC
5. Aligning the HCT so that the DPC is will slide smoothly into the overpack
6. Pushing the DPC into the overpack using a hydraulic ram
7. Securing the Overpack
8. Returning the empty transport cask to the rail siding
9. Repackaging the transport cask on the railcar.

Figure B4-1 through **Figure B4-6** in Appendix B4 show a number of unloading operations and canister transfer structures that could facilitate simplified horizontal and vertical operations. One of those innovations is shown here. The canister transfer facility at Diablo Canyon represents more recent innovations that eliminate steps required in the previous examples and uses a VCT that has single-failure-proof or redundant features that prevent drops and allows the VCT to hold the load several feet above the floor of the pit.

Figure 4-14
Holtec Below Grade Vertical Canister Transfer Facility at the Diablo Canyon ISFSI

Source: Holtec International

4.6.2 Canister Transfer Facility

The alternative to canister transfer operations in the Cask Handling Building is to use a structure or facility designed specifically to accommodate the stack-up condition. The Canister Transfer Facility (CTF) would allow the canister transfer operation to be performed at any point between the rail tracks and storage area thereby minimizing the impacts to the Pilot ISF. **Figures B4-3 through Figure B4-6** in Appendix B4 provide a number of actual CTFs in operation at nuclear power plants today.

There are various options that can be utilized for the CTF that are presented Appendix B4. Note that each method involves a number of different pieces of equipment that add to the overall cost of the project. In addition, the number of transfers between each piece of equipment should be minimized to reduce the overall dry cask storage operation impacts.

4.6.2.1 Below Grade CTF

Holtec has submitted a patent request for a Below Grade Canister Transfer Facility (BG-CTF) for vertical system transfers. The BG-CTF is a system for transferring a canister from a transfer cask to a storage cask without the need for a crane. The system is comprised of a below grade pit to house the storage overpack so that its top surface is approximately 3 ft. above grade, a mating device to connect the storage overpack to the transfer cask and the HI-LIFT VCT which is equipped with single-failure-proof hydraulic lifts and canister hoist (See **Figure 4-15**).

Figure 4-15
Holtec HI-LIFT VCT System

Source: Holtec International

The Pilot ISF would need to install two pits, one to house the transport cask and one to house the receiving storage overpack as well as a transfer cask that can be used to transfer the DPC in a shielded environment. The operation of this system is described in Appendix B4.

4.6.2.2 Above Ground Fixed CTF

The Dresden and Trojan ISFSIs used a CTF that consists of a fixed structure. These devices enabled the transfer cask to remain at a fixed location while the storage cask was inserted to receive the DPC and removed for transport to the storage pads. Therefore, the Pilot ISF would only need to install a single CTF. The operation of this system is described in Appendix B4.

Using air pads requires a level and smooth surface, jacks to raise the cask up so that the air bearings can be inserted, an air supply to the air pads, and a vehicle to move the cask and air bearings. The low profile transporter requires tracks (either for rail wheels or Hilman rollers) to maintain stability.

4.6.2.3 Gantry Crane CTF

This scenario consists of a single-failure-proof gantry crane CTF that is in a fixed location and is used to transfer the DPC from the transport cask to the transfer cask and from the transfer cask to the storage overpack. The gantry crane CTF could be used to perform both railcar offloads and canister transfer. Figure B4-9 in Appendix B4 is a drawing of the gantry crane CTF concept.

4.6.2.4 Other CTF Considerations

All of the CTF concepts discussed above and in Appendix B4 are located outdoors and therefore subject to weather conditions. However, any of these CTF concepts could be housed in a pre-engineered steel building. This would protect the CTF from corrosive conditions as well as provide a suitable environment for year around canister transfer operations. However, this could not be applied to the horizontal canister transfer. These constraints should be taken into consideration if the ISF is located in an area subject to frequent rain or snow.

Another consideration is that the vertical canister transfer process is very time consuming, having to move casks around to accommodate DPC transfer. However, these CTFs are relatively inexpensive. More than one CTF could easily be installed to increase DPC throughput.

Lastly, the nature of all these CTFs including the horizontal canister transfer process exposes workers to potential high doses. If employed, some means of reducing doses must be considered. For example, loaded transfer casks are typically limited to 125 tons which meets most power plant crane capacities. The Pilot ISF could accommodate much heavier transfer casks fitted with additional shielding.

4.6.3 Concept of Operations

Appendix B4 contains detailed descriptions of the Concept of Operations for all of the systems described above, along with the staffing studies to confirm operational throughput. This analysis shows that the S-OPS can process between one and one and two thirds full-sized DPCs placed into storage every week. This assumes a single heavy lift gantry crane at the rail siding, one cask transporter of each type and a heavy lift crane at the CTF (The heavy lift crane at the CTF could be either the gantry crane or a single-failure-proof VCT). Vertical DPCs can be processed at a rate of five every four weeks because the gantry crane is used for many of the steps in the four shift operation. Horizontal DPCs can be processed at an average rate of one and two thirds DPCs per week with one HCT or two and one half DPCs per week with two HCTs. The horizontal DPCs have an advantage because most of the activity conducted on the HCT which frees up the gantry crane to begin preparing another package.

As with C-OPS, A-OPS and R-OPS, the largest operations challenge for the S-OPS alternative is controlling the supply chain to ensure that the proper storage system is available to match the DPC being received from the generator. The coordination of the supply chain for the Overpack Fabrication and the SNF storage operations will be the largest management challenge for this design alternative.

4.6.4 Performance

Appendix B4 contains detailed time and motion analyses, as well as structural, radiological, and licensing evaluations. No major obstacles were identified for the S-OPS Alternative. As expected, radiation doses are higher with this alternative. Details are provided in Section 7. This handling alternative is based on some existing approaches that have already been reviewed and approved by the NRC and conceptual approaches that would be expected to be approved by the NRC as well.

4.6.5 Summary

S-OPS is a relatively low-cost, extremely predictable cask handling alternative that should be seriously considered if construction of the Cask Handling Building is deferred for any reason. The S-OPS approach could permit the ISF to begin operations while construction of the infrastructure necessary for other approaches is completed. As such, it represents an alternative that does not preclude other options.

This alternative can process a vertical DPC in 4 shifts and a horizontal DPC in 3 shifts. S OPS can only process an average of 1.25 vertical DPCs or 1.67 horizontal DPCs if only one gantry crane, one canister transfer facility, one horizontal cask transporter and one vertical cask transporter are used. However, doubling that number can achieve up to 2½ vertical DPCs and

2½ horizontal DPCs (5 DPCs total) per week resulting in an overall throughput of approximately 3,000 MTHM per year.

The average overall dose to workers is 458 mrem processing a vertical DPC and 203 mrem processing a horizontal DPC.

In summary, the pros and cons to this alternative, listed from the highest most significant impact to the lowest least significant impact are as follows:

Pros

- S-OPS offers the ability for the DOE to begin Pilot ISF operations without the cost or construction burden of a cask handling building. It could also be implemented with a plan that defers construction of a cask handling building to a later date while taking into account incremental startup of the transportation system (that is not included in this study). It is likely that S-OPS would be capable of keeping up with the arrival of initial SNF shipments until the CHB is constructed.
- S-OPS would use transfer casks and ancillary equipment that have already been proven and licensed. Equipment such as single-failure-proof gantry cranes are reliable having been designed to nuclear codes and standards with NRC guidance for testing, operation and maintenance which increases reliability.
- The operation steps in S-OPS are similar to those in C-OPS which have been reviewed by the NRC. Normal, off-normal and accident scenarios are well understood. The Pilot ISF Site Specific license under 10CFR72 (Reference B4-20) can utilize all the existing operational information at the few power plants that use a CTF which will streamline the licensing process.
- The throughput can be increase by adding additional components.

Cons

- S-OPS is very labor intensive and time consuming compared to other approaches. Several steps are required for every canister transfer operation which increases the duration of the activities as well as the radiological dose.
- There are 13 different systems that need to be accommodated. Currently, each system has been designed to use its own specific equipment. The S-OPS alternative would likely use transfer casks and ancillary equipment designed and licensed for all 13 storage systems. Processing multiple systems will require space to store all the equipment, multiple procedures, and a variety of equipment that can introduce the potential for errors. Employing 13 sets of equipment to lift and offload a transport cask, transfer the DPC from the transport cask to a storage overpack could be burdensome. The creation of equipment that could be used for multiple systems would improve the process.

- The entire process could be conducted outdoors and exposed to the elements if the gantry and CTF are not enclosed in a weather enclosure. Adverse weather and other conditions directly impact the efficiency of operations and may, if severe enough, could preclude operations at the ISF under certain conditions.

5.0 STUDY 3 – ALTERNATIVE DRY STORAGE METHODS FOR STANDARD SNF CANISTERS

5.1 Background

The purpose of Design Study #3 is to evaluate the dry storage methods for standard SNF canisters that may be received at the Interim Storage Facility (ISF) or loaded at the ISF. The standard canisters evaluated are based on the "canister-based" systems using Standardized Transportation, Aging and Disposal (STAD) canisters. The DOE has decided to consider three STAD canister sizes which are as follows:

- Small - 4 Pressurized Water Reactor (PWR)/9 Boiling Water Reactor (BWR),
- Medium - 12PWR/32BWR and
- Large - 21PWR/44BWR assemblies.

The study utilizes information from the Canister Standardization study. Storage systems that are evaluated are listed below, along with the abbreviation used for each in this report:

- S-PAD: Above ground storage using systems similar to the currently deployed above ground vertical and horizontal DPC storage systems currently deployed.
- S-UGS: Below grade storage. Standard canisters would be placed into a below ground storage module consisting of a below grade cylindrical vertical storage cavity and closure lid that provides radiation shielding and structural protection during storage. Underground storage may offer improvements in security and safety.
- S-BGV: Vault System below grade. The primary feature of this system is below grade vault storage as a hardened reinforced concrete structure with an above grade structure providing an operating area for canister placement, storage, and removal via floor plugs. Natural ventilation would cool the SNF during storage, if necessary.
- S-AGV: Vault System above grade. An above grade vault would be similar to the below ground alternative.

Section 5.2 below provides the detailed systems engineering approach utilized in this study. That process, along with three sizes of STAD canister led to a number of variations to the four basic alternative designs listed above as follows:

1. S-PAD, Pad Storage using STAD canisters
    a. S-PADa, Pad Storage using 4P/9B Small STAD canisters
    b. S-PADb, Pad Storage using 12P/32B Medium STAD canister
    c. S-PADc, Pad Storage using 21P/44B Large STAD canister

2. S-UGS, Underground Storage using STAD canisters
    a. S-UGSa, Underground Storage using 4P/9B Small STAD canister
    b. S-UGSb, Underground Storage using 12P/32B Medium STAD canister
    c. S-UGSc, Underground Storage using 21P/44B Large STAD canister

3. S-BGV, Below Ground Vault using STAD canisters
    a. S-BGVa, Below Ground Vault using 4P/9B Small STAD canister
    b. S-BGVb, Below Ground Vault using 12P/32B Medium STAD canister
    c. S-BGVc, Below Ground Vault using 21P/44B Large STAD canister

4. S-AGV, Above Ground Vault using STAD canisters
    a. S-AGVa, Above Ground Vault using 4P/9B Small STAD canister
    b. S-AGVb, Above Ground Vault using 12P/32B Medium STAD canister
    c. S-AGVc, Above Ground Vault using 21P/44B Large STAD canister

5.2 Design Criteria for Study 3

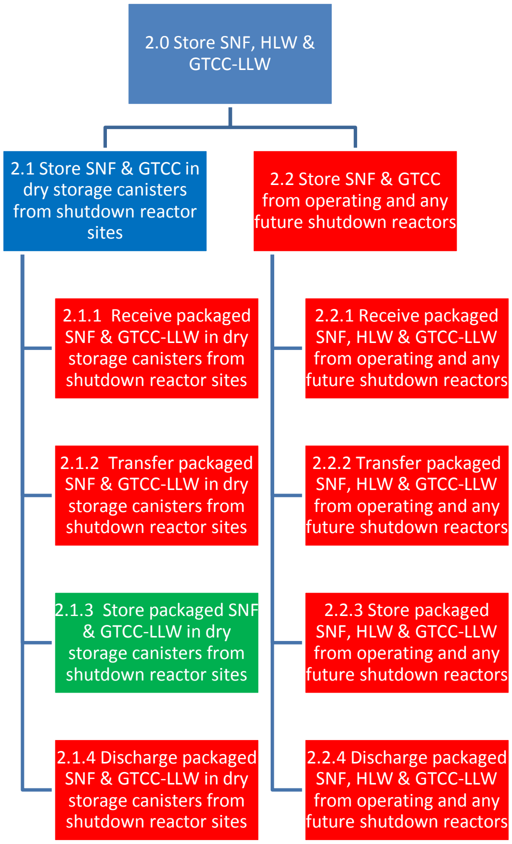
The objective for Design Study #3 is to evaluate various alternative storage methods that could be used to store standardized SNF canisters at an ISF.

Since the national geological repository requirements are not yet determined, and since STAD canisters are still conceptual with no proven or licensed designs upon which to conduct Study #3, it is not feasible to consider STAD canisters as a practical option for the Pilot ISF. Further, since most shutdown nuclear plants have decommissioned their spent fuel pools, it is not feasible to load SNF in STAD canisters at most shutdown sites without installing considerable infrastructure such as a SNF pool or hot cell. However, STAD canisters might be an option for future ISF concepts envisioned by the BRC and the Strategy.

5.2.1 Functional Requirements

The "*Nuclear Fuel Storage and Transportation Requirements Document (NFST)*" developed a number of system level functions applicable to the overall Waste Management System. **Figure 5-1** shows the top-level function (2.1.3) that applies to this Design Study #3 effort.

Figure 5-1
Study 3 Top-Level Functions



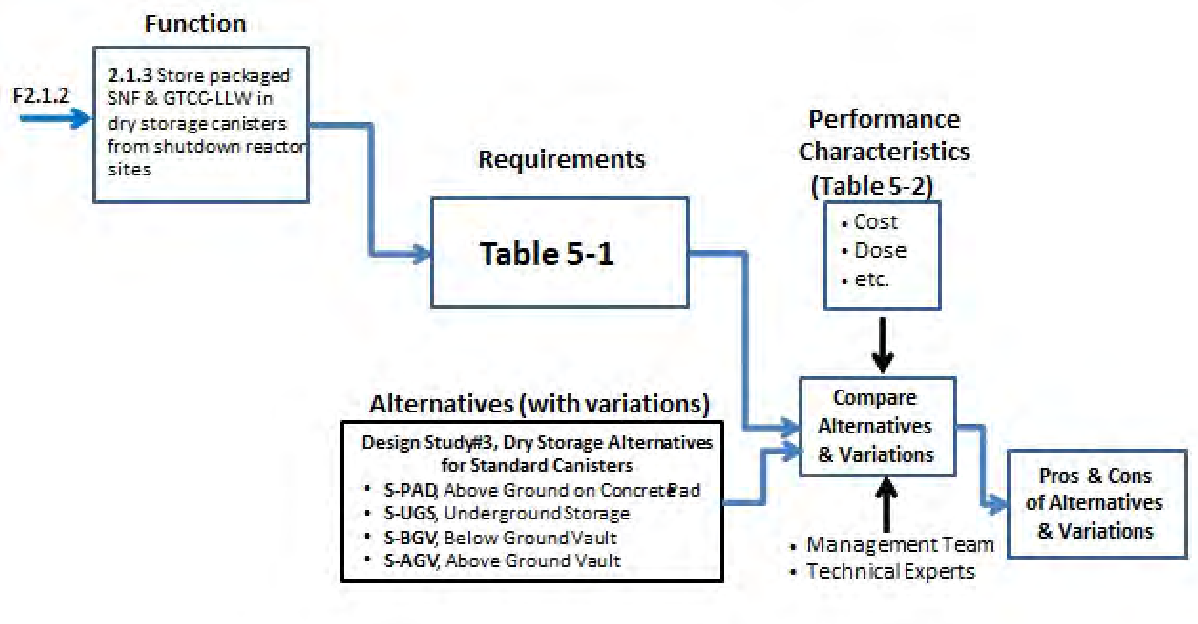
The systems engineering approach used for Study 3 is a structured process, based on hierarchical decomposition that transforms the mission need for long-term management of commercial SNF into a preferred storage concept which best satisfies the need. The basic approach was to apply the functions-requirements-architecture (F-R-A) process as shown in **Figure 5-2**. Functions define what the system must do, requirements specify how well it must be done, and architecture (at the top levels of the hierarchy) identifies the preferred strategy for accomplishing it. The F-R-A process was applied to each of the functions encountered over the lifecycle of the Study 3 Alternatives.

This systematic approach ensured the following:

- All storage functions that are both necessary and sufficient to contribute to satisfaction of the mission were identified.
- Important requirements associated with the storage function were specified.

- Specific strategies, technologies, and systems for performing the storage function subject to its requirements were formulated and consistently evaluated; and the pros and cons of each alternative were established.
- The eventual preferred concept will be a well-integrated system.

Figure 5-2
Systems Engineering Approach for Evaluation of Standard Canister Storage Alternatives



Specific design requirements from the TO16 SOW and referenced documents that are applicable for the Study 3 effort are shown in **Table 5-1**.

Table 5-1
Evaluation of Standard Canister Storage Alternatives

Requirements from *Nuclear Fuel Storage and Transportation Requirements Document* (FY2014)
R 0.6 WMS shall provide a platform for ongoing R&D to better understand how the storage system will perform over time.
R 0.10 The Storage System shall have a design life of at least 80 years
R 0.11 The Packaging System infrastructure shall have a design life
Requirements from *A Project Concept for Nuclear Fuels Storage and Transportation* (June 15, 2013)
3.1.2.1 Design to be generic, within NWPA regulations.
3.1.2.1 Capacity in the range of 5,000 to 10,000 metric ton heavy metal (MTHM).
3.1.2.1 Capable of receiving, handling, and storing all dry storage canisters currently licensed for storage and transportation in the existing canisters without opening the canisters.

3.1.2.1 Able to obtain the necessary environmental, state and local permits.
3.1.2.1 Licensed by the NRC meeting 10CFR72 requirements.
3.1.2.1 Facility must meet security requirements of 10CFR73.
3.1.2.1 Operational life will be the time to receive and hold SNF until a repository is ready to receive shipments, including the time to ship all stored SNF to a repository. Design life is 100 years.
3.1.2.2 Design will include a “laboratory” to periodically examine some fuel in storage to ensure the long term stability of the materials and performance, especially high burnup fuels. The laboratory may also have the capability to develop and demonstrate any repackaging techniques required to support the repository operations. Other R&D associated with the repository will be performed elsewhere.
3.1.2.2 The design may include a canister repackaging facility (CRF) capable of removing individual assemblies and packaging them in disposal canisters suitable for transport to the repository. Since the repository requirements are not currently known the design will investigate the impact of multiple disposal canister sizes.
3.1.2.2 Operational life will be the time to receive and hold SNF until a repository is ready to receive shipments, including the time to ship all stored SNF to a repository. Design life is 100 years.
3.1.2.2 Flexible design using modular concepts to allow for future expansion.
NRC Requirements
10 CFR 72, NRC Licensing Requirements For The Independent Storage Of Spent Nuclear Fuel, High-Level Radioactive Waste, And Reactor-Related Greater Than Class C Waste
TO 16 SOW Requirements
Standard SNF Canister – 4PWR / 9 BWR
Standard SNF Canister – 12PWR / 32 BWR
Standard SNF Canister – 21PWR / 44 BWR
Storage capacity to hold 5,000 MTHM

5.2.2 Performance Characteristics

Each alternative was evaluated with respect to the requirements specified in **Table 5-1**. Trade studies were performed on each feasible alternative to estimate its expected performance with respect to the performance characteristics required by the SOW (See **Table 5.2-2**). The overall project team then deliberated to identify the pros and cons of each alternative, some of which were necessarily based on qualitative evaluations.

This systematic approach ensured the following:

1. All performance characteristics referenced in the SOW pertaining to the storage function were specified, verified and considered

2. Specific alternatives for performing the storage function subject to its requirements were formulated, consistently evaluated, and explicitly compared

The eventual preferred concept will be well-integrated within the overall waste management system.

Table 5-2
Performance Characteristics for Standard Canister Storage Alternatives

SOW Performance Characteristics and Checklist
Performance requirements for SSCs important to safety
Total estimated cost (TEC) ($)
Annual operating and maintenance (O&M) costs ($/year)
Concept of operations, including assessments of the time and motion required for transferring the fuel from the transport casks to the storage configurations (hours)
Anticipated worker dose (mr/hr.)
Licensability
Equipment maintenance requirements
Security requirements
Physical protection requirements

5.2.3 TO 16 References, Regulations, Codes and Standards

The TO16 SOW provided a number of specific references to be used for the study effort. In addition, there are several regulations, codes and standards that may be applicable to the ISF design and storage of canisters. The TO 16 references, regulation, codes and standards are listed in **Table 5-3**.

Table 5-3
TO 16 References, Regulations, Codes and Standards

DOE Requirements
FCRD-NFST-2013-000020, "Used Fuel Management System Architecture Evaluation, Fiscal Year 2012," Argonne National Laboratory (ANL), Savannah River National Laboratory (SRNL), and Oak Ridge National Laboratory (ORNL), Revision 0, October 2012.
FCRD-NFST-2013-000132, "A Project Concept for Nuclear Fuels Storage and Transportation", Nuclear Fuels Storage and Transportation Planning Project (NFST), Revision 1, April 2013
FCRD-NFST-2012-000613, "Preliminary Evaluation of Removing Used Nuclear Fuel from Nine Shut-down Sites," Pacific Northwest National Laboratory (PNNL), Savannah River National Laboratory (SRNL), and Sandia National Laboratory (SNL),
FCRD-NFST-2013-0000263, "Nuclear Fuels Storage and Transportation Planning Project Inventory Basis", Revision 0, August 30, 2013.

“Fuel Cycle Technologies Quality Assurance Program Document, ”U.S. Department of Energy, Revision 2, December 2012
Quality Rigor Level 3 guideline No. 1 Study shall be conducted in accordance with the Laboratory’s DOE-approved quality assurance program.
Quality Rigor Level 3 guideline No. 2 Deliverables shall receive a technical review
Quality Rigor Level 3 guideline No. 3 The general requirements specified in FCT QAPD Section 6 shall also be met
NRC Regulations
10 CFR 71, “Packaging and Transportation of Radioactive Material,” U.S. Nuclear Regulatory Commission
10 CFR 72, “Licensing Requirements For The Independent Storage Of Spent Nuclear Fuel, High-Level Radioactive Waste, And Reactor-Related Greater Than Class C Waste,” U.S. Nuclear Regulatory Commission
10 CRF 73, Physical Protection of Plants and Materials U.S. Nuclear Regulatory Commission, Revision 1, July 2010
Regulatory Guide 1.76, “Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants,” Nuclear Regulatory Commission, Revision 1, March 2007
NUREG-1536, “Standard Review Plan for Dry Cask Storage Systems,” U.S. Nuclear Regulatory Commission, Revision 1, July 2010
NUREG-1567, “Standard Review Plan for Spent Fuel Dry Storage Facilities,” U.S. Nuclear Regulatory Commission, Revision 0, March 2000
NUREG-1617, “Standard Review Plan for Transportation Packages for Spent Nuclear Fuel,” U.S. Nuclear Regulatory Commission, March 2000.
NUREG-0554, “Single-Failure-Proof Cranes for Nuclear Power Plants,” U.S. Nuclear Regulatory Commission, May 1979
NUREG-0612, “Control of Heavy Loads at Nuclear Power Plants,” U.S. Nuclear Regulatory Commission, July 1980
Industry Codes and Standards
ASME III, Division 3, Containment Systems for Spent Fuel and High Level Waste Transport Packaging, American Society of Mechanical Engineers, 2013.
ASME Code Case N-595-4, “Requirements for Spent Fuel Storage Canisters.” ASME III, Division 1, American Society of Mechanical Engineers, 2013
ACI 349, “Code Requirements for Nuclear Safety Related Concrete Structures,” American Concrete Institute, 2006
ANSI/AISC N690, “Specification for Safety-Related Steel Structures for Nuclear Facilities,” American Institute of Steel Construction, 2012
NFPA 70, “National Electric Code,” National Fire Protection Association, 2014

5.2.4 Interim Storage Facility Design Criteria

The ISF design is important as it relates to features for the storage area and DPC processing area. It is assumed that all DPCs will arrive at the ISF in a transport cask via railcar or tractor-trailer. The transport cask is offloaded from the railcar or tractor-trailer in a DPC processing facility (e.g., Cask Handling Building).

Standardized canisters will only be considered at the larger ISF and not Pilot ISF, which is designed to store existing SNF from shutdown reactors as presented in Design Study 1. The design criteria for the ISF is derived from the requirements in the TO 16 SOW and as developed for the study.

The design criteria for the ISF are shown in **Table 5-4**.

Table 5-4
ISF Operational Design Criteria

Description	Parameters
ISF Module Capacity	Approx. 5,000 MTHM
Percentage of PWR Canisters	62%
Percentage of BWR Canisters	38%
ISF MTHM Receipt Rate, Yearly	1,500 MTHM (min.) 3,000 MTHM (avg.) 4,500 MTHM (max.)
ISF Access	Rail and Truck
ISF Design Life	40 years 80 years
High Seismic Ground Motion Acceleration	0.75g
Low Seismic Ground Motion Acceleration	0.25g
Design Temperature	125°F

5.2.5 Standard SNF Canister Systems Data

For Design Study 3, the ISF is required to receive and handle the following standard SNF canisters:

- 4 PWR/9 BWR
- 12PWR/32BWR
- 21PWR/44BWR

In an effort to promote a dry SNF storage system that could meet the requirements in the Department of Energy’s waste management disposal system, a specification was developed in 2008 for a Transportation Aging Disposal (TAD) canister system. The specification was intended to facilitate temporary storage at an aging facility, interim storage at a Monitored Geologic Repository (MGR), and ultimate disposal at a geologic repository operations area (GROA). This specification as well as a new DOE specification issued in 2014 for small and medium STAD canisters will be used to assist in forming the basis for the STAD canister system parameters in Design Study 3. These specifications are as follows:

- *Transportation, Aging, and Disposal Canister System Performance Specification*, DOE/RW-0585, US Department of Energy, Office of Civilian Waste Management, Revision 1/ICN 1, March, 2008.
- *Performance Specification for Small and Medium Standardized Transportation, Aging and Disposal Canister Systems*, FCRD-NFST-2014-000579, U.S. Department of Energy, Fuel Cycle Research & Development, July 2014.

In 2012, the DOE Office of Used Nuclear Fuel Disposition (UFD) issued a scope of work to solicit a study for the feasibility of development and licensing of a standardized transportation, aging and disposal canister system (STAD). The study was to provide the DOE ideas and recommendations to support a future DOE decision regarding the development and licensing of a standardized canister system. This scope of work was awarded to two contractors, AREVA and Energy Solutions. Their reports for Task Order 12, "Standardized Transportation, Aging and Disposal Canister Feasibility Study," will also be used to form a basis for the STAD cansiter system parameters in Design Study 3. The Task Order SOW and reports are as follows:

- U.S. Department of Energy, Office of Nuclear Energy, Task Order 12 Statement of Work, *Standardized Transportation, Aging and Disposal Canister Feasibility Study*. August 2012.
- Advisory and Assistance Contract Task Order 12, *Standardized Transportation, Aging, and Disposal Canister Feasibility Study*, RPT-3008097-000, AREVA Federal Services LLC, June 2013.
- Advisory and Assistance Contract Task Order 12, *Standardized Transportation, Aging and Disposal Canister Feasibility Study*, Energy Solutions, June 2013.

Table 5-5 lists the STAD canister characteristics from the above references. The last column shows the basis that was determined for the STAD canister which is used for this report.

Table 5-5
STAD Canister System Dimensions and Weights

Description	DOE Performance Specifications	AREVA TO 12 STAD Parameters	Energy Solutions TO 12 STAD Parameters	Assumed TO 16 STAD Parameters
Small Standard SNF Canister System				
Canister Configuration	SS container	SS cylinder	SS cylinder	SS cylinder
Canister Capacity	4 PWR / 9 BWR	4 PWR / 9 BWR	4 PWR / 9 BWR	4 PWR / 9 BWR
Canister Outside Diameter	unspecified	31.0”	29.0”	29.0”
Canister Outside Length	186.0” – 212.0”	198.0”	194.0”	186.0” – 212.0”
Canister Weight	unspecified		16,200 - 16,600 lbs.	
Canister Closure	Welded lids	Welded lids	Welded lids	Welded lids
Transport Cask Orientation (shipping)	Horizontal	Horizontal	Horizontal	Horizontal
Transport Cask Capacity	1 or more canisters	3 canisters	4 canisters	4 canisters
Transport Cask Weight (Loaded)	unspecified	250,000 lbs. max	250,000 lbs. max	250,000 lbs. max
Transport Cask Closure	Bolted lid	Bolted lid	Bolted lid	Bolted lid
Storage Cask Type	unspecified	Module or Cask	Cask	Varies
Storage Cask Orientation	Horizontal or vertical	Horizontal or Vertical	Vertical	Vertical
Storage Cask Capacity	unspecified	3 canisters	4 or 7 canisters	4 or 8 canisters
Storage Cask Outside Diameter	unspecified		143.0” or 165.0”	
Storage Cask Closure	unspecified	Bolted lid	Bolted lid	Bolted lid
Thermal Heat Load per Canister	1.7kw max		4kw	4kw max 2.5kw avg.
System Design Life	150 years			150 years
Medium Standard SNF Canister System				
Canister Configuration	SS container	SS cylinder	SS cylinder	SS cylinder
Canister Capacity	12 PWR / 32 BWR	12 PWR / 24 BWR	12 PWR / 32 BWR	12 PWR / 32 BWR
Canister Outside Diameter	unspecified	43.25”	52.0”	52.0”
Canister Outside Length	186.0” – 212.0”	198.0”	194.0”	186.0” – 212.0”
Canister Weight	unspecified		46,500 - 50,000 lbs.	
Canister Closure	Welded lids	Welded lids	Welded lids	Welded lids
Transport Cask Orientation (shipping)	Horizontal	Horizontal	Horizontal	Horizontal
Transport Cask Capacity	1 or more canisters	1 canister	1 canister	1 canister
Transport Cask Weight (Loaded)	unspecified			
Transport Cask Closure	Bolted lid	Bolted lid	Bolted lid	Bolted lid
Storage Cask Type	unspecified	Module or cask	cask	Varies
Storage Cask Orientation	Horizontal or vertical	Horizontal or vertical	vertical	Horizontal or vertical
Storage Cask Capacity	unspecified	1 canister	1 or 3 canisters	1 canister

Description	DOE Performance Specifications	AREVA TO 12 STAD Parameters	Energy Solutions TO 12 STAD Parameters	Assumed TO 16 STAD Parameters
Storage Cask Weight (loaded)	unspecified			
Storage Cask Closure	unspecified	Bolted lid	Bolted lid	Bolted lid
Thermal Heat Load per Canister	9kw max		28kw	12kw max 7.5kw avg.
System Design Life	150 years			150 years
Large Standard SNF Canister System				
Canister Configuration	SS cylinder	SS cylinder	SS cylinder	SS cylinder
Canister Capacity	21 PWR / 44 BWR	21 PWR / 44 BWR	24 PWR / 68 BWR	21 PWR / 44 BWR
Canister Outside Diameter	66.0” - 66.5”	66.25”	72.0”	66.0” - 66.5”
Canister Outside Length	186.0” - 212.0”	198”	195.0”	186.0” - 212.0”
Canister Weight	unspecified		94,000 - 101,000 lbs.	
Canister Closure	Welded lids	Welded lids	Welded lids	Welded lids
Transport Cask Orientation (shipping)	Horizontal	Horizontal	Horizontal	Horizontal
Transport Cask Capacity	1 canister	1 canister	1 canister	1 canister
Transport Cask Cavity Diameter	72.5” max			72.5” max
Transport Cask Outside Diameter	98.0” max			98.0” max
Transport Cask Dia. (w/ Impact Limiters)	126.0” max	126.0” max	126.0” max	126.0” max
Transport Cask Length	230” max			230” max
Transport Cask Weight (Loaded)	250,000 lbs. max	250,000 lbs. max	250,000 lbs. max	250,000 lbs. max
Transport Cask Weight w/ Impact Limiters and Skid (Loaded)	360,000 lbs. max	N/A	N/A	360,000 lbs. max
Transport Cask Closure	Bolted lid	Bolted lid	Bolted lid	Bolted lid
Storage Cask Configuration	right-circular cylinder	Module or Cask	Cask	Varies
Storage Cask Orientation	vertical	horizontal or vertical	vertical	vertical
Storage Cask Outside Diameter	144” max			144” max
Storage Cask Outside Height	264” max			264” max
Storage Cask Weight (loaded)	500,000 lbs. max			500,000 lbs. max
Storage Cask Design Life	100 years			100 years
Storage Cask Closure	Bolted lid	Bolted lid	Bolted lid	Bolted lid
Thermal Heat Load per Canister @ Canister Surface Temperature	11.8kw @ 525°F 18kw @ 450°F 25kw @ 358°F		28kw	24kw max 15kw avg.
System Design Life	100 years			100 years

5.3 Overview of Alternative Designs

The four alternatives evaluated under Study #3 use STAD canisters. They are evaluated in detail in Appendices C1 through C4, as follows:

- **Appendix C1:** Alternative 1 - Pad Storage with STAD Canisters (S-PAD)
- **Appendix C2:** Alternative 2 - Below Grade Storage with STAD Canisters (S-UGS)
- **Appendix C3:** Alternative 3 - Below Grade Vault Using STAD Canisters (S-BGV)
- **Appendix C4:** Alternative 4 - Above Grade Vault Using STAD Canisters (S-AGV)

In addition, **Appendix C5** provides Cost Estimate Details.

Much of the analyses in these four appendices are common or nearly identical for all four alternatives. This is intentional, since a common baseline of assumptions will enable these analyses to highlight the differences in cost, licensing risk, and other critical factors that are specific to each alternative. For example, each Alternative will include nearly identical sets of buildings (Cask Handling Building, Concrete Batch Plant, Administrative Building, etc.). Each Alternative will be evaluated with respect to nearly identical concepts for operation (similar staff organizational approach, similar assumptions regarding shift work/overtime, etc.). Further, each of these Alternatives is similar to its counterpart in Study #1. Hence, this subsection will overview key elements of the four alternatives that are common to all, in order to make “apples-to-apples” comparisons in the summaries of each Alternative that follow.

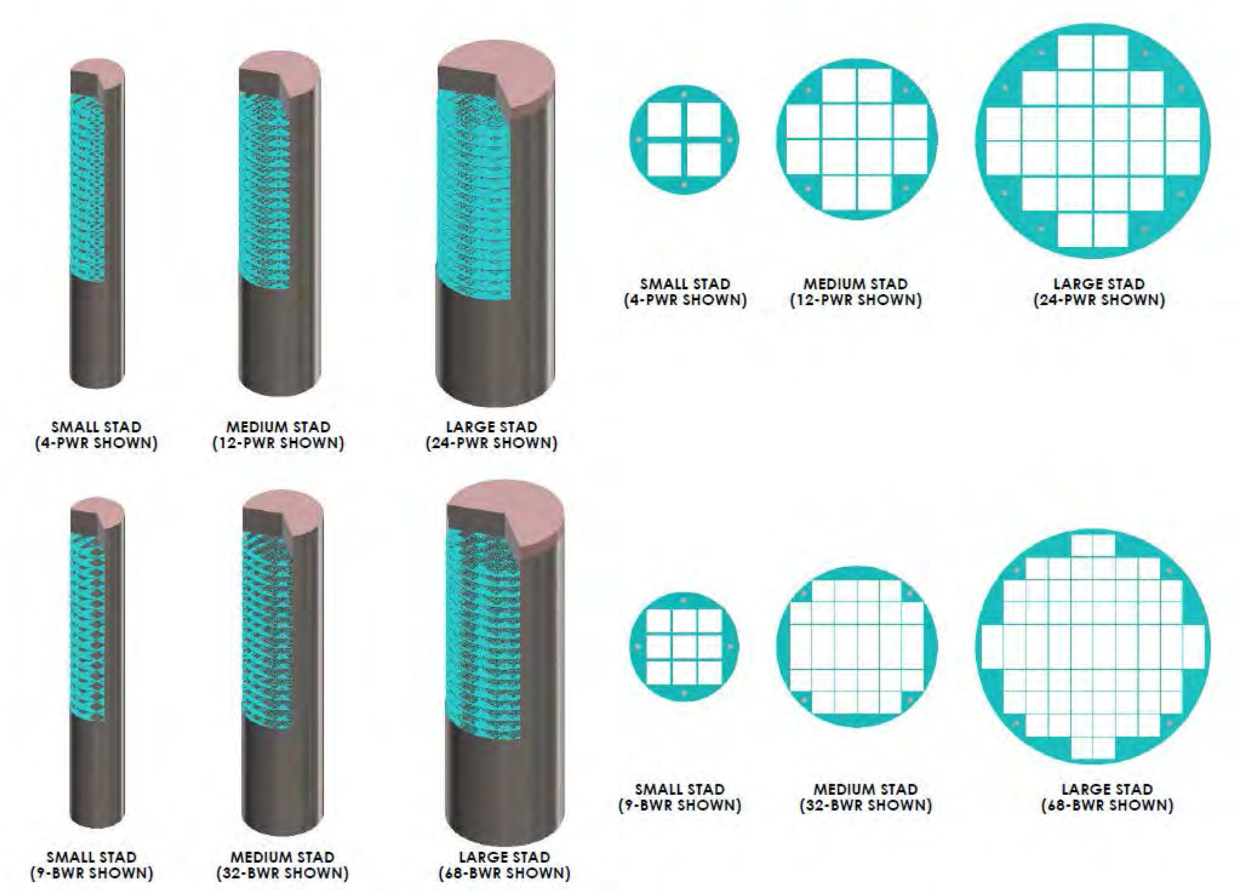
5.3.1 Overview of STAD Canisters

The concept of STAD canisters was developed by DOE as a means of addressing the variability of the SNF storage issues that confronted the Department when faced with consolidating the SNF at a single location. Some DPC systems were not designed for shipping and were either too large or unlicensed for this activity. In addition, some legacy sites were no longer serviced by rail, requiring that the SNF be repackaged in truck-shippable canisters. The Department has decided to consider three STAD canister designs. **Figure 5-3** shows the three STAD canister configurations.

Like all canister-based systems, the STAD canisters will be licensed under 10CFR72 for storage and 10CFR71 for transportation. The SNF is placed into a welded sealed metal container, the STAD canister, which provides the primary confinement boundary for the SNF. The STAD canister is placed in different overpacks or casks, which provide radiation shielding and physical protection, during canister transportation, transfer, or storage.

During SNF loading and STAD canister transfer between the fuel pool and dry storage or shipping, a metal transfer cask provides physical protection and radiation shielding. During transportation, a metal shipping cask protects the STAD canister from any credible accident that might occur. The casks are metal and provide the confinement boundary for the SNF assemblies. The metal cask is fitted with impact limiting devices for additional protection during transit. The shipping cask must comply with the requirements of 10CFR71.

Figure 5-3
Proposed STAD Canister Sizes



The small, medium and large STAD canisters will be considered together in this Section because the handling of them at the ISF will be the same.

The small STAD canisters are packed in a four STAD Multi-can storage container so that they can be handled as a single package, resulting in 16 PWR assemblies or 36 BWR assemblies being shipped in the Multi-can storage container. A single shipment of small STAD canisters has a slightly larger capacity than the medium STAD canister as far as the ISF is concerned. The medium STAD canister will be more efficient to load and to handle at the generator's site, but once it arrives at the ISF, it is the least efficient storage package for SNF. **Table 5-6** shows that since most STAD canister designs are smaller than commercial DPCs, they will require more shipments to move the equivalent SNF to the ISF, which increases cask handling operations at the ISF.

Table 5-6
Increased Shipments to Move Equivalent SNF to the ISF

STAD	Shipment Configuration	Cask Capacity		MTHM per Overpack	STAD throughput for 1500 MTHM/yr.	DPC throughput for 1500 MTHM/yr.
		PWR	BWR			
Small	4 STADs/cask	16	36	7.3	205	115 to 135
Medium	1 STAD/Cask	12	32	5.4	278	
Large	1 STAD/Cask	21	44	9.5	158	

This study has assumed that a 32 PWR assembly commercial DPC received at the ISF contains approximately 14.5 MTHM.[1] The large STAD canister contains only 66% of the number of PWR assemblies as the 32-assembly PWR DPC in current use. Part of the reasoning for this is that the lower-capacity STAD canister may be used to transport SNF with higher decay heat than could occur using a 32-assembly DPC. Smaller capacity packages generally can transport SNF with higher decay heat due to more efficient heat transfer in the smaller packages.

During transportation, the STAD canisters are loaded into a transport cask that provides shielding and structural protection to the STAD canister. Impact limiting devices are attached to the ends of the transport cask for additional protection during transit. The shipping package must comply with the requirements of 10CFR71. Four small STAD canisters will be shipped in a Multi-can storage container that uses a common handling mechanism to enable handling all of four small STAD canisters as a single entity. For storage, the STAD canisters must comply with the requirements of 10CFR72.

5.3.2 Concept of Operations

As with Study #1, the Interim Storage Facility (ISF) for Study #3 operates 24-hours, 7-days a week basis, but cask handling operations are limited to a single 8-hour shift, 40-hour work week. This has been done because the logistics issues associated with delivering a large number of transport casks to the site do not warrant around-the-clock cask handling operations.

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[1] Some of the legacy DPCs contain fewer fuel assemblies so that the average mass per DPC is actually 11.1 MTHM for the ISF.

The Storage Facility Surveillance and Maintenance Operations are ongoing activities that span the entire operational lifetime of the ISF. This consists of all the activities necessary to plan, to monitor the performance and aging of the storage systems used to house and cool the SNF, and to provide for the safeguards and security necessary to protect the facility from unwanted intrusions and/or damage. Storage Facility Surveillance and Maintenance Operations begin upon the commissioning of the ISF and continue until the last STAD canister has been removed.

During the Cask Handling Operations, many supporting activities need to be performed by the ISF staff. Fabrication of the Storage Overpacks is a full-time Cask Handling Operation activity, necessary to support STAD canister placement activities. The steel components of the storage systems are fabricated by the vendor under contract to the ISF. They are shipped to the site via rail and delivered to the overpack fabrication location near the concrete batch plant.

After receipt inspection to ensure that the components meet specifications, concrete is added to the steel components in accordance with the specification to complete the overpack design. It takes a minimum of 60-days after the arrival of the steel components from the manufacturer until the overpack is ready to accept SNF. It takes at least 30 days for the concrete to cure.

The procurement activities necessary to support the overpack production must be well ahead of the delivery of the SNF because the lead time for overpack components, delivery and final fabrication is on the order of 24 months. No shipment of SNF should be undertaken unless there is an appropriate Overpack available on site.

Another major activity at the ISF necessary to support SNF placement is maintenance of the equipment necessary to perform the heavy lifts and heavy load movements associated with Cask Handling Operations. While Cask Handling Operations are underway, the major equipment necessary to move the heavy loads around the ISF must be available and in working order. Cranes, carts and wheeled vehicles that handle SNF packages need to have single-failure-proof designs and be inspected and maintained rigorously to ensure operability and safety. Some of the commercially available machines may need to be modified to make them more robust to be able to meet the operational requirements and sustained work load during the early stages of the ISF life cycle.

Finally, the largest functional activity at the ISF is physical security. The security group's functions will include daily, routing site security activities as well as inspection of all materials coming onto the site. This security function is the largest single group of the organization and is a 24-7 operation. In addition, IAEA oversight systems need to be developed and maintained in order to meet the potential oversight functions associated with safeguards and security systems.

5.4 Alternative 1 – Pad Storage Using STAD Canisters (S-PAD)

5.4.1 Description of Storage Alternative

Alternative 1 evaluates the use of currently deployed and licensed above grade vertical and horizontal storage "canister-based" systems associated with DPC designs using STAD canisters. Therefore, this Alternative is designated S-PAD for STAD canisters stored on a concrete pad.

S-PAD is a straightforward application of existing SNF storage technologies brought together at a common site. All STAD canisters are vertical storage systems, so the ISF systems can be simplified to a single storage technology. Also, the STAD canisters are all standardized in terms of length and diameters, so there is no need for inserts/adaptors. The overpacks are designed to perfectly match the STAD canister dimensions. Generally, STAD canisters are stored in single overpacks on a concrete pad. However, there is an alternative for ganging four small STAD canisters together in a single large Multi-can STAD container or eight small STAD canisters into a concrete "pillbox" overpack depending on whether the small STAD canisters are shipped in the large STAD canister or as single small STAD canisters. **Figure 5-4** shows the arrangement of a 4-pack STAD canister

Figure 5-4
4-Pack Small STAD Canister Multi-Can Container

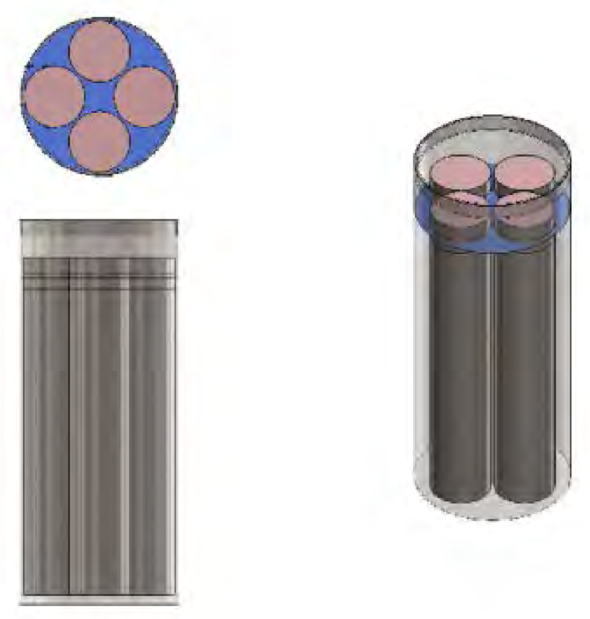
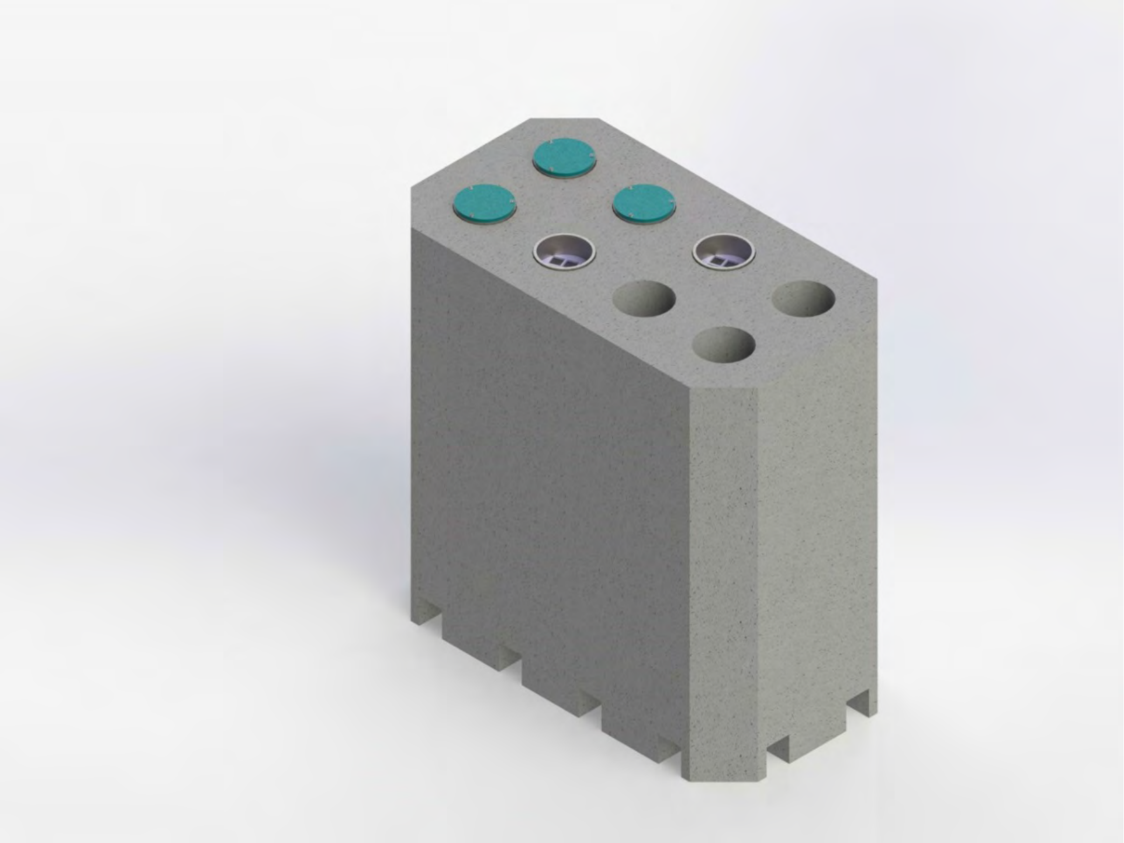


Figure 5-5 shows an 8-pack small STAD canister “pillbox” overpack.

Figure 5-5
8-Pack Small STAD Canister “Pillbox” Overpack

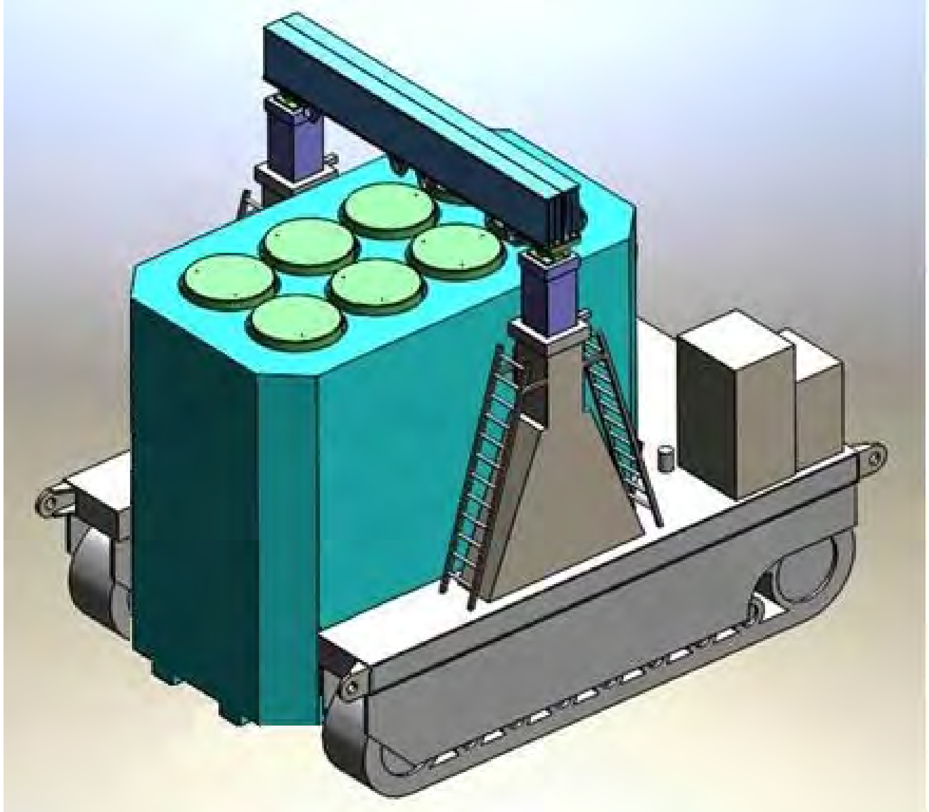


These approaches restructure the layout of the concrete pads and reduce the use of cask transporters by consolidating STAD canisters, but do not appreciably impact operations or throughput of the ISF. Whichever size STAD canister is used, they are taken to the Cask Handling Building (CHB) to be transferred from the transport cask to the storage overpack.

5.4.2 Concept of Operations

The Cask Transfer crews work in the CHB and transfer the STAD canister from the transport cask into the storage overpack before it is transported to the pad. As described above, there are two concepts for the overpack. The standard is a simple overpack similar to the designs used for vertical DPCs used at commercial nuclear facilities. The second approach utilizes a concrete “pillbox” overpack that houses eight small STAD canisters in a single overpack. These air-cooled overpacks are loaded in one of the CHB transfer cells and then hauled to the concrete pad. These overpacks need a specialized transporter and **Figure 5-6** shows this transporter loading small STAD canisters into one of the “pillbox” overpacks.

Figure 5-6
Vertical Cask Transporter Over a 8-Pack Small STAD canister Pillbox Overpack



Based on this study, the site organization staff will need to be increased by 44 workers to achieve the desired ISF throughput during the cask handling phase of the facility's life cycle. This results in a total ISF staff of 193.

As discussed in Appendix C1, the S-PAD throughput with all of the assumptions is 5 STAD canisters placed into storage each week. This conclusion is independent of what size STAD canisters were considered. So, while the movement of STAD canisters is the same, the placement of SNF into storage is very different**.**

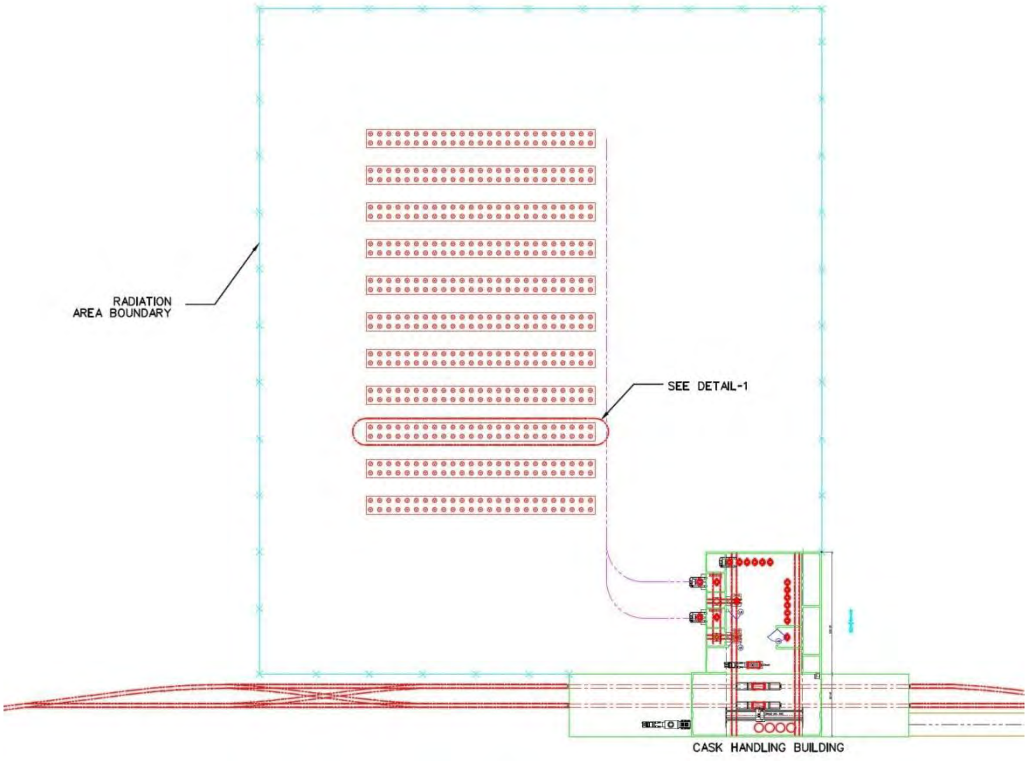
Several observations came out of the Time and Motion Analysis. First, the use of "pillbox" overpacks that accommodate eight STAD canisters in a single overpack has no impact on the ISF throughput. It has a negligible impact on dose rates and Cask Handling Crew size.

Second, with the CHB having two rail lines, it is the OTB cranes that determine the maximum throughput of the CHB. The single OTB crane is the limiting element in the throughput of this alternative. It precludes increasing the throughput of the facility and should it fail or experience an outage, it would effectively prevent the CHB from functioning.

Third, two overpack transporters are needed to be operational in order to maintain full ISF throughput. These are extremely slow moving machines. Their size and mass make them destructive of the road bed if they move too rapidly. Moreover, they are restrained from moving too rapidly when carrying STAD canisters in order to limit the potential impact should there be a failure of any kind. They become critical path constraints if any one of them is out of service. In addition, they are currently designed for a limited amount of duty. The ISF would use these machines far more than their design. This could force a great deal of maintenance to keep them available. One or two spares are considered necessary for the long-term functionality of the ISF.

Figure 5-7 shows the ISF layout storing 4-pack small STAD canisters.

Figure 5-7
ISF Layout for Small STAD Canister 4-Pack Overpack Storage



5.4.3 ISF Expansion

ISF expansion of another 5,000 MTHM would require constructing additional storage pads. Construction of the additional storage area should be performed outside of the ISF PA to facilitate construction activities without stressing security.

5.4.4 Performance of Structures, Systems and Components

Appendix C1 contains detailed evaluations of the S-PAD alternative against a number of performance issues, including structural and seismic, thermal, radiological exposure, design life/aging/maintenance, licensing, security, etc. No new issues or problem areas were identified.

This alternative is very similar to the current method of storage that is used at existing reactor site ISFSIs. A major advantage of these systems from a licensing standpoint is that they have already been designed and licensed and it is expected that the STAD canister canisters would have similar capabilities.

5.4.5 Summary; Pros and Cons for This Storage Alternative

In summary, the pros and cons to this alternative, listed from the highest most significant impact to the lowest least significant impact are as follows:

Pros

- The Pad Storage of STAD canisters in vertical concrete overpacks represents no departure from current practice. All of the processes, licensing expectations, and equipment needed will be completely standards and unremarkable. There will still need to be a new licensing effort but it is likely to be minimal.
- Pad Storage is very simple and easy to implement. It offers the ability to grow as capacity is required thereby spreading the capital costs over time.

Cons

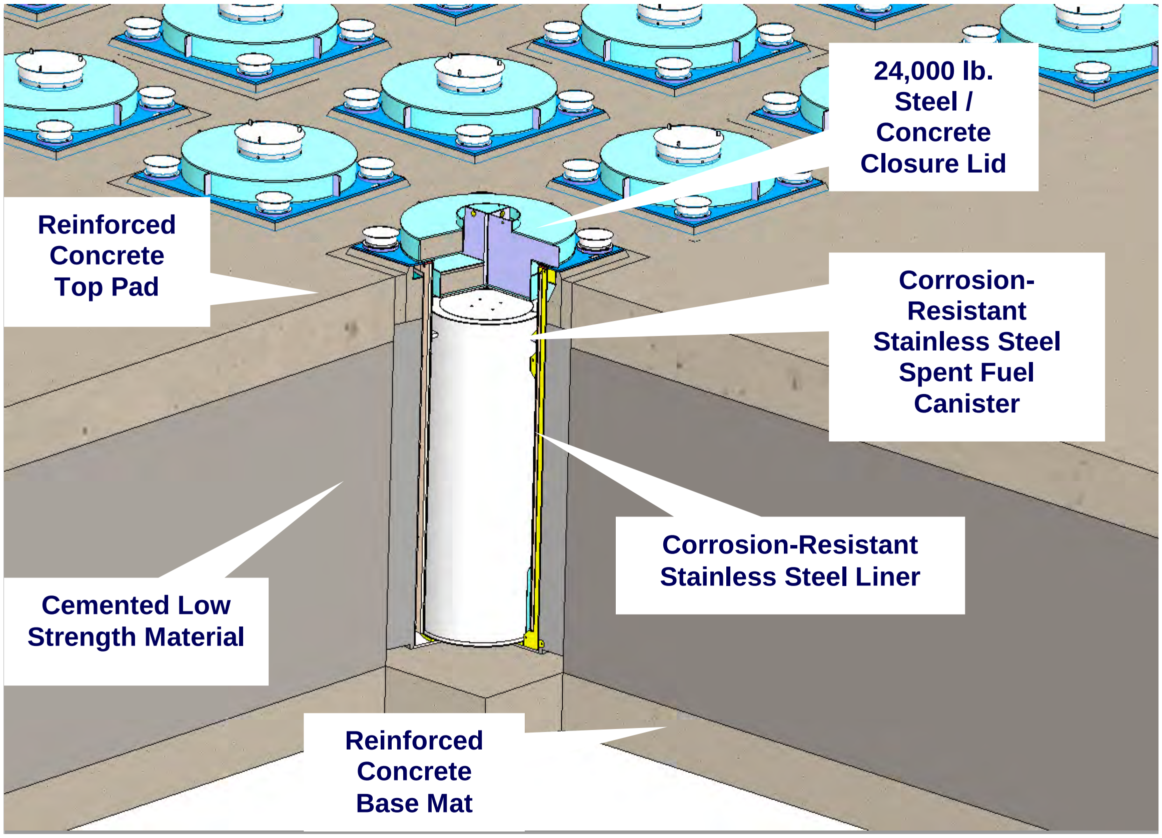
- STAD overpacks that rest on a concrete pad must be designed for seismic stability. This becomes even more critical for smaller packages because the height to width ratio is smaller such that the resistance to tipover in an earthquake is lessened. In high seismic areas, STAD overpacks may need to be bolted to the pad which increases pad thickness and overall cost.

5.5 Alternative 2 – Below Grade Storage Using STAD Canisters (S-UGS)

5.5.1 Description of Storage Alternative

Alternative 2 evaluates the use of a system that stores commercial SNF in STAD canisters in an underground silo. This alternative is designated S-UGS, for a STAD canister stored in an underground system. Currently there is only one company that provides an underground storage system, Holtec International. Holtec's HI-STORM UMAX (UMAX) system is the only underground storage system being used at this time. The Callaway nuclear plant is constructing the first UMAX system and San Onofre units 2 and 3 have ordered a UMAX system. The system is described in Section 3 (Study #1), Alternative 3 (C-UGS). This system is currently licensed and deployed for the storage of SNF. The S-UGS alternative description borrows heavily from the UMAX design approach. The UMAX system is shown in **Figure 5-8**.

Figure 5-8
Holtec HI-STORM UMAX Concept



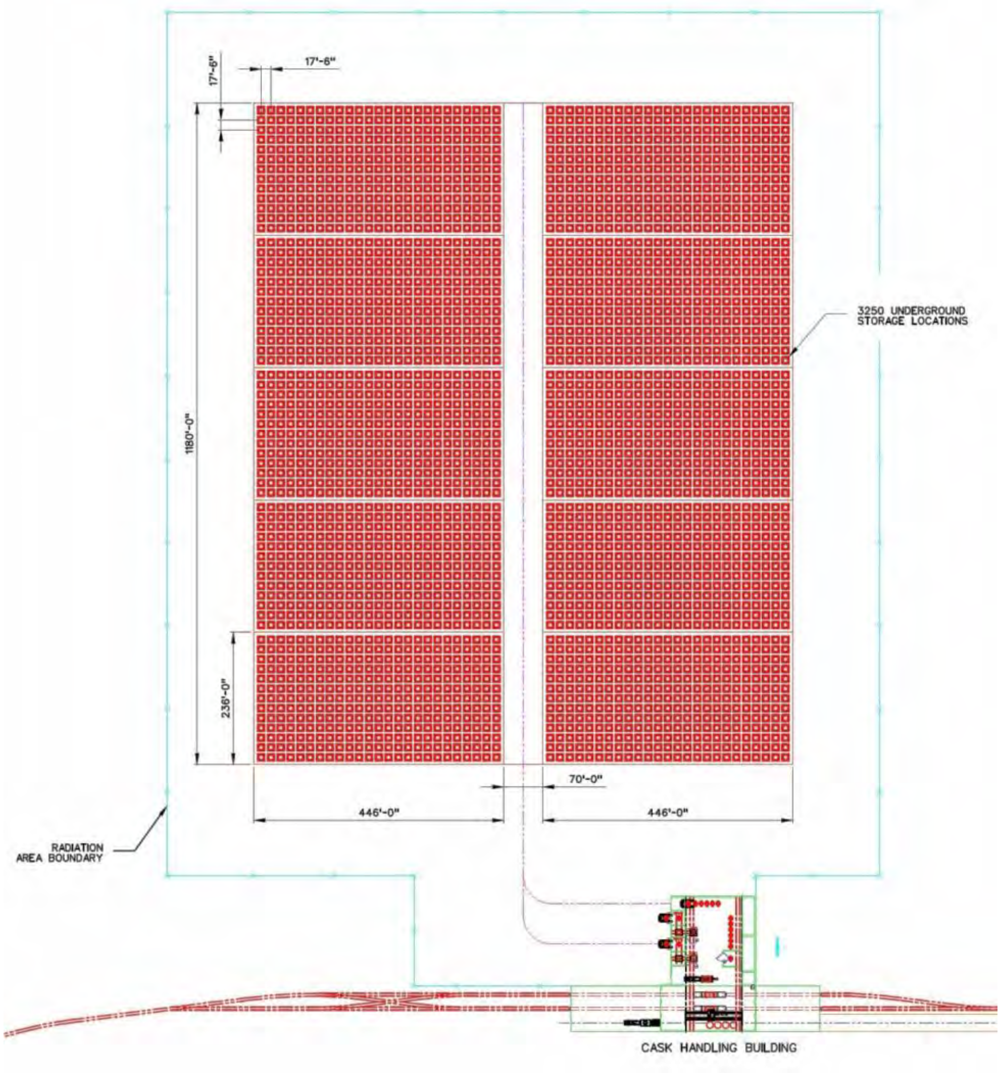
5.5.3 Concept of Operations

The concept of operations for S-UGS is essentially the same as for C-UGS in Section 3, without the complication of differing canister sizes and geometries, which could simplify operations. Based on the staffing study in Appendix C2, the ISF would require a total staff of 173.

It was determined that the S-UGS throughput with all of the assumptions is five STAD canisters (or five 4-pack small STAD canisters) placed into storage each week. This conclusion is independent of what size STAD canisters were considered. So, while the movement of STAD canisters is the same, the placement of SNF into storage is very different**.**

Figure 5-8 shows the ISF layout storing 4-pack small STAD canisters.

Figure 5-9
ISF Layout for Small STAD Canister 4-Pack Overpack Storage



5.5.4 ISF Expansion

ISF expansion of another 5,000 MTHM would require constructing additional storage pads. Construction of the additional storage area should be performed outside of the ISF PA to facilitate construction activities without stressing security.

5.5.5 Performance of Structures, Systems and Components

Appendix C2 contains detailed evaluations of the S-UGS alternative against a number of performance issues, including structural and seismic, thermal, radiological exposure, design life/aging/maintenance, licensing, security, etc. No new issues or problem areas were identified.

Regarding licensing, S-UGS does away with pad storage altogether and places each DPC into an underground “silo” referred to as a Vertical Ventilated Modules (VVMs). The Holtec HI-STORM UMAX system utilizes this type of storage method and is in the process of being licensed by the NRC. While the HI-STORM UMAX storage system is licensed to store Holtec MPC-37 canisters for PWR fuel and MPC-89 canisters for BWR fuel under a general license, Holtec has plans to amend the CoC No. 1040 to include all Holtec MPC designs, with further expansion of the type of MPCs beyond that as appropriate. The HI-STORM UMAX cavity is one size, which is large enough to store the largest certified canister with radial guides inside the Cavity Enclosure Container (CEC) to secure smaller diameter canisters, including STAD canisters.

The UMAX design removes the possibility of overpack tipover or sliding caused by an earthquake since the DPC is locked into position in the ground. The VVMs (which function as canister overpacks) are stabilized by surrounding soil so that overpack sliding or tipping during an earthquake is not a credible condition and is not required to be analyzed in the SAR. Another advantage of the UMAX design from a licensing standpoint is that the surrounding soil greatly reduces direct radiation from the sides of stored DPCs, with the earth providing extensive shielding.

5.4.5 Summary; Pros and Cons for This Storage Alternative

In summary, the pros and cons to this alternative, listed from the highest most significant impact to the lowest least significant impact are as follows:

Pros

- The Underground Storage of STAD canisters in silos represent no departure from current practice. Holtec's UMAX system is licensed and soon will be in use at operating nuclear plants. All of the processes, licensing expectations, and equipment needed will be available and in use. There will still need to be a new licensing effort but it is likely to be minimal.

- Underground storage offers a low seismic response spectra and makes the storage of SNF in underground silos attractive in high seismic zones. It removes the possibility of overpack tipover or sliding caused by an earthquake since the DPC is locked into position within the ground.

- Underground storage greatly reduces direct radiation from the sides of the STAD canister by using the earth as a shield.

- Underground storage minimizes security concerns since the STAD canisters 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.

Cons

- 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 ISF grows, the large sections of the underground storage system must be constructed prior to any storage. 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 making it more expensive than the Pad Storage concept.

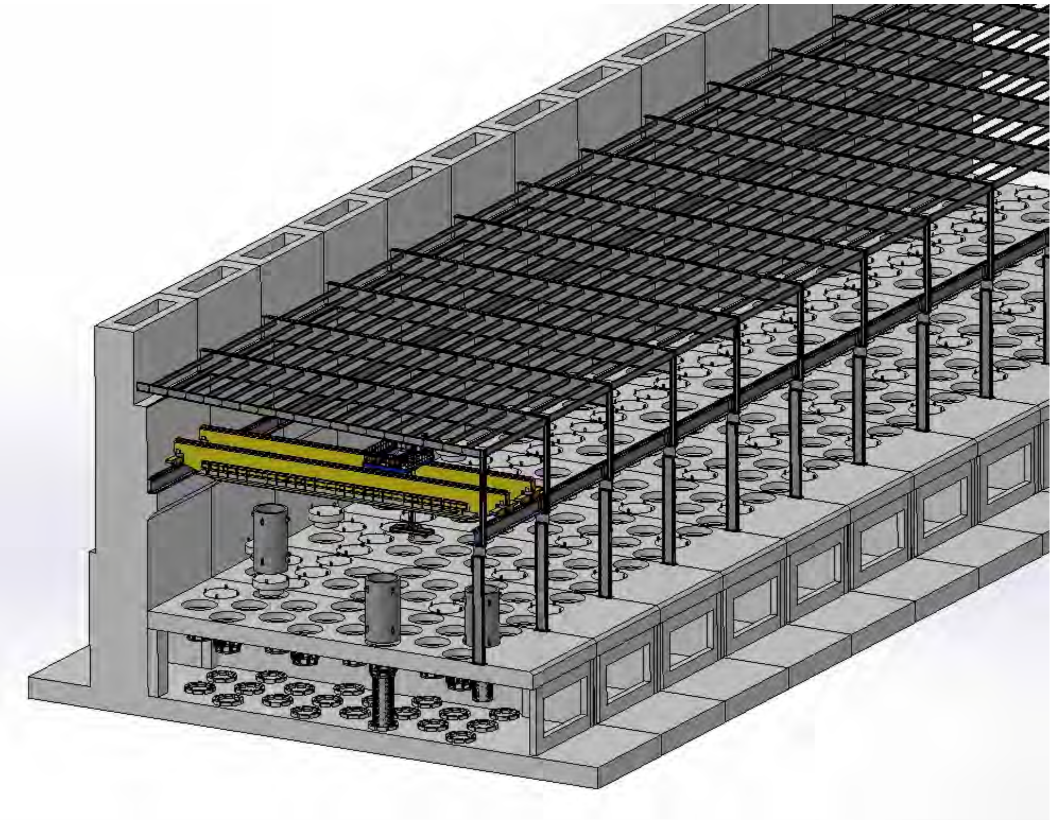
5.5 Alternative 3 – Below Grade Vault Using STAD Canister (S-BGV)

5.6.1 Description of Storage Alternative

Alternative 3 evaluates the use of below grade, air-cooled vaults to store STAD canisters. Internationally, air-cooled vaults have been used to store SNF and high level wastes from reprocessing plants. In the USA, air-cooled vaults have been used or proposed to store non-LWR SNF. An air-cooled vault design was chosen to house the SNF from the decommissioned Fort St. Vrain (FSV) High Temperature Gas Cooled Reactor.

In this concept, a large shielded structure is constructed that houses an array of storage locations into which STAD canisters 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 STAD canister in a way that prevents movement in the event of a seismic event. **Figure 5-10** shows a 3D rendering of a conceptual vault design that could store commercial SNF.

Figure 5-10
3D Rendering of a Conceptual Vault



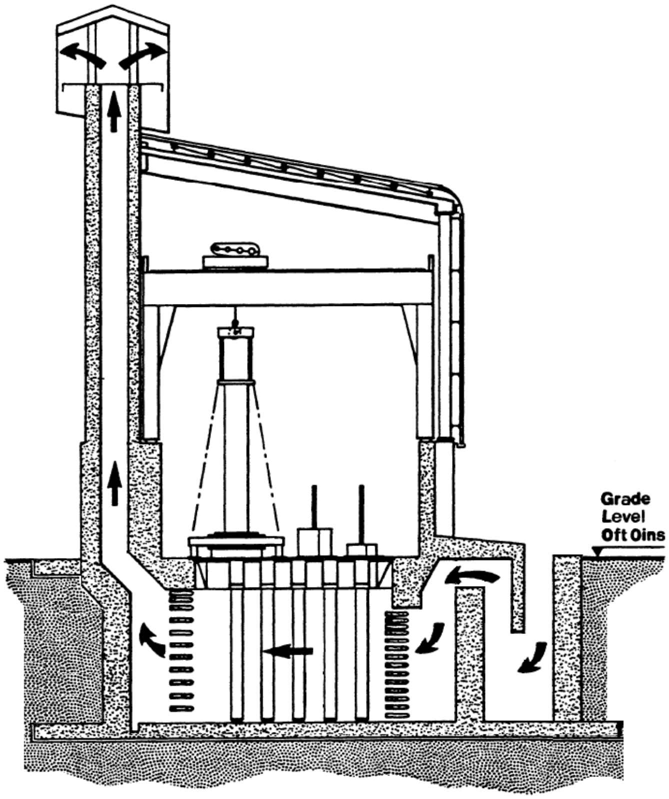
Note that the vault area beneath this shield floor is designed to encourage passive air flow around the STAD canisters. Exhaust stacks on one side of the vault allow the air warmed by the STAD canisters to escape while air inlets on the other side of the vault draw cool outside air into the building. This natural draft system provides bulk cooling to remove decay heat from the SNF.

Typically, air-cooled vaults used for the storage of nuclear wastes have stored individual fuel assemblies in vertical storage locations. The ISF air-cooled vaults will need to accommodate STAD canisters that house many fuel assemblies and it will need to accommodate STAD canisters designed to be stored vertically.

Since the vault is a massive concrete structure and the STAD canisters are stored below grade, there will be little to no radiation dose outside of the vault structure. Even on the operating floor, as long as the shield plugs are in place, there will be less than a 1mrem/hr. dose rate.

A typical below grade vault configuration is shown on **Figure 5-11**.

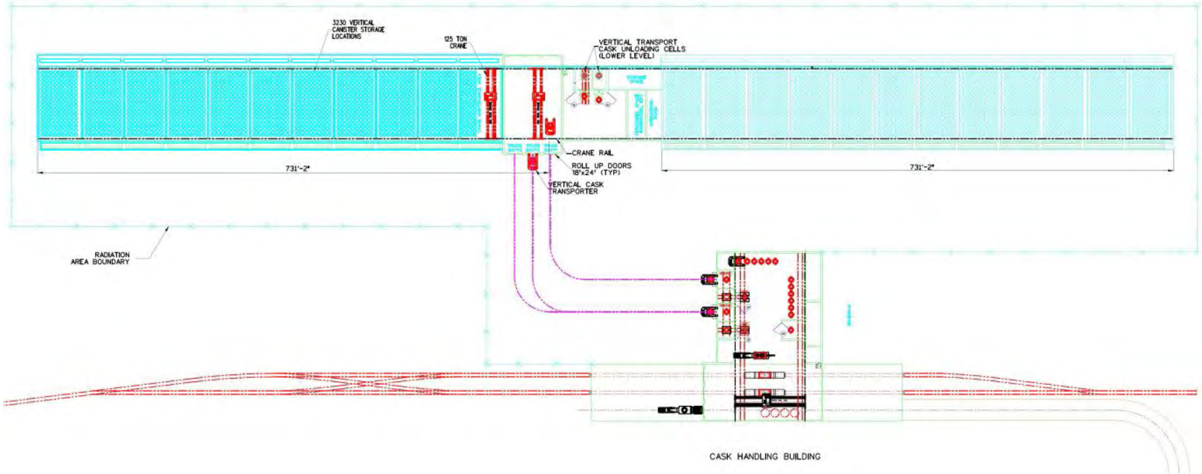
Figure 5-11
Typical Below Grade Vault Storage System – Elevation View



5.6.2 Concept of Operations

The designs of the S-BGV variants are impacted by the size of the STAD canister. Small STAD canisters require more storage space to store the same amount of SNF. **Figure 5-12** shows a vault arrangement with small STAD canisters and a standalone CHB which requires 1132 storage locations thereby increasing the vault building length. This arrangement is showing individual small STAD canisters which is easier for a vault to store than the 4-pack small STAD canister container.

Figure 5-12
Conceptual Site Plan of the S-BGV Using Small STAD Canisters



The STAD canister is transferred from the transport cask into a shielded transfer cask in the CHB. The shielded transfer cask is picked up by a Vertical Cask Transporter (VCT) and transported to the vault building operating floor. The total cycle time for a cask handling evolution is determined by how rapidly the crew can turn around the transport cask. Using the shielded transfer cask enables the crew to begin recycling the transport cask in parallel with the placement of the STAD canister. This adds several complex and heavy components to the ISF inventory but it significantly increases the throughput. It also concentrates most of the STAD canister preparation activities in the CHB. This allows for better utilization of the work crews by segregating the types of work into the appropriate buildings.

Once inside the vault building, the STAD canister is removed from the shielded transfer cask into a shielded transfer sleeve in a dedicated vertical transfer vault. The shielded transfer sleeve is attached to the overhead traveling bridge crane that moves the STAD canister to the storage location in the vault.

Staffing and time and motion studies in Appendix C3 establish how large the crew sizes need to be to support this alternative. Staffing estimates are approximate since not all crafts are required for an entire shift. Based on these studies, this alternative will require a total ISF staff of 151 for the integral CHB.

It should be noted that there are no significant differences in the processing times necessary for STAD canisters regardless of their size. Since they all contain SNF that is just as susceptible to damage regardless of how many assemblies are in each container and since the dose rates and weights are all substantial, all lifts and other movements must be carefully planned and executed to avoid damage to the fuel or injury to the workers. The difference is that the number of STAD canisters necessary to achieve a given ISF capacity is larger for the smaller STAD canisters.

It was determined that the throughput with all of the assumptions is an average of 2.5 STAD canisters placed into storage each week for vaults with integral CHBs and 5 STAD canisters placed into storage each week for vaults with standalone CHBs. Several observations came out of the Time and Motion Analysis.

First, the benefit of the vault with Standalone CHBs comes from the ability to readily support a two railbay CHB. It requires more people to staff the site during the cask handling activities, and it takes longer for each STAD canister to be placed into storage. But it permits better work force efficiency and doubles the throughput of the integral CHB design. The throughput is independent of what size STAD canisters were considered. So, while the movement of STAD canisters is the same, the placement of SNF into storage is very different.

Second, the Vault Building (or vault area) OTB cranes are fully utilized and possibly overextended. Using more cranes with more limited roles might make for a more reliable system, albeit at the price of complexity and the need for more operators. The need to swap out the lifting devices between picking the shielded transfer cask and managing the complex Shielded Transfer Sleeve may be too daunting of a design challenge. However, as currently configured, the Cranes in the Vault Building are at the limits of their capability.

Third, there needs to be two VCTs on site to develop and maintain full ISF throughput for the standalone CHB design. These are extremely complex machines and could be unreliable if used as much as this concept requires. One VCT would possibly be able to maintain the ISF throughput, but having two is seen as a necessary precaution.

Fourth, this concept is easier for the security team to protect because it is concentrated and contained. External threats and internal threats are easier to identify and to defeat than is the case for an outside facility.

Finally, this concept is unaffected by weather and other environmental conditions during the loading process. Therefore, STAD canister placement is not impacted by external conditions so the ISF can be sited anywhere without the throughput being impacted. The minimal impact of the movement of the transfer cask containing the STAD canister from the CHB to the Vault building was judged to be of negligible importance.

5.6.3 ISF Expansion

ISF expansion of another 5,000 MTHM would require constructing another vault building. Construction of additional storage area should be performed outside of the ISF PA to facilitate construction activities without stressing security. Once the new vault is constructed, the PA would be expanded to encompass it. Of course, this type of construction would mean that a significant corridor would need to be placed between vaults to ensure that construction workers receive as low as reasonably achievable (ALARA) radiation dose from the existing loaded storage units.

5.6.4 Performance of Structures, Systems and Components

Appendix C3 contains detailed evaluations of the S-BGV Alternative against a number of performance issues, including structural and seismic, thermal, radiological exposure, design life/aging/maintenance, etc. No new issues or problem areas were identified.

There are significant licensing challenges with Alternative 3 since vault storage for large commercial STAD canisters is still conceptual, unlike other storage methods. In order to store 450 DPCs, a vault 100 ft. in width would need to be about 800 ft. long. Since STAD canisters are smaller than commercial DPCs the vault size increases dramatically. If the vault is designed to store 5,000 MTHM, then the same vault would have to have a capacity to house approximately 3230 individual small STAD canisters and would be approximately 1500 ft long. For medium size STAD canisters the capacity and vault length would be approximately 1132 and 852 ft respectively. For large size STAD canisters the capacity and vault length would be approximately 626 and 912 ft respectively.

The use of a vault does away with pad storage and places each STAD canister into a large self-contained vault module structure. The ISFSI at the former Fort St. Vrain (FSV) reactor site in Colorado uses the Modular Vault Dry Store (MVDS) system in an above grade vault. The FSV MVDS has a specific license (Materials License No. SNM-2504), so has its own SAR and Technical Specification, with analyses specific to the FSV site. The canisters (fuel storage containers) at FSV are carbon steel cylinders one-half inch thick, 16 ft. long but only 18 inches diameter, so designed for a single column of fuel (which at FSV consists of 6 graphite blocks stacked end-to-end). The FSV canister lid is 1.5 inches thick bolted to the body of the canister by means of 24 one-half inch diameter steel bolts, sealed with double metal O-rings. For this type of canister closure, leakage of the gas inside the canister to atmosphere is a credible event, so the FSV SAR assumes leakage of fission products past the O-ring seals in what is termed the

"Maximum Credible Accident in the FSV SAR." For storage of commercial STAD canisters with their redundant seal welded closure lids, accidents involving leakage of STAD canisters are not credible and not required to be postulated or analyzed in the ISF SAR.

Canisters stored in the existing FSV vaults do not have the increased performance issues such as weight and thermal loading characteristic of commercial STAD canisters. Since the performance capability of a vault is unknown, rigorous analyses will need to be performed to show that the STAD canisters could be safely stored in a vault, the vault could perform as desired, and the results of these analyses described in the ISF SAR. These analyses would include structural, thermal and radiation shielding analyses of the STAD canisters in vault storage. In addition, it is considered that criticality analyses will be necessary since there is potential for neutrons from one STAD canister reaching adjacent STAD canisters due to the relatively close packing of canisters stored in vaults with no intervening materials that would shield and attenuate the neutron flux.

Most STAD canisters in existing dry fuel storage systems will have a much higher decay heat rate than the FSV canisters. When canisters were initially loaded into the FSV MVDS, a canister containing average decay heat fuel elements would have 330 watts total decay heat. In contrast, a single commercial STAD canister could have up to 100 times this heat release rate, or on the order of 33 kW. The thermal study performed by CB&I for this report determined that heat removal using the chimney stack effect for natural convection cooling in a vault is limited to thermal outputs much less than the licensed limits in existing commercial STAD canister storage methods. STAD canisters with hotter SNF may not be able to be adequately cooled in a vault which would require longer pool cooling prior to storage. This would need to be addressed in the ISF SAR and the ISF licensing process.

Design and licensing tasks would be extensive and involve significantly more time than the other storage methods. As noted above, the FSV MVDS is operated under a specific ISFSI license and the FSV SAR cannot be referenced as is the case for FSARs associated with an ISFSI general license. In addition, the NRC has never licensed a vault system for storing large commercial STAD canisters. The performance characteristics of a vault would need to be licensed as part of the ISF Specific License which would require considerable development in the ISF SAR costing more NRC review time.

5.6.5 Summary; Pros and Cons for This Storage Alternative

In summary, the pros and cons to this alternative, listed from the highest most significant impact to the lowest least significant impact are as follows:

Pros

- Since the STAD canister storage is effectively indoors, the vault alternative may provide a more controlled environment than other Alternatives. The STAD canisters 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 STAD canisters. The STAD canisters would likely feel humidity changes during wetter weather and temperature changes between summer and winter).
- The ground provides radiation shielding and protection from design basis explosions.
- The below grade vault is lower than an above grade vault which improves its resistance to earthquakes. The overhead crane is lower so it won't exert the loads on the structure during an earthquake.
- A vault shields STAD canisters from view, easing security concerns.
- A vault removes the possibility of STAD canister tipover caused by an earthquake or other postulated accidence since the STAD canisters are locked into position within the vault.

Cons

- A vault is a large nuclear structure impacted by potential seismic, construction, cost issues typically associated with large nuclear projects. In order to store 500 to 1,000 STAD canisters, a vault 100 feet in width would need to be between 1,000 and 2,000 feet long increasing the complexity of the structure.
- The thermal characteristics of STAD canisters are unknown. FSV canisters have relatively low energy densities compared to STAD canisters containing much hotter newer SNF. The study performed by CB&I determined that heat removal using stack effect in a vault is limited. Newer STAD canisters with hotter SNF may not be able to be adequately cooled in a vault which would require longer pool cooling prior to storage.
- Vault throughput is limited due to cask handling congestion in the storage hall.

5.7 Alternative 4 – Above Grade Vault Using STAD Canister (S-AGV)

5.7.1 Description of Storage Alternative

Alternative 4 evaluates the use of above grade, air-cooled vaults to store STAD canisters. 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.

5.7.2 Concept of Operations

The concept of operations for the above grade vault is essentially the same as for the below grade vault, as summarized above in Section 5.6. Staffing and time and motion studies in Appendix C4 establish how large the crew sizes need to be to support this alternative. Staffing estimates are approximate. Based on these studies, the S-AGV alternative will require a total ISF staff of 151 for an integral CHB, the same number as for the S-BGV alternative.

The S-AGV with standalone CHB design has two railbays and two independent OTB cranes servicing the railbays. Also, the design separates the placement of STAD canisters into the vault storage locations from the activities in the railbays which is a significant improvement in operations. So, while the S-AGV with integral CHB places a waste package in 2½ shifts compared to 4 shifts for the S-AGV with standalone CHB, the latter can place 5 STAD canisters into storage per week.

Several observations came out of the Time and Motion Analysis, which were identical to those listed above for the Below Grade Vault. See section 5.6.2 or Appendix C4 for details.

5.7.3 ISF Expansion

ISF expansion of another 5,000 MTHM would require constructing another vault building. Construction of additional storage area should be performed outside of the ISF PA to facilitate construction activities without stressing security. Once the new vault is constructed, the PA would be expanded to encompass it. Of course, this type of construction would mean that a significant corridor would need to be placed between vaults to ensure that construction workers receive as low as reasonably achievable (ALARA) radiation dose from the existing loaded storage units.

5.7.4 Performance of Structures, Systems and Components

Appendix C4 contains detailed evaluations of the S-AGV Alternative against a number of performance issues, including structural and seismic, thermal, radiological exposure, design life/aging/maintenance, etc. No new issues or problem areas were identified.

There are significant licensing challenges with Alternative 4 since vault storage for large commercial STAD canisters is still conceptual, unlike other storage methods. Those licensing challenges are identical to those listed above for S-BGV, as detailed in Appendix C4.

5.7.5 Summary; Pros and Cons for This Storage Alternative

In summary, the pros and cons to this alternative, listed from the highest most significant impact to the lowest least significant impact are as follows:

Pros

- Since the STAD canister storage is effectively indoors, the vault alternative may provide a more controlled environment than other Alternatives. The STAD canisters 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 STAD canisters. The STAD canisters would likely feel humidity changes during wetter weather and temperature changes between summer and winter).
- A vault shields STAD canisters from view, easing security concerns.
- A vault removes the possibility of STAD canister tipover caused by an earthquake or other postulated accidence since the STAD canisters are locked into position within the vault.

Cons

- A vault is a large nuclear structure impacted by potential seismic, construction, cost issues typically associated with large nuclear projects. In order to store 500 to 1,000 STAD canisters, a vault 100 feet in width would need to be between 1,000 and 2,000 feet long increasing the complexity of the structure.
- The thermal characteristics of STAD canisters are unknown. FSV canisters have relatively low energy densities compared to STAD canisters containing much hotter newer SNF. The study performed by CB&I determined that heat removal using stack effect in a vault is limited. Newer STAD canisters with hotter SNF may not be able to be adequately cooled in a vault which would require longer pool cooling prior to storage.
- The Above Grade Vault positions the STAD canisters so that direct radiation from the sides of STAD canisters must be shielded by thicker concrete walls.
- Higher structure and crane height from S-BGV requires increased strength to resist seismic loading.
- Vault throughput is limited due to cask handling congestion in the storage hall.

6.0 CROSS CUTTING ANALYSES

6.1 Seismic Analysis

6.1.1 General

Structural evaluations of storage alternatives must be performed to demonstrate compliance with the applicable requirements given in 10CFR72, sections 72.122 and 72.236. These sections specify structural performance requirements for facilities and storage systems to maintain the confinement, sub-criticality, radiation shielding, and retrievability of the SNF under normal operations, off-normal conditions, accident scenarios, and design basis natural phenomena conditions. For all dry canister storage systems associated with the shutdown NPP's, the DPC is designated as the confinement boundary. The types of structural loading that the DPC must be qualified to withstand at the ISF include deadweight, internal pressure, and thermal expansion under normal and off-normal environmental conditions, handling loads, drops and tip-over events, explosive overpressure events, and design basis natural phenomena events including fires, floods, tornado winds, and earthquakes. NUREG-1536 provides guidance for the types of structural modeling, structural analysis methods, NRC-approved design codes and standards for different storage system components, loading conditions and combinations, and acceptance criteria for performing the structural analyses required to meet the functional requirements described above.

Structural evaluations of each of the commercial storage and transportation systems considered in this report which meet the requirements described above have already been performed by vendors and documented in safety analysis reports accepted by the NRC during licensing. The environmental, accident and natural phenomena loading conditions, structural models, material properties, and displacement, force, and stress-strain results documented in these evaluations are used in this report as a basis of comparison, to make judgments regarding the seismic performance of storage and transportation systems under the general loading conditions defined for the Pilot and Expanded ISFs. Whereas many of the loads requiring evaluation are common to all sites (e.g. deadweight, internal pressure, thermal expansion, explosive overpressure, fires) and capabilities to withstand them are fully evaluated in the vendor SARs, they will not be addressed in this report. The focus of this report will be on those events where the load and/or structural response varies from one storage alternative to another, e.g. earthquakes, and their attendant sliding and tip-over effects.

Vendor storage system safety analysis reports only address the capabilities of the containers in which the SNF is transported and stored. The seismic response of a storage system is also affected by the pad or building which supports the system and the soil in which the building foundation is embedded. In licensing an ISFSI at a NPP, separate structural models of the casks and support structures including site-specific soil parameters and loading are developed to qualify individual storage systems for in-situ structural performance. In this report, similar models will be developed in order to size structural elements in the interest of refining cost analyses. Since these models require site-specific soil data and seismic loading as inputs to the analyses, and this report is intended to apply generally to sites independent of location, generic values for inputs are used in the analyses as described below.

6.1.2 Evaluation Parameters

The key parameters required to evaluate the seismic response of a given storage system and its supporting structure are the structural loading applied, the geometry and material properties of the components in the design, the boundary conditions at points of structural interface, and the criteria used to determine acceptable performance. These parameters are addressed in the sections below.

6.1.2.1 Seismic Loading

In this report, seismic demands on structures are defined in terms of peak ground accelerations (PGA) and ground motion response spectra (GMRS). A PGA represents the maximum acceleration in a given direction that a point on the ground surface will experience during a seismic event. Separate acceleration values are usually specified in each global horizontal and vertical direction. PGA's are site-specific, typically established by deterministic or probabilistic studies of seismicity in the region. In this report, storage alternatives will be evaluated based on a maximum PGA of 0.75G (G corresponds to the acceleration due to gravity), which was directed for use in the project design criteria to be representative of large earthquakes which are predicted to occur at sites in the western United States (see **Table 3.2-4**). Earthquakes in other parts of the United States are predicted to be lower than in the west. 10CFR72, section 72.102 specifies a seismic PGA demand of 0.25G for use in designing SNF storage facilities at most sites east of the Rocky Mountain front. Since the design of a structure to resist earthquakes is a significant part of the overall cost of the structure, storage alternatives in this report are evaluated using both a PGA of 0.75G and a PGA of 0.25G in order to provide more refined cost estimates applicable to sites located in different parts of the United States.

The other component used in defining seismic demand, the GMRS, represents the magnitude of the damped acceleration response of a structure vibrating at different frequencies to seismic excitation input at the base of the structure. Although site-specific response spectra can be developed, the typical approach adopted in industry and in this report is to use generic spectral shapes which have accepted for use by regulatory agencies tasked with nuclear industry oversight. The spectral shapes used in the storage alternative seismic evaluations are documented in USNRC Regulatory Guide 1.60 (Reference 4-6.1.2). This guide provides acceleration response spectra curves for both vertical and horizontal earthquakes, for several different values of structural damping. The curves used in storage alternative seismic evaluations correspond to a 7% of critical damping ratio, which is applicable to the response of concrete structures (Reference 6.1.3). The curves are normalized to a PGA value of 1.0 at the high frequency cutoff; therefore they must be scaled by the applicable site-specific PGA. The resulting vertical and horizontal GMRS used as input to the storage alternative seismic evaluations for both the 0.75G and 0.25G earthquakes are shown in **Figures 6.1.2.1-1 and 6.1.2.1-2**, respectively.

The storage alternative seismic responses are calculated using the time history method of dynamic analysis, which requires the seismic demand to be input as a series of acceleration values at discreet time intervals. The seismic excitation in the time history input should be equivalent to the seismic excitation in the GMRS input. The acceleration vs. time curves used in the time history analyses were developed to meet the criteria with respect to mean zero period acceleration values, target spectra frequency matching, power spectral density, frequency intervals, statistical independence, and cross correlation described in ASCE-4, section 2.3.

Figure 6.1.2.1-1
Ground Motion Response Spectra for 0.75G Design Earthquake

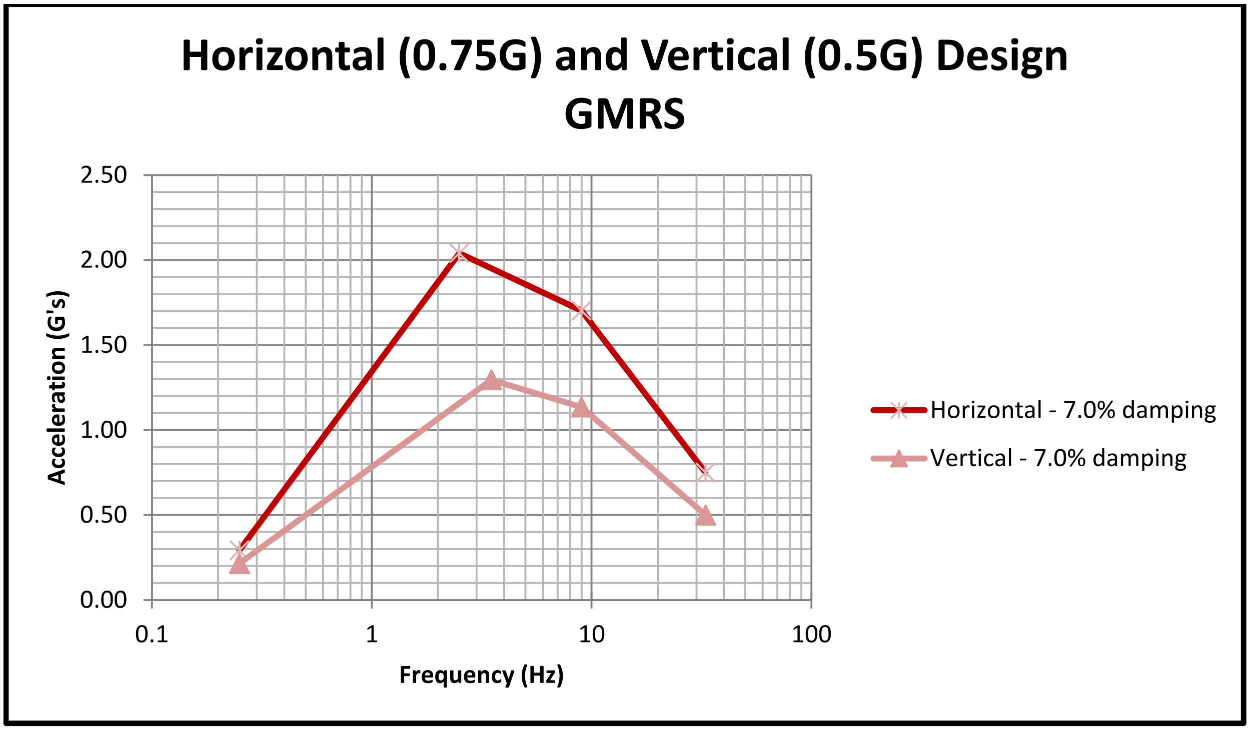
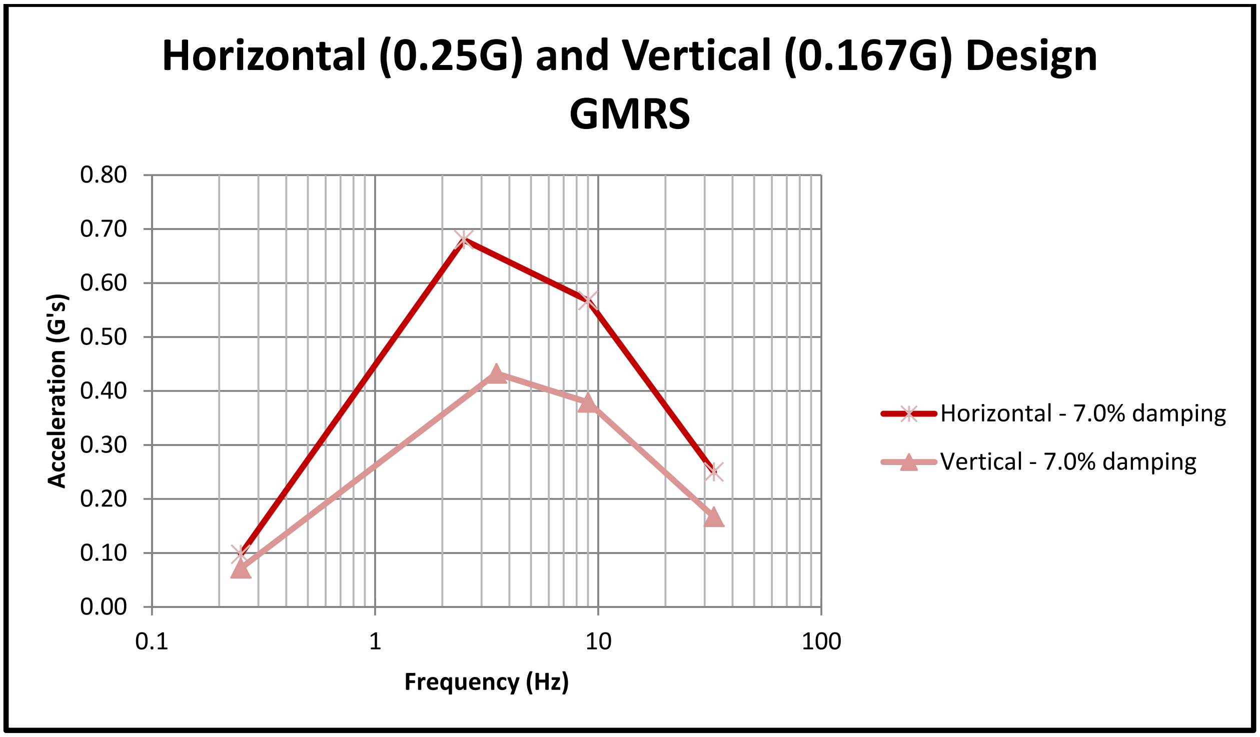


Figure 6.1.2.1-2
Ground Motion Response Spectra for 0.25G Design Earthquake



6.1.2.2 Structural Material Properties

Structural material properties for the concrete and steel used in developing seismic models of the storage alternatives are documented as follows:

Concrete: Material properties used to represent the concrete beams and slabs in the seismic models are as follows:

Ultimate strength: $f'_c = 4000$ psi
Density: $W_c = 145$ pcf
Poisson's Ratio: $\mu = 0.17$
Elastic Modulus (uncracked): $E_c = W_c^{1.5}\,33\,[f'_c]^{½} = 3.644 \times 10^6$ psi
Elastic Modulus (cracked): $E_c' = 0.6\,E_c = 2.186 \times 10^6$ psi
Shear Modulus (uncracked): $G_c = E_c / 2(1 + \mu) = 1.557 \times 10^6$ psi
Shear Modulus (cracked): $G_c' = 0.6\,G_c = 9.342 \times 10^5$ psi

Both the elastic and shear moduli are de-rated by a factor of 0.6 to account for section cracking.

Carbon Steel: Material properties used to represent the carbon steel members in the seismic models are as follows:

Material Type: SA-36
Elastic Modulus: $E = 29.0 \times 10^6$ psi
Yield strength: $F_Y = 36{,}000$ psi
Density: $W_c = 490$ pcf
Poisson's Ratio: $\mu = 0.3$

Stainless Steel: Material properties used to represent the stainless steel members in the seismic models are as follows:

Material Type: Type 304
Elastic Modulus: $E = 29.0 \times 10^6$ psi
Yield strength: $F_Y = 30{,}000$ psi
Density: $W_c = 490$ pcf
Poisson's Ratio: $\mu = 0.3$

6.1.2.3 Soil Properties

The soil conditions at the site have a major impact on the response of structures to seismic loading. Soil conditions at candidate sites can range from silts and soft clays with shear wave velocities of 500 ft./sec to hard shales and bedrock with shear wave velocities of 5000 ft./sec or more. All storage alternatives, and particularly the vaults, require relatively stiff soil to support the large, concentrated mass associated with the structure and SNF containers. Therefore, the storage alternative seismic models are developed assuming based on competent soil conditions.

In the event that a site is selected with less than adequate conditions, provisions to over-excavate the native soil and backfill with engineered soil will be required.

The soil model used in all storage alternative seismic evaluations represents a layered, deep soil site, underlain by bedrock at a depth of 270 feet. The uppermost layer is conservatively modeled using the soil properties corresponding to silts and soft clays. The density, stiffness, compressibility, and damping properties of each layer change with depth as shown in **Table 6.1.2.3**.

Table 6.1.2.3
Soil Profile Used in Seismic Response Analyses

Depth [ft.]	Layers [-]	$W_{SPECIFIC}$ [k/ft^3]	V_{SHEAR} [ft./sec]	G [k/ft^2]	K [k/ft^2]	λ [k/ft^2]	Poisson [-]	Damping [-]
0 – 120	12	0.1092	492	821.7	1780.3	1232.5	0.3	0.05
120 - 200	8	0.1292	951	3632.2	4842.9	2421.5	0.2	0.04
200 - 270	7	0.1311	1771	12781.7	13999	5477.8	0.15	0.03
270 - 300	3	0.1686	5314	147996	135662	36999	0.1	0.02

Pad seismic evaluations will consider an allowable bearing pressure of 3.0 k/ft^2 and an allowable friction angle of 30^o, which are typical values of these parameters for engineered fill at a 95% compaction rate. Seismic evaluations for the vault, which requires a deep foundation, will consider an allowable bearing pressure of 62.1 k/ft^2, developed based on the Meyerhof analyses method included in Appendix D1-2, and an allowable friction angle of 30^o.

6.1.3 Seismic Analysis Procedures

In this report, seismic analyses are performed in order to determine fundamental responses of storage structures to earthquake motions, to verify that structural elements are sized to resist the inertial loads caused by earthquakes, and to predict the onset of sliding or tip-over of storage systems placed on pads. The procedures required to perform each type of analysis are outlined below.

6.1.3.1 Calculation of Structural Responses to Earthquake Motions

In structural response evaluations, simple lumped mass/beam models of structures or representative portions of structures are developed where geometric features are condensed down to basic structural elements in order to predict overall fundamental dynamic responses to seismic loading. These condensed models are typically coupled to soil models which have been developed in separate dynamic analyses of the soil column beneath the structure (see section

6.1.2.3). The coupled models are the used to predict fundamental rocking and translation responses of the structure in order to estimate the magnitudes of accelerations on floor slabs, shear distributions, and base reactions at the foundation.

6.1.3.2 Structural Integrity Evaluations for Seismic Inertia Loading

In structural integrity evaluations, mass-stiffness models are developed which incorporate all significant geometric features of the structure in order to calculate structural dynamic responses. More refined models are required in order to accurately determine stress distributions in individual beams and slabs. Masses can either be lumped at nodes or distributed across beam and plate elements, provided that all significant mass is captured in the model. The response to seismic loading in three directions is calculated either by modal dynamic analysis or time history dynamic analysis. In modal analysis, the results in each of the three global directions are calculated separately and combined by SRSS or by the 100%-40%-40% method described in ASCE 4 (Reference 4-6.1.4). In time history analysis, the results in each direction are calculated simultaneously by direct integration of the equations of motion. Analysis output consists of deflections, forces and moments, and stresses throughout the structure, and reactions at the base of the structure as a function of time.

6.1.3.3 Calculation of Sliding and Tip-Over Thresholds

Pad mounted storage systems are not usually anchored to the pads unless seismic demands at the site exceed the sliding and/or tip-over thresholds. The sliding threshold is the combination of horizontal and net vertical accelerations at which a storage system overcomes the frictional resistance between its base and the pad and begins to slide. The governing equation is shown below:

$$F_{SLIDE} = M_{CASK}\,(a_{PAD\text{-}H1}{}^{2} + a_{PAD\text{-}H2}{}^{2})^{½} < F_{FRICTION} = M_{CASK}\,(1 - a_{PAD\text{-}V})\,\mu$$

where:

M_{CASK} = mass of storage cask

$a_{PAD\text{-}H1}$ & $a_{PAD\text{-}H2}$ = horizontal seismic accelerations at top of pad in orthogonal directions

$a_{PAD\text{-}V}$ = vertical seismic acceleration at top of pad

μ = coefficient of friction between pad and storage cask

If the seismic demand exceeds the sliding threshold, a kinematic response analysis of the storage system and pad can be performed statically by hand or dynamically using a computer code such as LS-DYNA to estimate the magnitude of the sliding or precessing displacements. Seismic restraints may have to be installed to anchor the storage systems to the pads in cases where the storage systems are at risk of displacing such they interact with each other or fall off the pad.

A tip-over event occurs under any combination of vertical and horizontal accelerations where the center of gravity of the storage system translates laterally beyond the storage system point of contact (edge or corner) with the pad. For analysis purposes, a tip-over is conservatively defined as the point where the overturning moment caused by the lateral seismic acceleration acting at the center of gravity of the cask exceeds the restoring moment caused by the net vertical weight (gravity minus the seismic vertical acceleration) of the cask acting at an offset from the contact point equal to the cask radius. The comparison can be expressed in terms of a factor of safety given by:

$$F.S. = M_{RESTORE} / M_{OVERTURN} = M_{CASK}\, r_{CASK}\, (1 - a_{CASK\text{-}V}) / M_{CASK}\, h_{CG}\, (a_{CASK\text{-}H1}{}^2 + a_{CASK\text{-}H2}{}^2)^{½}$$

where:

$a_{CASK\text{-}H1}$ & $a_{CASK\text{-}H2}$ = horizontal seismic accelerations at the C.G. of the cask in orthogonal directions
$a_{CASK\text{-}V}$ = vertical seismic acceleration at the C.G. of the cask
h_{CG} = cask center of gravity height
r_{CASK} = cask radius, or horizontal distance from tipping point to cask C.G.

If the overturning moment exceeds the restoring moment, a tip-over of the storage system is considered a credible event and the storage system must be anchored to the pad.

6.1.3.4 Seismic Acceptance Criteria

Acceptance criteria for evaluating the results of seismic analyses are specified in the applicable design codes governing concrete and steel design, and in the typical allowable values for soil bearing pressure and friction capacity specified in section 6.1.2.3. Stress results from the structural integrity analyses are reflected in the concrete and steel member sizes shown on the conceptual drawings for each storage alternative. Similarly, soil bearing pressure comparisons are used to determine if supplemental soil anchoring provisions are likely to be required based on the soil conditions assumed in the evaluations.

6.1.4 Seismic Evaluations of Storage Alternatives

6.1.4.1 C-PAD

Seismic evaluations for pad mounted storage systems are performed to ensure that the storage system is capable of withstanding the accelerations generated by the design earthquake, that the pad is sized to maintain structural integrity under loading applied by the storage systems, that the seismic restraints (if any) will transfer the inertia loading from the storage systems to the pad, and that the pad has sufficient engagement in the soil to prevent soil failure.

Seismic evaluations of the storage systems documented in vendor SARs determine the capacity to withstand accelerations applied at the top of the pad that each storage system is designed for. These capacities, shown in **Table 6.1.4.1-1**, are compared to the pad accelerations calculated in seismic response analyses documented in Appendix D1-1 to determine whether or not the storage system capacities envelope the pad seismic demands. The results of this comparison indicate that for the 0.25G earthquake, the capacities of both the vertical and horizontal storage systems for the Pilot ISF either envelope or are within 20% of enveloping the maximum responses calculated at the top of the pad. In cases where the seismic demands exceed the storage system capacities, there is generally enough margin between the seismic capacity credited in the vendor SARs and the actual maximum seismic capacity at the material design limits to qualify the storage systems for the 0.25G earthquake demands. Therefore, the risk of not being able to re-license the vendor designs for the higher loads is considered extremely low.

For the 0.75G earthquake, the acceleration demands at the top of the pad significantly exceed the accelerations that the storage systems are currently qualified to resist. In this case, the storage system seismic analyses documented in the vendor SARs will have to be revised to evaluate the higher seismic demand. Since NUREG-1536 (Reference 4-6.1.5) requires storage systems to survive a hypothetical tip-over event, and the decelerations of the DPC generated by this event are on the order of 45G's, re-qualification of the storage systems to withstand the much lower accelerations generated by the 0.75G earthquake is assured.

The design of the concrete pads must ensure that the pads are thick enough to distribute the weight of the storage systems to the soil without failing in bending or shear. If the storage systems are coupled to the pad the additional bending moments due to the horizontal seismic inertia response of the storage systems acting at their centers of gravity must also be considered. Most commercial systems use pads ranging from 18" to 24" for applications where the storage systems are not coupled to the pads, and 3' to 6' thick where storage systems are coupled. Maximum calculated vertical and horizontal pad bending moments for the 0.25G and 0.75G earthquakes are shown in **Table 6.1.4.1-2**, along with the ultimate moment capacities of each pad.

The sliding and tip-over resistances of the Pilot ISF storage systems are shown in **Table 6.1.4.1-3**. These resistances are calculated in accordance with section 6.1.3.3, using the accelerations calculated in the seismic response analysis documented in Appendix D1-1. The tip-over results indicate that for the 0.25G earthquake, the overturning moments for all storage containers are less than the restoring moments, therefore there is virtually no risk of any of the casks tipping over during a seismic event of that magnitude.

The sliding threshold is determined based on the combination of horizontal accelerations which induce sliding and vertical accelerations which reduce the gravitational force available for friction. The coefficient of friction corresponding to the onset of sliding is determined by equating the sliding force (F_{SLIDE}) to the friction force ($F_{FRICTION}$). For the worst case combination of horizontal and vertical accelerations at the top of the pad calculated in the seismic response analyses for the 0.25G earthquake in Appendix D1-1, this limiting value for the coefficient of friction between the pad and storage system is 0.41. As shown in **Table 6.1.4.1-3**, the coefficients of friction between the pad and storage systems documented in vendor SARs ranged from 0.2 to 0.6, reflecting various degrees of conservatism. The coefficients used in all vertical storage systems SARs were below the limiting value, indicating that sliding would be credible and would have to be evaluated. The table also lists the maximum displacements that storage systems would travel during the design basis seismic event, calculated by various energy balance and kinematic evaluation methods. The range of displacement results calculated is indicative of the conservatism inherent in the various approaches, but in all cases, the maximum displacements were below the clearances provided between vertical storage systems on the pads. As mentioned above, horizontal storage systems are designed to be coupled to prevent overturning, and will slide as a unit.

For the 0.75G earthquake, the overturning moments for all storage systems are greater than the restoring moments, indicating that tip-overs are credible events. Therefore, seismic restraints which couple the storage systems to the pads must be installed. A concept for a 16-point pad seismic restraint is shown in drawing TO16-S1-CPAD-DET-17. Whereas the shielding provided by the storage casks near the base is reduced due to the vent openings, installation of these seismic restraints will significantly increase the occupational dose to workers. The use of local shielding will mitigate some of the dose to the general area, but the proximity to the cask makes it difficult to provide adequate shielding, particularly to the extremities. By anchoring the storage systems to the pads, the seismic inertia loading applied to both the pad and storage system will increase. The pads and seismic restraints are both sized to resist the seismic inertia loading associated with the 0.75G earthquake. However, individual storage systems will have to be re-licensed for base anchorage, including a re-design of the support configuration to enable the load transfer, and a re-qualification of the entire storage system for the new loads. The risk of not being able to develop a suitable method of coupling the storage systems to the pad is considered low.

Table 6.1.4.1-4 lists the maximum vertical and horizontal reactions on the soil calculated in the springs at the base of the pad models. These reactions are compared to the bearing and shear capacity of the soil referenced in section 6.1.2.3 to ensure the soil will not fail under the applied seismic loads. The results of this comparison show that for the 0.25G earthquake, the soil has sufficient bearing and shear capacity to resist the deadweight and seismic reactions from the pad. However, for the 0.75G earthquake, seismic reactions on the soil exceed the combined bearing and shear capacities for both horizontal and vertical storage systems. In these cases, additional bearing capacity will have to be developed via micropiles or some other storage anchoring system. The parameters for designing a micropile system which provides the required additional bearing capacity are listed in **Table 6.1.4.1-4**.

Table 6.1.4.1-1
Structural Capacities for Vertical and Horizontal Storage Systems

Nuclear Site	Storage Orientation	Seismic Capacity (Top of Pad)			Seismic Capacity (Storage System C.G.)			Seismic Demand (Top of Pad) 0.25G / 0.75G			Seismic Demand (Storage System C.G.) 0.25G / 0.75G		
		ALAT [G]	ALONG [G]	AVERT [G]	ALAT [G]	ALONG [G]	AVERT [G]	ALAT [G]	ALONG [G]	AVERT [G]	ALAT [G]	ALONG [G]	AVERT [G]
Big Rock Point	Vertical	0.25	0.25	0.25	0.82	-	0.51	0.297 0.891	0.287 0.861	0.219 0.657	0.320 0.960	0.352 1.056	0.198 0.594
Humboldt Bay	Vertical	0.25	0.25	0.125	0.25	0.25	0.125						
Trojan	Vertical	0.38	0.38	0.25	0.38	0.38	0.25						
Maine Yankee	Vertical	0.26	0.168	0.168	0.5	-	0.5						
Lacrosse	Vertical	0.45	0.45	0.3	0.45	0.45	0.3						
Conn Yankee	Vertical	0.25	0.25	0.167									
Yankee Rowe	Vertical	0.25	0.25	0.167									
Zion	Vertical	0.25	0.25	0.167	0.5	-	0.5						
Rancho Seco	Horizontal	0.25	0.25	0.167	0.32	-	0.22	0.309 0.927	0.310 0.930	0.207 0.621	0.313 0.939	0.423 1.269	0.197 0.591
San Onofre	Horizontal	1.50	1.50	1.00									
Kewaunee	Horizontal	0.25	0.25	0.167	0.32	-	0.22						
Crystal River	Horizontal	0.30	0.30	0.20	0.37	0.33	0.2						

Table 6.1.4.1-2
Maximum Vertical and Horizontal Pad Bending Moments

Earthquake[1]	Storage Orientation	Max Calculated Bending Moment [ft-k/ft]	Reinforcing Steel Design [-]	Pad Ultimate Moment Capacity [ft-k/ft]
0.25G	Vertical	67.9	#11 @ 1' (min)	244.7
	Horizontal	156.2	#11 @ 1' (min)	244.7
0.75G	Vertical	144.9	#11 @ 0.5' (min)	978.7
	Horizontal	265.9	#11 @ 0.5' (min)	978.7

[1] Includes gravity loads.

Table 6.1.4.1-3
Sliding and Tip-over Resistances for Vertical and Horizontal Storage Systems

Nuclear Site	Storage System Weight [k]	Seismic Demand - 0.25G (Storage System C.G.)			Storage System CG		Tip-over		Sliding			
		A_{LAT} [G]	A_{LONG} [G]	A_{VERT} [G]	Height [in]	Offset[1] [in]	$M_{OVERTURN}$[2] [in-k/k]	$M_{RESTORE}$[2] [in-k/k]	Friction Coeff	F_{SLIDE} [k]	$F_{FRICTION}$ [k]	Displ [in]
Big Rock Point	253.2	0.320	0.352	0.198	118.0	68.0	44.20	62.61	0.3	120.5	60.9	0.3”
Humboldt Bay	245.0				64.0[2]	41.625	23.97	38.33	0.25	116.6	49.1	1.24"
Trojan	290.0				108.8	65.0	40.75	59.85	0.25	138.0	58.1	5.2"
Maine Yankee	323.9				117.1	68.0	43.86	62.61	0.25	154.1	64.9	
Lacrosse	195.9				83.0	64.0	31.09	58.93	0.2	93.2	31.4	4.4"
Conn Yankee	251.8				100.0[3]	64.0	37.46	58.93	0.2	119.8	40.4	
Yankee Rowe	206.1				83.0[3]	64.0	31.09	58.93	0.2	98.0	33.1	
Zion	331.5				118.0	63.77	44.20	58.72	0.35	157.7	93.1	
Rancho Seco	573.0	0.313	0.423	0.197	102.0	76.0	45.00	70.01	0.6	301.5	276.1	
San Onofre	400.3				121.1	50.5	53.42	46.52[4]	0.6	210.6	192.9	44"
Kewaunee	351.2				121.1	50.5	53.42	46.52[4]	0.6	184.8	169.2	
Crystal River	414.9				118.9	52.0	52.45	47.90[4]	0.6	218.3	199.9	

[1] Offset defined as the horizontal distance from the storage system C.G. to the nearest edge contacting the pad.

[2] Values shown are divided by cask weight.

[3] Height of storage system center of gravity estimated.

[4] Results are for single HSM. HSM’s are designed to be coupled together to prevent tip-over.

Table 6.1.4.1-4
Soil Bearing Pressures and Design Parameters for Pad Seismic Analyses

Parameter	Units	0.25G Earthquake		0.75G Earthquake	
		Vertical	Horizontal	Vertical	Horizontal
$F_{\text{VERT DW+SEISMIC}}$	[k]	23393	12759	38131	16952
$F_{\text{VERT DW-SEISMIC}}$	[k]	15701	8565	15057	8414
$F_{\text{LATERAL SEISMIC}}$	[k]	6093	3321	18280	9963
$F_{\text{LONGITUDINAL SEISMIC}}$	[k]	6223	4050	19269	12149
Pad Width	[ft]	450	101	450	101
Pad Length	[ft]	36	92	36	92
Pad Thickness	[ft]	3	3	6	6
Friction Shear Capacity	[k]	10994	4945	8693	4858
Micropiles - Lateral - Rows	[-]	0	0	1	2
Micropiles - Lateral - Length	[ft]	0	0	200	101
Micropiles - Lateral - Depth	[ft]	0	0	7.0	8.4
Micropiles - Longitudinal - Rows	[-]	0	0	14	3
Micropiles - Longitudinal - Length	[ft]	0	0	36	92
Micropiles - Longitudinal - Depth	[ft]	0	0	8.1	8.1
Bearing Pressure - Max Vertical	[ksf]	1.87	1.65	3.63[1]	2.65
Bearing Pressure - Net Lateral	[ksf]	0	0.61	3.00	3.00
Bearing Pressure - Net Longitudinal	[ksf]	0	0.82	3.00	3.00

[1] Maximum vertical bearing pressure exceeds nominal capacity of engineered fill specified. Bearing pressure can be reduced by decreasing thickness of pad, provided pad retains sufficient strength to resist bending loads. Alternatively, higher strength engineered fill may be used.

6.1.4.2 C-STD

The seismic performance for the pad mounted standard vertical and horizontal overpacks in the C-STD storage alternative will be quite similar to that of the vendor storage systems described in the C-PAD storage alternative. The standard vertical overpack will be oversized to be able to accommodate the largest diameter and the longest length DPC. This will require radial and axial shims to be installed inside the overpack to prevent uncontrolled movements of the DPC under seismic loading. By enveloping the dimensions of all DPCs, the standard vertical overpack will have a slight increase in tip-over radius, a somewhat greater increase in center of gravity height, and will weigh more than any other vertical overpack. This will result in an increased tendency to tip-over which will not be enough to alter the overpack’s seismic response to the 0.25G earthquake, but will increase the demands on the pad and seismic restraints for the 0.75G earthquake. One significant advantage of using a standard vertical overpack instead of the range of vertical overpacks in the Pilot and Expanded ISF commercial storage systems is that a universal interface between the overpack base flange and the seismic restraint on the pad can be developed, without having to retrofit and re-license each different vendor’s design.

The storage of horizontal DPCs in the standard vertical overpack will require re-analysis to account for the redistribution of the accelerations due to gravity and the three-directions of seismic inertia loading applied to the DPC and its internals. The risk of exceeding the capacity of DPC components to maintain the configuration of the fuel due to the increase in acceleration in a given direction is considered extremely low. However, horizontal DPCs stored in vertical overpacks are oriented upside down, with the weight of the fuel assemblies bearing down on their top assemblies. Since the assemblies were not designed to be stored in this position, this represents an unreviewed safety question which must be resolved by license amendment. The risk of not being able to qualify and license the DPC for this mode of storage is considered low.

The standard horizontal overpack described in section A2-1.0, like the standard vertical overpack, must be sized to accommodate the largest diameter and longest length DPC in the Pilot and Expanded ISF inventory. However, unlike the standard vertical overpack, no shims or spacers other than seismic pins at either end of the DPC are required to secure the DPC inside the overpack. This is because the DPC lies on its side on rails which provide adequate vertical and lateral support to withstand deadweight and seismic inertia loads. Since the diameters of vertical DPCs are generally larger than the NUHOMS horizontal DPCs, and since the acceleration demands for the 0.75G earthquake are higher than those that the NUHOMS Horizontal Storage Module is currently qualified for, the rails may have to be positioned wider apart than in the NUHOMS storage system to ensure that the DPC center of gravity will remain between the rails under maximum seismic inertia loads. Other than a potential increase in the center of gravity height associated with vertical DPCs, the seismic performance of the standard horizontal overpack will be nearly identical to the seismic performance for the HSM design determined in section 6.1.4.1, because the total mass will be enveloped.

The storage of vertical DPCs in the standard horizontal overpack should be readily licensable from a seismic performance standpoint because vertical DPCs are qualified to be transported in a horizontal orientation where 10CFR71 requires them to be qualified to maintain fuel geometry under a free drop from 30’ onto a flat unyielding surface. Even though the qualification is performed considering the DPC to be inside a transport cask protected by impact limiters, the deceleration of the DPC calculated during the drop accident bounds any credible acceleration generated by earthquakes.

6.1.4.3 C-UGS

The underground storage system consists of steel silos set on an underground concrete base slab with their tops set at grade. Large vented concrete caps are placed on top of the silos which provide radiation shielding, as well as protection from weather, tornado missiles, and intruders. The areas between the silos are filled with lean concrete. The underground storage system is a considered a shallow embedded structure which is much stiffer and has more mass than the soil it replaces. There are two soil-structure interaction effects associated with a structure of this type, both of which tend to reduce the seismic response of the structure relative to the free field ground motion of the soil it is embedded in. The high stiffness of the structure compared to the soil tends to average out incoherent ground motion waves that are generated by earthquakes, particularly at high frequencies. The high relative stiffness also increases the period and damping associated with the inertial response. Therefore, it is conservative to use the design earthquake peak ground acceleration of 0.75G to evaluate the seismic performance of the underground storage vault. Since seismic excitation is considered to act simultaneously in all three global directions, the maximum applied horizontal acceleration is the vector sum of the two horizontal components, or 1.06G.

The underground storage vault is designed for vertical storage only, so like the standard vertical overpack, it must be sized to accommodate the largest diameter and the longest length DPC. Radial shims for undersized DPCs will be required both at the bottom of the DPC to prevent sliding and at the top of the DPC to prevent tip-over, in order to eliminate potential damage to the DPC and overpack due to interactions.

The Holtec UMAX system is currently the only commercial underground storage system which has been licensed for use by the NRC. This system has been qualified to withstand a horizontal peak ground acceleration of 1.0G. Therefore, there is virtually no risk of being able to extend the qualification to encompass the maximum horizontal design acceleration of 1.06G. Since the DPC inside the underground storage system is rigid, it will not amplify the applied peak ground accelerations and therefore be subject to a maximum horizontal acceleration of 1.06G. Since this acceleration value exceeds the acceleration demand that the DPCs are qualified for in the current SARs, they will have to be re-qualified and re-licensed as discussed in section 6.1.4.1. The displacement boundary conditions applied to the DPCs in the requalification analyses are more advantageous for the underground storage system than for the vertical pad storage system, because of the fact that in underground storage, tip-over is prevented by lateral constraint at the top of the DPC, whereas in pad storage, tip-over is prevented by constraining moments at the base.

6.1.4.4 C-BGV/C-AGV

The below and above grade vaults are long, narrow concrete structures, which house bare DPCs inside ventilated, shielded concrete storage bays. The design of the two vaults are identical, except the above grade vault has the top of its base slab located at grade, and the below grade vault has the top of the operating floor located at grade. The seismic response of the below grade vault will be enveloped by that of the above grade vault, due to the building embedment. Parametric studies of similar structures indicate that partial embedment on the order of 0.2 times the building width reduces the peak seismic demands by as much as 67%. Therefore, the results from the seismic analysis of the above grade vault will be used as representative of the seismic performance of the below grade vault, accounting for the reduced demand by decreasing the reinforcing bar by 10%. Also, there are five optional floor plans for each vault, which are differentiated based on storage orientation (all vertical, all horizontal, and both vertical and horizontal) and transport cask unloading location (integral to vault, and in a separate CHB). In order to limit the number of evaluations to something manageable, the vault with the highest projected cost - the above grade vault with all vertical storage and a separate CHB for cask unloading – will be seismically evaluated, and the results will be used to develop the base cost estimate. Approximate costs for other options will be determined by accounting for the design differences between options, where significant.

The vaults all have a concrete stack running lengthwise down the building along one side. The stack is sized both to induce sufficient natural convective flow to cool the DPCs and to transfer horizontal shear loads in the upper parts of the building down to the base elevation. The vaults are placed on a 6 foot thick base slab, which overhangs the building by 15 feet on each side in the transverse direction in order to provide support for the stack and to reduce the building rocking mode about its longitudinal axis. In vaults designed for vertical storage, DPCs are placed directly on the base slab by overhead bridge cranes which lower them through penetrations in the 5 foot thick, concrete operating floor. The bridge cranes run on a common set of rails 37’-6’ above the operating floor. The crane bay is formed by the stack on one side, a steel (for 0.25G earthquake) or concrete (for 0.75G earthquake) wall on the other side, and steel roof girders and decking. In vaults designed for horizontal storage, the DPCs are placed in floor mounted concrete supports by rail-guided transfer carts, eliminating the need for penetrations, bridge cranes, and a building superstructure above the storage bay ceilings. DPCs enter the vaults through a receiving area located either at one end for all vertical or all horizontal storage, or centrally for both vertical and horizontal storage. This area of the building is steel framed or of lighter concrete construction, and has no stack.

The seismic performance of the vault is dominated by its long, narrow footprint on the soil. Although 68% of the mass of the building and contents is below the operating floor, there is enough mass up high at the crane rail and roof elevation to induce a large overturning moment about the building longitudinal axis under lateral seismic acceleration. The base slab and operating floor are coupled in shear by 2 foot thick concrete walls every 36 feet which form the vault bays, so the lower portion of the building is extremely stiff in all directions. The stack, however, must transfer all shear loads above the operating floor as a cantilever, which induces a large moment at the base of the stack and renders it impractical to design the stack so its fundamental natural frequency is anywhere close to the rigid range. The seismic response of the vault in the longitudinal direction is primarily translational, due to the overall length of the building and the rigidity of the stack in that direction. The eccentric location of the stack relative to the building centerline will induce a torsional load on the base, but the length of the structure will reduce the impact of the torsional moment on soil bearing loads at the base.

Seismic evaluations of the vault are performed to determine the maximum accelerations generated by the design earthquake, ensure that the vault concrete slabs are sized to maintain structural integrity under the applied seismic loading, that the seismic restraints will transfer the inertia loading from the storage systems to the vault operating floor and base slab, and that the base slab has sufficient engagement in the soil to prevent soil failure.

The seismic responses of the vault to the 0.25G and 0.75G design earthquake loadings are calculated using a simplified lumped mass, stick model of a 3-bay portion of the vault shown in **Figure 6.1.4.4-1** below. This model is formulated to capture the lateral rocking mode in the building, since this mode amplifies the ground motion more than any other mode. The stick model is coupled to a soil model and analyzed using the time-history procedure described in **Section 6.1.3.1**. The model inputs, loadings, and outputs for the 0.25G vault seismic response analysis are documented in Appendix D1-2. Since all model parameters and loads are linear, the response to the 0.75G earthquake can be determined by multiplying the results from the 0.25G analysis by a factor of three. Results of the analyses are given in terms of the maximum acceleration calculated at each model lumped mass which occurs at any point in the time history record. These maximum accelerations for the 0.25G and 0.75G earthquake response analyses are listed in **Table 6.1.4.4-1** below. The accelerations calculated in the longitudinal direction for nodes up the stack are very conservative, since the model only encompasses a short length of the vault in this direction resulting in a fictitious rocking mode about the lateral axis.

The accelerations calculated at each node are then multiplied by the corresponding lumped mass, and applied as nodal forces to a fixed-base version of the stick model to determine deadweight and seismic forces and moments in the beam members used to model the stack and base slab reactions on the soil. The resulting forces and moments are used to size the concrete sections, including the stack and operating floor slabs. Maximum bending moments calculated in these sections are compared to ultimate capacities in **Tables 6.1.4.4-2 and 6.1.4.4-3**. The accelerations on the base slab are used to calculate the inertial response of the vertical and horizontal DPCs from which design loads at seismic restraints and supports are determined. Seismic restraint concepts for the top and base of vertical DPCs are shown on drawings TO16-S1-CBGV-VB-22 and TO16-S1-CBGV-VB-23, respectively.

The reactions at the base slab support nodes used to verify that the foundation design is adequate for the applied loads are shown in **Table 6.1.4.4-4**. The vault is a heavy structure, which applies a large eccentric load on the soil due to the weight of the stack. The deadweight of the structure and contents applies an average bearing pressure of 3.27 ksf on the soil, which increases to a maximum bearing pressure of 5.22 ksf beneath the stack. Seismic loads for the 0.25G earthquake increase these values to 3.88 ksf (average) and 7.12 ksf (maximum). Seismic loads for the 0.75G earthquake increase these values to 5.10 ksf (average) and 10.90 ksf (maximum). The ultimate bearing stress for deep foundations given in section 6.1.3.3 is 60.8 ksf, which corresponds to very competent soil. The factors of safety on the ultimate bearing capacity are 8.73 for the 0.25G earthquake and 5.70 for the 0.75G earthquake. A factor of safety of 3 is typically considered acceptable for these foundations.

Soil reactions in the horizontal directions are resisted by a combination of soil friction on the bottom of the base slab and bearing on the ends of the base slab. For the 0.25G earthquake, the soil friction capacity calculated based on the net vertical load (deadweight minus seismic) exceeds the applied horizontal acceleration demand, therefore no bearing loads on the ends of the base slab need be credited with resisting horizontal loads. For the 0.75G earthquake, the soil friction capacity is much less than the applied horizontal load. For C-BGV, the below grade portion of the vault is engages enough of the soil to maintain average bearing pressures below the allowable limit of a factor of safety of 3 on ultimate, or 20.28 ksf. For C-AGV, the base slab only engages soil to a depth of 6 feet, which loads the soil above the allowable bearing pressure. Therefore, micropiles will be required to provide the additional shear resistance required. The micropile design parameters are listed in **Table 6.1.4.4-4**.

Figure 6.1.4.4-1
Stick Model for Seismic Response Analysis of 0.25G and 0.75G Earthquakes

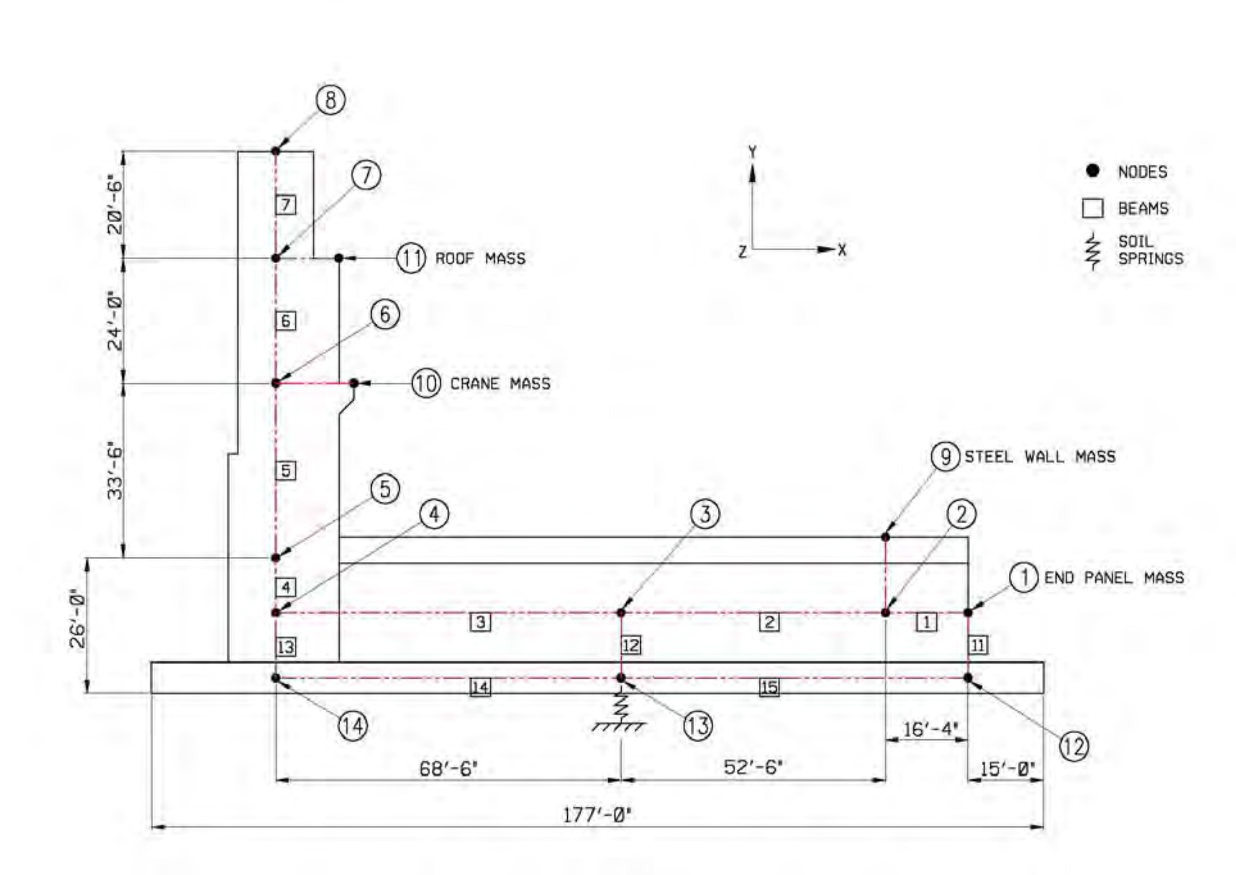


Table 6.1.4.4-1
Accelerations at Key Points in Vault Stick Model for 0.25G and 0.75G Earthquakes

Node	Mass Point	0.25G			0.75G		
		Lateral [G]	Vertical [G]	Longitudinal [G]	Lateral [G]	Vertical [G]	Longitudinal [G]
Node 1	Vault endwall	0.265	0.197	0.259	0.795	0.591	0.777
Node 3	Vault center	0.259	0.178	0.275	0.777	0.534	0.825
Node 4	Vault stack	0.263	0.186	0.290	0.789	0.558	0.870
Node 8	Stack - top	0.447	0.191	0.423	1.341	0.573	1.269
Node 9	Steel wall	0.262	0.192	0.274	0.786	0.576	0.822
Node 10	Crane rail	0.321	0.193	0.340	0.963	0.579	1.020
Node 11	Roof steel	0.387	0.191	0.383	1.161	0.573	1.149

Table 6.1.4.4-2
Bending Moments in Stack at Operating Floor Interface

Earthquake		Loading / Design	3 bays [ft.-k]	1 bay [ft.-k]
0.25G	Demand	Deadweight	5553	1851
		Seismic	261788	87263
		Extreme	267341	89114
	Capacity	3' wall x 6' Flue		135189
0.75G	Demand	Deadweight	5553	1851
		Seismic	785364	261788
		Extreme	790917	263639
	Capacity	3' wall x 10' Flue		415778

Table 6.1.4.4-3
Bending Moments in Operating Floor One Way Slab

Earthquake		Loading / Design	V [k]	M_{B+} [ft.-k]	M_{B-} [ft.-k]
0.25G	Demand	Deadweight	169	756	962
		Live Load	113	750	375
		Seismic @ 0.2G	34	151	192
		1.2D + 1.0LL + 1.0E	350	1808	1722
	Capacity	5' deep beam (8) #9 top (10) #9 bottom #6 stirrup @ 6”	376	2298	1859
0.75G	Demand	Deadweight	169	756	962
		Live Load	113	750	375
		Seismic @ 0.6G	101	454	577
		1.2D + 1.0LL + 1.0E	417	2111	2107
	Capacity	5' deep beam (10) #9 top (12) #9 bottom #6 stirrup @ 4"	477	2725	2298

Table 6.1.4.4-4

Soil Bearing Pressures and Design Parameters for Vault Seismic Analyses

	Units	0.25G Earthquake		0.75G Earthquake	
		C-AGV	C-BGV	C-AGV	C-BGV
$F_{VERT\ DW}$	[k]	62578	62578	62578	62578
$M_{ECCENTRIC\ DW}$	[ft.-k]	670962	670962	670962	670962
$F_{VERT\ DW+SEISMIC}$	[k]	74207	74207	97468	97468
$M_{ECCENTRIC\ DW+SEISMIC}$	[ft.-k]	1112806	1112806	1996494	1996494
Base Slab Length	[ft.]	177	177	177	177
Base Slab Width	[ft.]	108	108	108	108
Base Slab Thickness	[ft.]	7	30	7	30
Bearing Pressure - Max Vertical	[ksf]	7.12	7.12	10.90	10.90
Bearing Capacity - Ultimate	[ksf]	62.1	62.1	62.1	62.1
Factor of Safety on Ultimate	[-]	8.73	8.73	5.70	5.70
$F_{LATERAL\ SEISMIC}$	[k]	17423	17423	52268	52268
$F_{LONG\ SEISMIC}$	[k]	17986	17986	53957	53957
$F_{SHEAR\ APPLIED}$	[k]	25041	25041	75122	75122
$F_{FRICTION\ CAPACITY}$	[k]	29415	29415	15985	15985
Bearing Pressure - Lateral End	[ksf]	0	0	20.70	7.75
Bearing Pressure - Longitudinal End	[ksf]	0	0	20.70	13.11
$F_{SHEAR\ MICROPILES\ LATERAL}$	[k]	0	0	41146	0
$F_{SHEAR\ MICROPILES\ LONGITUDINAL}$	[k]	0	0	42475	0
Micropiles - Lateral - Rows	[-]	0	0	2	0
Micropiles - Lateral - Length	[ft.]	0	0	108	0
Micropiles - Lateral - Depth	[ft.]	0	0	10	0
Micropiles - Long - Rows	[-]	0	0	2	0
Micropiles - Long - Length	[ft.]	0	0	177	0
Micropiles - Long - Depth	[ft.]	0	0	6	0

6.1.4.5 Cask Handling Building

The cask handling building (CHB) is a slab-on-grade, steel framed or concrete structure which sits on a 4 foot thick concrete base slab. A 100 foot wide crane bay runs the length of the building in which two bridge cranes operate on a common set of rails. Transport casks are introduced to the building on railcars which travel on tracks located at either end of the crane bay. Light framed weather enclosures with roll-up doors extend along the tracks beyond the building in both directions. The building construction varies, depending on the magnitude of the design earthquake it must withstand. For the 0.25G earthquake, the main walls of the building are braced frame construction, with steel columns, roof girders, siding and decking. For the 0.75G earthquake, the walls are made of reinforced concrete, with deep beams spanning the crane bay columns. In both cases, a series of concrete cask transfer cells runs along one side of the building just outside the columns which support the crane runway. The cell walls are two feet thick, in order to shield operators from radiation doses caused by bare DPC transfer operations conducted inside the cells. A cart travels along a set of rails located above the transfer cells which raises and lowers DPCs into and out of a shield bell mounted on the cart through ports in the transfer cell ceilings. A number of other rail-guided carts and fixed DPC handling equipment access the cells from the ground floor through shield doors, performing various transport, transfer, and/or storage cask handling operations, as described in section 6.5.

The seismic performance of the CHB will be bounded by the response of the vault. The 356’ x 168’ footprint of the CHB on the soil is squarer and less likely to exhibit the large rocking motion characteristic of the vault response. The overall weight of the structure, estimated to be 60,000 kips, is much less than the total weight of the vault at 360,400 kips, and the 1.0 ksf soil bearing pressure under deadweight loads is much less than the vault’s 3.27 ksf. The presence of the concrete transfer cells along one side of the crane bay will serve to stabilize racking of the building in both the lateral and longitudinal directions under seismic loads, similar to the way that the stack stabilizes the seismic response of the vault. The lateral and longitudinal stiffness of the CHB will be less than the vault, but the vertical distribution of mass is such that the center of gravity height of the CHB is actually lower than that of the vault. This means that although the frequencies of the overturning modes may be lower, corresponding to higher spectral accelerations, the mass participation of each mode will also be lower, counteracting the effect on seismic response. All of the preceding arguments point to the fact that the response of the CHB to seismic inertia loading will be enveloped by that of the vault, and since the steel framing in the vault is designed to withstand the 0.25G earthquake, it will also be adequate for the CHB.

At higher levels of seismic excitation, moment connections in steel framed structures used to resist lateral loads become unwieldy, particularly when lifting the heavy loads associated with cask transfers. Concrete walled structures are much more suited to transferring the high shear and compression loads induced by building inertia and material handling loads. For the Private

Fuel Storage Facility, the crane bay in the Cask Transfer Facility was design with 3 foot thick concrete walls and a steel-support concrete roof. Since the two facilities are roughly the same size (356’ long x 168’ wide x 83’ high for the CHB, vs 267’ long x 197’ wide x 84’ high for the PFSF), and the seismic demands are comparable (0.75G for the CHB and 0.67G for the PFSF), the concrete wall thickness developed for the PFSF will be sufficient for the CHB. The crane bay for the CHB has a 100’ span vs. the 65’ span at the PFSF, so in the interest of reducing weight, a steel decking design supported by steel roof girders is proposed for the CHB.

6.1.5 Seismic Evaluation References

6.1.5.1 10CFR72

6.1.5.2 USNRC Regulatory Guide 1.60

6.1.5.3 USNRC Regulatory Guide 1.61

6.1.5.4 ASCE 4-06

6.1.5.5 NUREG-1536

6.2 Thermal Analyses of Storage Alternatives

6.2.1 General

Thermal evaluations of storage alternatives must be performed to demonstrate compliance with the applicable requirements given in 10CFR72, sections 72.122 and 72.236. The basic thermal performance requirement is for the storage system to provide adequate passive cooling capacity to maintain the temperatures of storage system materials below their allowable limits. NUREG-1536 provides guidance for the types of thermal modeling, the basic heat transfer considerations, the environmental conditions and accident scenarios, and temperature acceptance criteria for the fuel cladding that the thermal evaluations must address.

Thermal evaluations of each of the commercial storage and transportation systems considered in this report which meet the requirements described above have already been performed in Safety Analysis Reports accepted by the NRC during the licensing process. The environmental conditions, thermal models, and temperature results documented in these evaluations are used in this report as a basis of comparison, to make judgments regarding the thermal performance of storage and transportation systems under the conditions defined for the Pilot and Expanded ISFs.

6.2.2 Evaluation Parameters

The heat rejection capability of a particular design is a function of the amount of decay heat being produced, the thermal properties of the components in the design, the transfer of heat between internal components by conduction, convection, and radiation, and the temperature and heat capacity of the environmental heat sink which ultimately receives the heat. These parameters are addressed in the sections below.

6.2.2.1 Decay Heat Loads

The decay heat limits for the storage and transportation systems for the (12) shutdown plants identified in **Section 2.1.4** are shown in **Table 6.2.2.1**. These limits represent the maximum amount of decay heat generated by the SNF that the DPC at any stage in the loading, transfer, and storage process can reject and still maintain material temperature limits below allowable values. The limits for storage systems are typically higher than for transportation systems, because vented storage casks can transfer heat more efficiently than transportation casks which must be sealed. Since SNF must be transported to the Pilot ISF in licensed transportation systems, the decay heat limits on transportation systems represent the maximum demand that ISF storage alternatives must consider.

In determining the maximum heat demand for the Pilot and Expanded ISF, the effect of fuel aging on the decay heat generated by SNF should also be considered, so as not to produce overly conservative thermal evaluations. The decrease in decay heat occurs at a predictable rate based on fuel burnup. **Figure 6.2.2.1** shows the decrease in heat generation for high and low burnup PWR and BWR fuels as a function of time. **Table 6.2.2.1** lists the dates that SNF at each nuclear site was loaded into DPCs and placed on the ISFSI pads, or alternatively, the year that the reactors at the site were shut down and the fuel began to decay. These two parameters are used to calculate the heat load that a transport cask with a full payload of fuel assemblies of the type and age specific to each plant will generate at the projected opening of the Pilot ISF in 2022, shown in **Table 6.2.2.1**. Based on this information, storage alternatives will be evaluated for thermal performance using an upper bound limit of 25kW per DPC.

Table 6.2.2.1
Decay Heat Limits for Pilot and Expanded ISF Storage and Transport Systems

Nuclear Site	Vendor	Storage System		Transportation System		Final ISFSI Load Dates	Transport
		Overpack / Canister	Heat Load	Transport Cask	Heat Load		Heat Load in 2022
Big Rock Point	Fuel Solutions	W150 / W74	24.8 kW	TS125	17.6 kW	03/2003	-
Humboldt Bay 3	Holtec	HI-STAR HB / MPC-80	18.5 kW	HI-STAR 100HB	18.5 kW	12/2008	-
Trojan	SNC / Holtec	TRANSTOR / MPC-24E-EF	34 kW			09/2003	-
Maine Yankee	NAC	UMS / UMS-24	23 kW	UMS-UTC	20.0 kW	03-2004	-
Lacrosse	NAC	MPC / LACBWR	4.5 kW			09/2012	-
Conn Yankee	NAC	NAC-MPC / MPC-24	16.2 kW	NAC STC	15.7 kW	03/2005	-
Conn Yankee	NAC	NAC-MPC / MPC-26	17.5 kW	NAC STC	17.0 kW	03/2005	-
Yankee Rowe	NAC	NAC-MPC / MPC-36	12.5 kW	NAC STC	12.5 kW	06/2003	-
Zion 1 & 2	NAC	MAGNASTOR / TSC-37	35.5 kW	MAGNATRAN	33.0 kW	1997[1]	17.0 kW[2]
Rancho Seco	AREVA TN	NUHOMS HSM/ FO-, FC-DPC	13.5 kW	MP187	13.5 kW	08/2002	-
Rancho Seco	AREVA TN	NUHOMS HSM/ FF-DPC	9.9 kW	MP187	9.9 kW	08/2002	-
San Onofre 1	AREVA TN	NUHOMS HSM-ADV / 24PT1	14.0 kW	MP187	13.5 kW	2005	-
Kewaunee	AREVA TN	NUHOMS HSM-80 / 32PT	24 kW	MP197HB	24.0 kW	2009	-
Crystal River	AREVA TN	NUHOMS HSM-H/ 32PTH	34.8 kW	MP197HB	26.0 kW	2009[1]	22.3 kW[3]

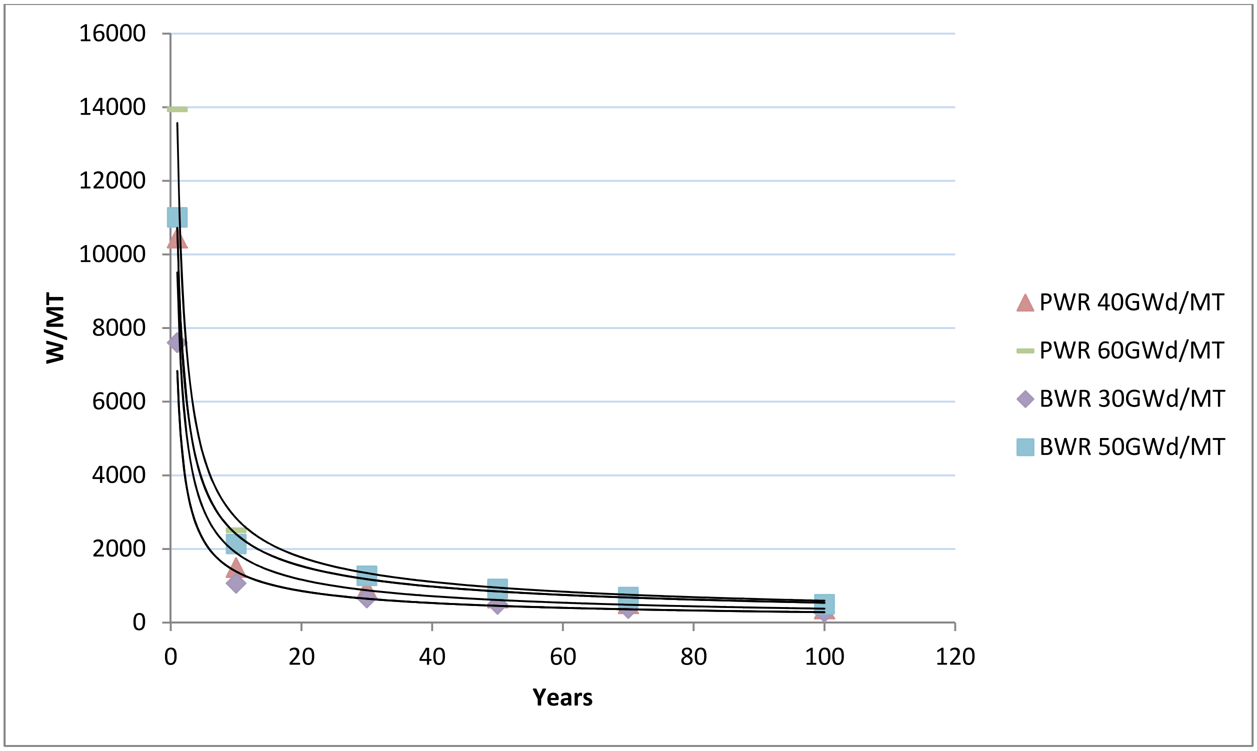
Notes:

[1] Year of nuclear reactor shutdown.

[2] Zion SNF inventory has 1019 MT in 2226 FA's, or 0.458 MT/FA. The maximum heat load that 37 FA's at 0.458 MT/FA can generate @ 1kW/MT is 17.0kW.

[3] Crystal River SNF inventory has 383 MT in 824 FA's, or 0.465 MT/FA. The maximum heat load that 32 FA's at 0.465 MT/FA can generate @ 1.5kW/MT is 22.3kW.

Figure 6.2.2.1
Rates of Decay in Heat Generation for High and Low Burnup PWR and BWR SNF



Fuel / Burnup	[Years]	1	10	30	50	70	100
PWR 40GWd/MT	[W/MT]	10444	1492	910	666	509	368
PWR 60GWd/MT	[W/MT]	13936	2505	1458	1036	773	541
BWR 30GWd/MT	[W/MT]	7603	1067	667	493	380	278
BWR 50GWd/MT	[W/MT]	11008	2137	1271	914	693	498

6.2.2.2 Environmental Conditions

NUREG-1536 requires thermal evaluations of SNF storage systems to be performed under a prescribed set of environmental conditions and accident scenarios. The applicable environmental conditions which must be considered are as follows:

Normal Storage -	typically, a mean summertime temperature at a site taken from ASHRAE tables or some other rational basis. Since this report is site independent, a value of 80˚F (26.7˚C) has been assumed.
Off-normal Storage -	typically, an upper bound temperature at a site (e.g. design summertime dry bulb with a 1% chance of exceedance) taken from ASHRAE tables or some other rational basis. Since this report is site independent, a value of 100˚F (37.8˚C) has been assumed.
Extreme Storage –	a site-specific accident condition where the maximum temperature corresponds to the lower bound limit for annual probability of occurrence considered in safety analyses. Since this report is site-independent, a value of 120˚F (48.9˚C) has been assumed.

Storage alternatives which are exposed to sunlight are also required to consider an insolation heat load for normal, off-normal, and extreme conditions. Insolation values for transportation systems given in 10CFR71.71 are normally used in thermal evaluations of storage alternatives under 10CFR72. The vendor storage and transportation system SARs list the insolation values considered in each analysis.

6.2.2.3 Material Allowable Temperature Limits

The vendor safety analysis reports for storage systems and transportation packages reference a number of different sources to establish the material allowable temperature limits used to determine the maximum heat loads. The sources referenced in this report generally reflect the most current information used in licensing commercial storage systems.

The allowable temperature limits for the fuel cladding vary by material and loading condition, as shown in **Table 6.2.2.3** below. The allowable temperature limits for other materials used in thermal evaluations of storage and transport systems in this report are applicable to all environmental loading conditions:

Table 6.2.2.3
Allowable Temperature Limits for Storage and Transportation System Materials

Material	Normal Condition (long-term)	Off-normal Condition (short-term)	Extreme Condition (short-term)	Ref
Zircaloy Cladding	752°F (400°C)	1058°F (570°C)	1058°F (570°C)	6.2.2
Stainless Steel Cladding	644°F (340°C)	806°F (430°C)	806°F (430°C)	6.2.5
Austenitic Stainless Steel	← 800°F (427°C) →			6.2.6
Concrete (Portland Cement)	← 300°F (149°C) →			6.2.2
Aluminum Plate	← 400°F (204°C) →			6.2.6

6.2.2.4 Material Property Variations with Temperature

Storage and transport system materials experience significant changes in temperature when loaded with SNF. The thermophysical properties for these materials which affect heat transfer vary as a function of temperature as shown in **Table 6.2.2.4** below.

Table 6.2.2.4
Variations in Storage and Transport System Material Properties with Temperature

Material	Temperature	Specific Heat (BTU / lb - °F)	Thermal Conductivity (BTU / hr- ft -°F)
Zircaloy	100°F (38°C) 400°F (204°C) 800°F (427°C)		6.82 7.11 7.64
Stainless Steel	-60°F (-51°C) 140°F (60°C) 640°F (338°C)	0.100 0.115 0.135	7.7 8.95 11.50
Concrete	100°F (38°C) 200°F (93°C) 500°F (260°C)	0.25 0.25 0.25	1.17 1.14 1.04
Helium	80°F (27°C) 260°F (127°C) 495°F (257°C)	1.24 1.24 1.24	0.0866 0.1037 0.1283

Although the variation in material properties can be as much as 50% from the ambient temperature to the maximum temperature associated with a full load of SNF, the variation associated with a temperature change of 20˚F is small by comparison. This implies that over small temperature ranges, the differential temperatures between components in a storage system will remain effectively constant for a given heat input load, but the overall temperature distribution will move in parallel with the environmental temperature (e.g., see **Figure 6.2.3.1.a**).

6.2.2.5 Effects of Changes in Storage Orientation

Passive cooling by free convection relies upon an increasing temperature gradient in the direction of flow that decreases the air density and induces the differential pressure which drives the flow. For the typical vertical storage system shown in **Figure 6.2.2.5.a**, the temperature gradient on the exterior surface of the DPC ranges from 101˚F at the base to a maximum temperature of 351˚F near the mid-point of the active fuel region, and tapers off to 199˚F at the top of the DPC. The maximum temperature of the fuel cladding at the centerline is 648˚F. The temperature distribution is axi-symmetric. For the typical horizontal storage system shown in **Figure 6.2.2.5.b**, the temperature gradient on the exterior surface of the DPC ranges from a minimum value of 250˚F approximately 25% up from the base to a maximum of 355˚F at the air vent at the top. The maximum temperature of the cladding is 711˚F just above the centerline of the DPC. The temperature distribution is mirror-image symmetric about the vertical plane through the DPC. In both cases, the temperature distributions indicate that the primary heat flow is radial, by conduction, as opposed to by convection of the helium gas circulating inside the DPC. The horizontal DPC exhibits a temperature difference of 32˚F between the lowermost assembly and the uppermost assembly, which is attributable both to convective heat transfer inside the DPC and the increase in the DPC exterior wall temperature of 100˚F in the vicinity of the two assemblies. But that difference is small compared to the temperature difference between the outermost assembly and the exterior temperature of the DPC wall adjacent to the assembly which averages over 250˚F around the circumference. Since radial conduction to the DPC exterior surface is the primary heat transfer mechanism, and the vertical DPC exhibits little heat transfer in the axial direction (the horizontal DPC exhibits no heat transfer in its axial direction), the expectation is that the horizontal DPC will reject heat very similarly in either the vertical or horizontal orientation. Therefore, those storage systems where horizontal DPCs are oriented vertically are considered to pose low risk of not being capable of rejecting enough heat to maintain fuel cladding centerline temperatures below allowable limits.

Figure 6.2.2.5.a
Normal Temperature Distribution in Vertical Storage System – 23kW PWR SNF

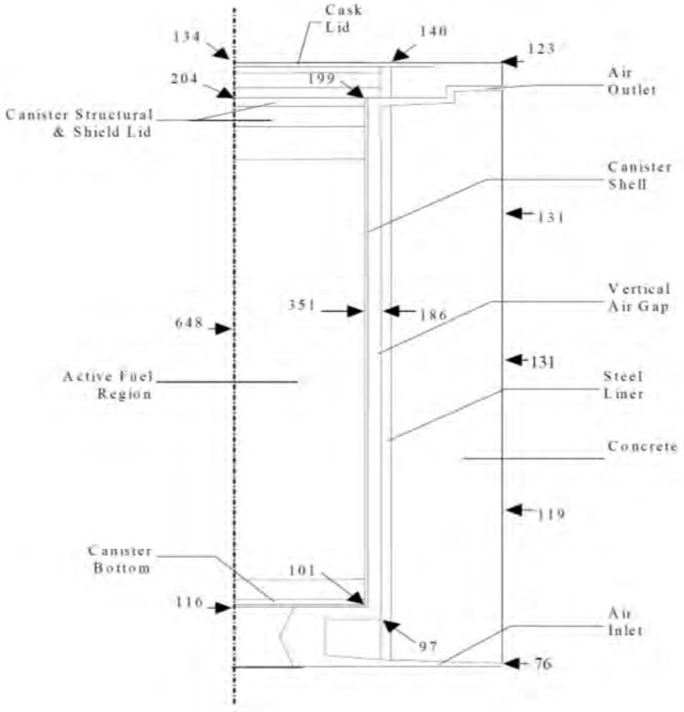
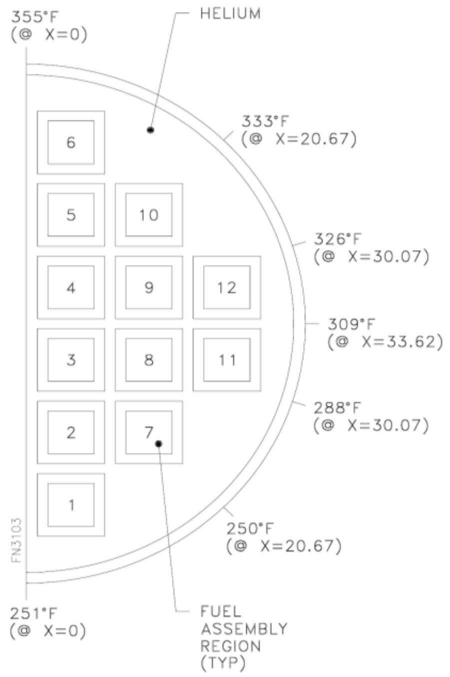


Figure 6.2.2.5.b
Normal Temperature Distribution in Horizontal Storage System – 23kW PWR SNF

FUEL ASSEMBLY ID NUMBER	MAX FUEL CLAD TEMP (°F/°C)
1	552/289
2	660/347
3	706/374
4	711/377
5	673/356
6	585/307
7	602/317
8	664/351
9	665/352
10	617/325
11	563/295
12	561/294



6.2.3 Thermal Evaluations of Individual Storage Alternatives

6.2.3.1 C-PAD

Thermal evaluations for existing storage and transportation systems are documented in vendor Safety Analysis Reports, prepared in accordance with 10CFR72 and 10CFR71, respectively. In these evaluations, thermal models of the complete storage systems are developed which capture the principal design features affecting heat rejection. In particular, DPCs are modeled in sufficient detail to be able to predict temperatures at the centerline of the array of fuel assemblies based on the heat which conducts out through the basket, through the helium gas which occupies gaps between the basket and outer shell, through the shell itself, and eventually transfers away from the exterior surfaces of the DPC by convection and radiation (see **Figure 6.2.3.1.a**). Both vertical and horizontal storage overpacks have multiple openings at the bottom to introduce air to the space between the exterior surface of the DPC and the interior surface of the overpack. The air is drawn up along the sides of the DPC, is warmed by the DPC via free convection, and is exhausted through vents in the overpack at the top (see **Figure 6.2.3.1.b**). Up to 70% of the decay heat generated in the DPC is transferred by convection. The remainder of the heat transfers by radiation to the interior surfaces of the surrounding overpack. From there it transfers through the overpack to the exterior surfaces by conduction and on to the environment by convection and re-radiation. A small amount of heat transfers out the base of the overpack by conduction to the pad.

In the vendor SARs, the storage system thermal models are analyzed for design heat loads under the environmental conditions described in **Section 6.2.2.2**. **Table 6.2.3.1** shows the maximum temperatures of the fuel cladding at the centerline of the DPC and the exterior surfaces of the DPC obtained from vendor SAR analyses. As shown, there are minor variations in the environmental input temperatures, and in a few cases, the fuel cladding acceptance criteria associated with each loading condition. In all cases, however, there is sufficient margin between the maximum calculated cladding temperature and the allowable cladding temperature to consider the DPCs qualified for pad storage in their corresponding storage overpacks for the common set of normal, off-normal, and accident environmental conditions.

Figure 6.2.3.1.a
Typical Radial Temperature Distribution in Vertical Storage System

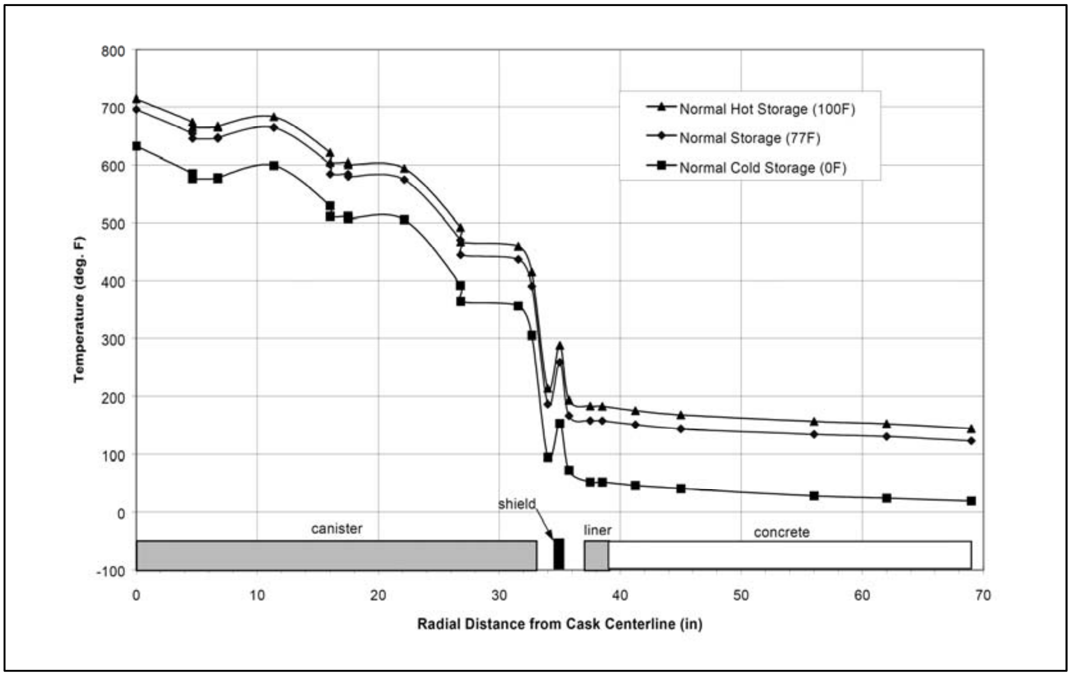


Figure 6.2.3.1.b
Typical Passive Cooling Flow Distribution in a Horizontal Storage System

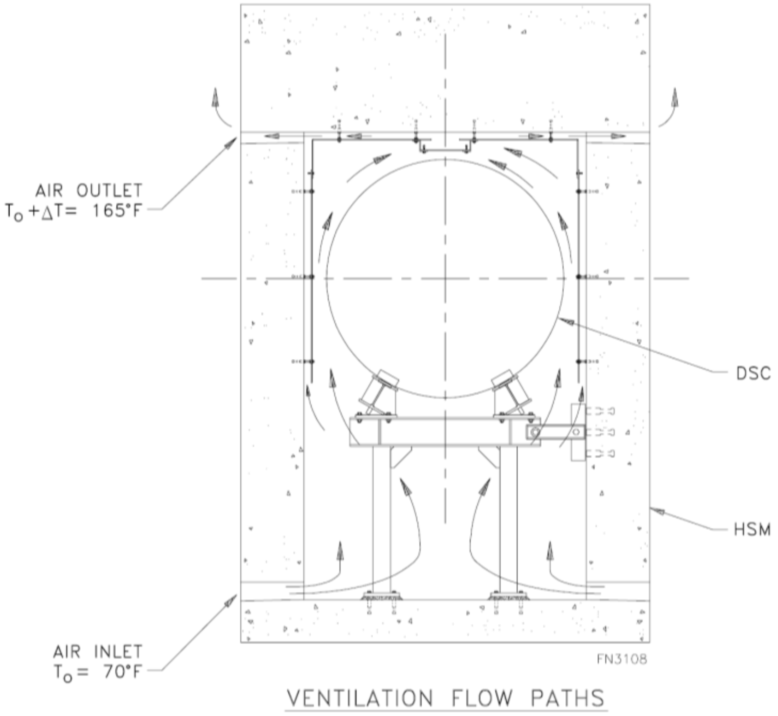


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Table 6.2.3.1
Thermal Evaluation Results for Shutdown NPP SNF Storage Systems

Nuclear Site	Design Heat Load	Loading Condition	Environ Temp	DPC Surface Temp		Cladding Temp		Notes
				Side	Top	Max	Allow	
Big Rock Point	24.8 kW	Normal Off-normal Extreme	77°F 100°F 125°F	407°F 431°F	- same - - same -	704.7°F 724.3°F	725.9°F 725.9°F	
Humboldt Bay	18.5 kW (7.82 kW actual)	Normal Off-normal Extreme	80°F 100°F 125°F	331°F	-	741°F	736°F 1058°F 1058°F	(1) (2)
Trojan	34 kW	Normal Off-normal Extreme	80°F 100°F 125°F	469°F 489°F 514°F		711°F 731°F 756°F	638°F 1058°F 1058°F	(7)
Maine Yankee	23 kW	Normal Off-normal Extreme	76°F 106°F 133°F	351°F 405°F 432°F	204°F - -	648°F 672°F 690°F	752°F 1058°F 1058°F	
Lacrosse	4.5 kW	Normal Off-normal Extreme	75°F 105°F 125°F	349°F 381°F 408°F	- same - - same - - same -	443°F 694°F 715°F	806°F	
Conn Yankee	17 kW	Normal Off-normal Extreme	100°F	351°F	220°F	611°F		
Yankee Rowe	12.5 kW	Normal Off-normal Extreme	75°F 100°F 125°F	319°F 346°F 372°F		563°F 585°F 607°F	644°F 806°F 806°F	(3)
Zion	35.5 kW	Normal Off-normal Extreme	76°F 106°F 133°F	457°F 485°F 510°F		714°F 752°F 786°F	752°F 1058°F 1058°F	
Rancho Seco	13.5 kW	Normal Off-normal Extreme	70°F 101°F 117°F	399°F 423°F	245°F 282°F	527°F 746°F	1058°F	
San Onofre	14 kW	Normal Off-normal Extreme	70°F 104°F 117°F	399°F 443°F 646°F	294°F 350°F 426°F	618°F 658°F 749°F	690°F 806°F 806°F	(5) (6)
Kewaunee	24 kW	Normal Off-normal Extreme	70°F 100°F 117°F	 374°F 382°F		638°F 658°F 663°F	752°F 752°F 1058°F	
Crystal River	34.8 kW	Normal Off-normal Extreme	100°F 115°F	392°F 407°F		669°F 684°F	752°F 1058°F	(4)

Notes:

1) HI-STAR transfer cask is sealed. Acceptance criteria is air temp at outside surface of DPC in vault (161°F max) < gas temp at DPC outer surface in HI-STAR (292°F).
2) Temperatures based on DB BWR fuel (272 watt/assy.). Actual BWR fuel is low heat emitting (115 watt/assy.).
3) Off-normal results calculated based on the average of the normal and extreme temperatures.
4) Off-normal results calculated by off-setting the normal temperatures
5) Temperatures during normal transfer mode are a minimum of 40°F higher than for normal storage mode.
6) Cladding allowable temperatures are for stainless steel material.
7) Temperatures based on MPC-32 with 34kW heat load. Results for MPC-24E with 34kW are bounded.

6.2.3.2 C-STD

The thermal performance of the vertical standardized storage overpack is dependent on design details which have not yet been established. Therefore, there is a degree of uncertainty as to whether an overpack with a single interior diameter and height will, in all cases, be able to establish the required convective flow to maintain centerline cladding temperatures below their required temperature limits. Thermal models of each different DPC to be stored in a vertical orientation inside of the standardized overpack must be developed and analyzed. Since the amount of free convection flow established inside an overpack is a function of the flow area and the height of the air column between the DPC and the overpack, a single standardized design will reject heat from different size DPCs with varying degrees of success. The fact that current heat loads generated in the DPCs are well below their design values increases the likelihood that a standard design can be developed that will perform as required in all cases. Therefore, the risk with the design of the vertical standardized overpack for all Pilot and Expanded DPCs not meeting thermal performance requirements is considered low.

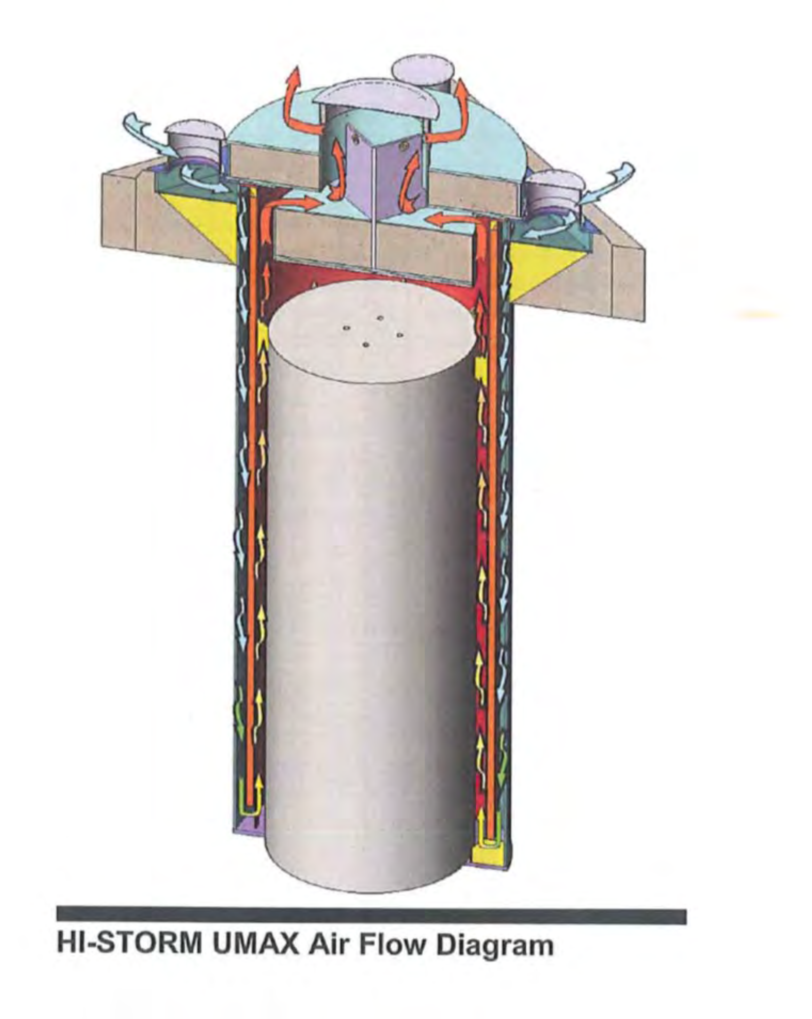
The NUHOMS horizontal storage module model HSM-H is proposed as the standardized storage overpack for all horizontal DPCs. This high temperature version of the standard NUHOMS storage module is designed to reject up to 35kW of decay heat from each horizontal DPC. Since the only horizontal DPCs to be stored at the Pilot and Expanded ISF are NUHOMS DPCs, and they all have approximately the same diameter and length, there is little risk of not being able to design a standardized horizontal overpack which can meet the thermal performance requirements for all Pilot and Expanded ISF horizontal DPCs.

6.2.3.3 C-UGS

The underground storage vault primarily relies upon free convection passive cooling to reject the heat generated by the DPC it contains (see **Figure 6.2.3.3**). In order to introduce the flow of cooling air at the base of the DPC, the underground system utilizes a cylindrical sleeve which encircles the DPC mid-way between the interior surface of the vault and the exterior surface of the DPC. The sleeve extends from the surface of the ground almost all the way down to the bottom of the vault. The air flows from the ground surface down the gap between the vault wall and the outside of the sleeve, through the narrow opening at the bottom of the vault, and up the gap between the DPC exterior surface and the sleeve interior surface. The air exhausts through vents in the concrete cap which sits on top of the vault. The gaps are sized to provide sufficient flow to remove both the heat coming off of the exterior surface of the DPC and the heat coming off the sleeve which transfers from the DPC to the sleeve by radiation.

Underground vaults at the Pilot and Expanded ISF must be sized to accommodate the complete range of diameters and heights of vertical DPCs, as well as horizontal DPCs in lift frames. The thermal performance of the underground storage vault is affected by the gaps and the height of the air column between the DPC and the sleeve. The gap spacing is more critical than with the standardized vertical overpack because the differential pressure which drives the flow must overcome the additional frictional losses between the air intake at ground level and the gap at the base of the sleeve. Thermal models of all DPCs – vertical as well as horizontal in lift frames - must be evaluated. The risk of the design not being able to develop sufficient flow to maintain centerline cladding temperatures below their allowable limit is nominally higher than for the standardized overpack. However, since the heat generated by the fuel is below the design heat load for the DPC due to aging, the heat transfer required to meet the allowable temperature limits is also less. Therefore, the risk associated with the underground storage vault design not meeting thermal performance requirements with shutdown NPP SNF is considered low.

Figure 6.2.3.3
Passive Cooling Flow in an Underground Storage Vault



6.2.3.4 C-BGV/C-AGV – Vertical Storage

In the below and above grade vaults, vertical DPCs and horizontal DPCs in lift frames are stored standing up on the base slab which forms the floor of the vault (see **Figure 6.2.3.4**). The vault storage area is isolated from the occupied portions of the building one floor above by the five foot thick operating floor. Shield plugs in the operating floor can be removed to provide access for placement and retrieval of DPCs using an overhead crane, but when installed, isolate the atmosphere in the vault storage area from the area above the operating floor. The vault storage area is separated into individual bays which span the width of the building by concrete walls which isolate one bay from the next. A concrete stack runs the length of the storage area along one side of the building. Each bay has an air intake on one side of the building and is open to the stack on the other side. When DPCs are placed in a bay and the shield plugs are re-installed, the decay heat from the DPCs warms the air in the bay which exhausts upward through the stack. The air exiting the stack is replaced by air flowing into the bay through the air intake on the opposite side of the bay. Thus, a self-sustaining cross flow develops which passively removes the decay heat from the bay. The amount of airflow through the bay is a function of the heat generated in the bay, the stack height and flow area, and the frictional losses along the flow path. Since the stack height and flow area are fixed parameters, the airflow reaches an equilibrium state where the differential pressure due to the stack effect is balanced by the frictional losses along the flow path. After equilibrium is reached, the flow is self-regulating, in that any decrease in the decay heat generated will reduce the driving pressure due to the stack effect, which reduces the flow and associated frictional losses until the system reaches a new equilibrium state at a lower value of flow. Therefore, the thermal performance of a vault is evaluated by determining if the decay heat generated induces sufficient airflow to maintain DPC temperature limits within their allowable values.

In Appendix D2-1, a computational fluid dynamics (CFD) analysis of the proposed design for the BGV/AGV has been performed to verify whether or not the vault design meets required thermal performance criteria. In the analysis, a thermal model of a representative section through a vault bay was developed, including the air intake, the vault storage area with the base slab below and operating floor above, a row of (8) DPCs, and the exhaust stack. Appropriate (symmetric) boundary conditions were coded along the cut faces of the model. Adiabatic boundary conditions were coded on concrete surfaces, which is a good first approximation since concrete is a rather poor conductor of heat. Each DPC was assigned a decay heat generation rate of 25kW, which is conservative with respect to the maximum heat load for SNF from any shutdown plant documented in Section 6.2.2.1. The heat from each DPC was distributed to the model as a uniform heat flux over the DPC sides and top. This uniform distribution is conservative compared to the actual DPC heat flux distribution, where a shield plug at the top of the DPC blocks almost all heat transfer through the top, directing it preferentially out the sides.

The environmental temperature considered in the analysis was the extreme accident temperature of 120˚F, given in Section 6.2.2.2.

The CFD solver calculated the steady-state temperature distribution, the airflow rates, and the heat fluxes throughout the model, based on the input geometry, the constitutive properties of air, and the applied heat loading described above. Both convection and radiation heat transfer mechanisms were considered in solving the model. Temperature contour plots of the model were generated, as well as tabular results, including the projected maximum centerline cladding temperature, maximum stainless steel temperatures, and maximum concrete temperatures. These results are discussed in the following sections.

6.2.3.4.1 Maximum cladding temperatures at DPC centerline

Since the CFD model did not include any details of the interior part of the DPC, cladding temperatures at the DPC centerline were not calculated. Instead, the centerline cladding temperature results for each vertical DPC in the vault can be determined by off-setting the surface temperature of the DPC calculated in the CFD analysis by the difference between the centerline cladding temperature and the DPC surface temperature calculated for each loading condition in the vendor SAR, as follows:

$$T_{\mathrm{CLADDING\text{-}CFD}} = T_{\mathrm{SURFACE\text{-}CFD}} + (T_{\mathrm{CLADDING\text{-}SAR}} - T_{\mathrm{SURFACE\text{-}SAR}})$$

The vault temperature results must also be corrected to reflect the design heat load that each DPC is generating given in the vendor SAR, rather than the 25kW heat load assumed in the CFD analysis. The correction is based on the results of a preliminary CFD study of the vault in which a model with (8) DPCs each generating 25kW was compared to the same model with the DPCs each generating 15kW. The maximum surface temperature calculated for each DPC in the 15kW heat load model averaged 101˚F lower than the surface temperature in the 25kW model. Therefore, maximum DPC surface temperatures will be determined based on a 10˚F/kW correction factor, as follows:

$$T_{\mathrm{SURFACE\text{-}CFD}} = T_{\mathrm{SURFACE\text{-}25kW}} - (25\mathrm{kW} - Q_{\mathrm{DESIGN\text{-}SAR}}) * (10^{\circ}\mathrm{F/kW})$$

In several cases, the actual heat load documented in the vendor SAR was substantially below the design heat load evaluated. Rather than evaluate the actual heat load, the vendor SAR indicated that the actual temperature distribution throughout the storage system was bounded by the design values. Since temperature distributions vary linearly with heat load, the actual distribution can be calculated based on the design distribution, as follows:

$$T_{\mathrm{SURFACE\text{-}ACTUAL}} = (Q_{\mathrm{ACTUAL\text{-}SAR}} - Q_{\mathrm{DESIGN\text{-}SAR}})\,(T_{\mathrm{SURFACE\text{-}DESIGN}} - T_{\mathrm{ENVIRON}}) + T_{\mathrm{ENVIRON}}$$

The maximum centerline cladding temperature for each different DPC stored in the vault can be determined by combining these three equations. The results appear in **Table 6.4.3.4.1** below. As shown, all projected cladding temperatures in the vault are below allowable values.

6.2.3.4.2 Maximum stainless steel temperatures in vault storage areas

The temperature data tabulated in Appendix D2-1 lists maximum temperatures for the sides and tops of the stainless steel DPCs for the design heat load. Note that these temperatures are calculated assuming a uniform heat flux over the top and sides of the DPC. In actual DPCs, a radiation shield plug is installed in the top of the DPC which suppresses the heat flux out the top, increasing the flux out the sides of the DPC. Since the maximum temperature calculated anywhere on the DPC is on the top, the results are conservative with respect to verifying the maximum temperature of the DPC stainless steel surface. The maximum calculated temperature on any DPC lid is 525˚F. The normal allowable for austenitic stainless steel (other than stainless steel cladding) is 800˚F (Reference 6.2.6). Therefore, the vault design provides ample cooling capacity to maintain the DPC surface temperatures below their normal allowable values at the design heat loads.

6.2.3.4.3 Maximum concrete temperatures in vault storage areas

The temperature contour plots in Appendix D2-1 show the temperature distribution throughout the air intake structure, vault storage area, and stack. Steady-state temperatures on concrete surfaces were elevated due to the heat that radiated to the surface and was absorbed. The maximum temperatures calculated on the floor, ceiling, and underside of the concrete shield plugs for the design heat loading were 278˚F, 330˚F, and 303˚F, respectively. Maximum temperatures calculated in the air intake and stack were not significantly greater than the ambient temperature. The maximum allowable temperature for concrete for long-term exposure is 300˚F (Reference 6.2.7). Since the maximum concrete surface temperatures calculated under the design heat load were above this value, radiation heat shields have been included in the design for those areas of the walls, ceilings, and shield plugs which require shielding to keep the temperature below the allowable limit. (Reference Drawing TO16-S1-CBGV-VB-19). These radiation heat shields may be omitted in cases where the heat load in each vault bay is significantly below the design heat loads.

Figure 6.2.3.4

DPC Storage In Below Grade and Above Grade Vaults

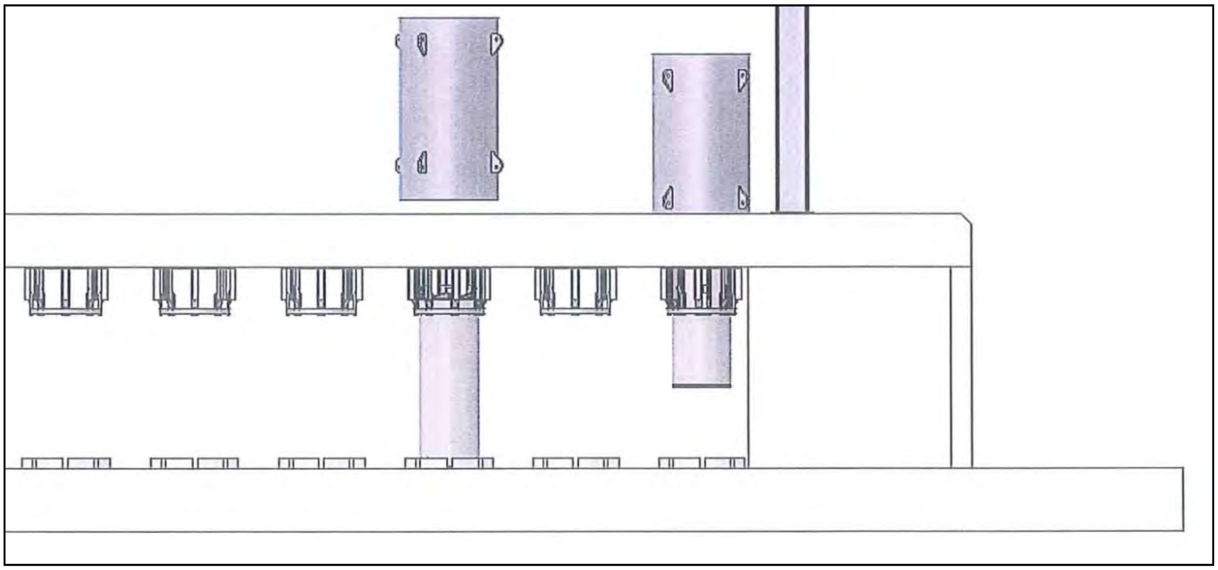


Table 6.2.3.4
Maximum Projected Cladding Temperatures in Below and Above Grade Vaults

Storage Overpack DPC	Environ Temp [^{o}F]	Design			Actual			DPC Vault		
		Q_{DESIGN} [kW]	Tside [^{o}F]	Tclad [^{o}F]	Q_{ACTUAL} [kW]	Tside [^{o}F]	Tclad [^{o}F]	$Tside_{25kW}$ [^{o}F]	Tclad [^{o}F]	$Tclad_{ALLOW}$ [^{o}F]
W150	77	24.8	407	704.7	24.8	407	704.7	430	725.7	725.9
W74	100		431	724.3	24.8	431	724.3	450	741.3	725.9
	125									
HI-STAR HB	80	18.5	331	741	7.82	186	359	430	431.5	736
MPC-80	100	(7.82								1058
	125	actual)								1058
TRANSTOR	80	34.0	469	711	25	366	544	430	607.9	-
MPC-24E-EF	100		489	731	25	386	564	450	627.9	1058
	125		514	756	25	411	589	470	647.9	1058
UMS	76	23	351	648	23	351	648	430	707.0	752
UMS-24	106		405	672	23	405	672	450	697.0	1058
	133		432	690	23	432	690	470	708.0	1058
MPC	75	4.5	349	643	4.5	349	662	430	538.0	806
LACBWR	105		381	694	4.5	381	694	450	558.0	-
	125		408	715	4.5	408	715	470	572.0	-
NAC-MPC	100	16.2	351	611	17	351	611	430	610.0	-
MPC-24										
NAC-MPC	100	17.5	351	611	17	351	611	430	610.0	-
MPC-26										
NAC-MPC	75	12.5	319	563	12.5	319	563	430	549.0	644
MPC-36	100		346	585	12.5	346	585	450	564.0	806
	125		372	607	12.5	372	607	470	580.0	806
MAGNASTOR	76	35.5	457	714	25	344	525	430	611.0	752
TSC-37	106		485	752	25	373	561	450	638.0	1058
	133		510	786	25	398	593	470	664.4	1058
NUHOMS HSM	70	13.5	399	527	13.5	399	527	430	443.0	-
FO-DPC	101									
FC-DPC	117		423	746	13.5	423	746	470	678.0	1058
NUHOMS HSM	70	9.9	399	527	13.5	399	527	430	443.0	-
FF-DPC	101									
	117		423	746	13.5	423	746	470	678.0	1058
NUHOMS	70	14	399	618	14	399	618	430	539.0	690
HSM-ADV	104		443	658	14	443	658	450	555.0	806
24PT1	117		646	749	14	646	749	470	463.0	806
NUHOMS	70	24								
HSM-80	100		374	658	24	374	658	450	724.0	752
32PT	117		382	663	24	382	663	470	741.0	1058
NUHOMS	70	24								
HSM-80	100		374	658	24	374	658	450	724.0	752
32PT	117		382	663	24	382	663	470	741.0	1058

6.2.3.5 C-BGV/C-AGV – Horizontal Storage

In the below and above grade vaults, horizontal DPCs and vertical DPCs oriented horizontally are stored laying down, supported by concrete v-blocks on either end of the DPC. The DPCs are placed in storage in the v-blocks by a rail-based transfer cart which traverses the length of the vault storage area. The vault is designed to have four sets of rails running side-by-side, longitudinally down the storage area. For the vault to be cost effective at all, it must have the capacity to store the entire inventory of SNF designated for the Pilot ISF. Since there are approximately 200 horizontal DPCs slated for storage in the Pilot ISF, each set of rails must be able to access an average of 50 storage locations, requiring a storage area of over 650 feet in length. This length is too long for passive cooling which relies upon differential pressure to establish airflow to be effective. The airflow necessary to cool a fully loaded vault with 25kW per DPC would require a stack with an area of up to 60 feet in depth times the width of the building. When the first DPC is placed into the vault, the heat generated would be insufficient to establish a coherent flow up a stack with such a large cross-sectional area. When the vault is fully loaded, the combined heat from each successive DPC would result in a bulk air temperature near the stack opening that would be too high to transfer the required heat and still maintain the fuel cladding temperature below the allowable limit. Due to the configuration of the rails, the only way to divide the storage area up into bays to try and enhance passive cooling would be by installing walls running parallel to the rails, which would not solve the overall length problem. Therefore, the most cost-effective way to design the horizontal vault is to provide active cooling for the storage area. An active vault storage area cooling system could be configured to establish ventilation flow across the width of the vault, using thermostatically controlled fans which exhaust the air at grade, requiring no stack. The system would require redundant power sources and controls, but the number of fans required to establish the design flow would provide sufficient diversity such that backup fans would not be required.

6.2.4 Thermal Evaluation References

6.2.1 10CFR72

6.2.2 NUREG-1536

6.2.3 FCRD-NFST-2013-000132

6.2.4 10CFR71

6.2.5 EPRI-TR-106440

6.2.6 ASME B&PV Code, Section II, Part D, Tables 1A, 1B

6.3 Time & Motion Analyses

6.3.1 General

The Time and Motion Analyses were performed for each design alternative covered by this study. The results are discussed in detail in the Appendices that cover these alternatives. Some general observations have resulted from these analyses.

First, there is not a great deal of difference among the alternatives. The results for all design alternatives result in five SNF canisters placed per week or 2.5 SNF canisters placed per week. The differences are dictated by how many railbays the design has. Designs with two railbays can place five SNF canisters placed per week; designs with one railbay can place 2.5 SNF canisters per week. This is the result of time it takes to unpack a Transport Cask from its protective components. Impact limiters, cover and tie-down systems are heavy, extremely strong components that require a great deal of care and effort to disassemble and to reassemble.

However, doubling the number of railbays may not result in doubling the throughput. This is only true for designs that permit the crane unrestricted access to the railbays. There needs to be operational independence between the railbay cranes and the SNF storage operations. For example, the vault with integral CHB designs use the same cranes to service the railbay and the storage vault. The operations are not separable and additional rail lines or railbays would have no impact unless the railbay cranes are free to operate separately from the storage options.

On the other hand, the rest of the operations are relatively straight forward heavy lift processes that take about one shift. Even in cases that take two shifts, the important consideration is when the next SNF shipment can be brought into the CHB. Even if the waste placement is taking place in parallel to unpacking the Transport Cask, it has no impact on the throughput.

Second, the more complex storage approaches result in more effort and time but do not improve throughput. Storing horizontal SNF canisters in vertical positions simplifies the design of the facility but generate a range of adaptors, lifting frames and other devices that need to be produced and installed to achieve the “simplification.” Standardized overpacks are another example of capital cost savings that come at the expense of operational costs and complexity that do not improve throughput.

A series of improvements were considered in Study 2 alternatives that demonstrated that improvements focused on SNF storage activities had negligible impacts. When similar efforts were focused on the Transport Cask unloading and repackaging activities, the throughput was significantly improved. This would suggest that a redesign of the Transport Cask packaging with an emphasis on the ease of unloading and repackaging would result in superior performance of the ISF.

Finally, the use of STAD canisters has no impact on operations at the ISF. The dose rates, the sizes and the weights of STAD canisters are similar enough to the larger DPCs that there is no difference operationally. Unfortunately, STAD canisters contain fewer fuel assemblies than a typical DPC so it takes more operations to place the same number of assemblies into storage at the ISF.

6.3.2 Evaluation Parameters

The time and motion analyses are intended to identify the following:

1. The operational sequence for each design alternative
2. The overall time necessary for a complete process sequence to be completed
3. The number of processes that can be completed per unit time
4. A basis for the staffing necessary for each alternative design
5. Where people are located during radiological work and for how long

Performing time and motion analyses of systems that have never been used is always a challenge. No one has operated a national scale ISF for the dry storage of SNF. The alternatives for study were developed from extrapolations of existing dry storage concepts. Part of this design conceptualization effort was the development of a high-level operational sequence that enabled the movement of SNF canisters through the necessary steps to be placed into storage. The high-level activities in these sequences were decomposed down to their constituent activities. At this level, the activities were generally ones that had been performed by operators at existing nuclear facilities, or that could be estimated by small extrapolations of existing operational experience.

The detailed sequence for the C-PAD alternative is essentially a description of current ISFSI operations. This sequence was presented to a number of individuals with real, hands-on operational experience ISFSI operations to achieve a consensus on the completeness, the durations and the staff size necessary to achieve each of these constituent activities. They added certain activities that were not envisioned by the design team. These were then pieced together to develop a bottom up estimate of durations and crew sizes for each step. These were checked against existing ISFSI performance to ensure accuracy.

Then, these validated operational steps were applied for each alternative design and assembled into operational sequences for each. Additional steps were added to reflect the single 8-hour shift approach to this study. Most ISFSI operations involving the movement of the DPCs are continuous operations. When these operations are stopped at the end of a shift, additional operational steps are necessary to secure the work site and to have a “Plan of the Day” meeting and a safety meeting at the start of each shift before starting work.

Once the operational sequence was developed for a single SNF shipment, the sequence was considered in parallel to determine how many DPCs could be placed per week. Several basic assumptions were made. The first was that a large supply of transport casks on railcars was staged on the site ready for processing. If the ISF railyard is empty or contains only one or two railcars, this time and motion study does not apply. The railcars will be processed and the Cask Handling Crews will be given other duties to fill up the week. So, the first inherent assumption is that the logistics supply chain is adequate to fully challenge the capacity of the ISF.

Secondly, as already described, this study assumes that a single 8-hour shift is used for Cask Handling Activities. This occasionally impacted operations because of the third assumption that no SNF fuel operation will be begun in a shift, if it cannot be completed by the end of that shift. Therefore, any activity where the SNF is being moved can only be started if there is enough time to complete the movement. Occasionally, the extension of the work day by only a couple of hours would have permitted the movement. So, in those cases the combined assumptions of the 8-hour work day and the prohibition of leaving a SNF load “hanging” in a compromise position significantly impacted operations.

An intrinsic step in the development of the operational sequence was to identify the number of people required for each step in the sequence. This listing was further decomposed down into component activities with people allocated to each activity for a period of time. For instance, an activity may be to install the lifting lug assembly onto a DPC. This activity requires an hour to perform and requires ten workers to accomplish. However, when the details are examined, the actual worker exposures are two workers for 45 minutes at the top side of the cask and two workers for 20 minutes on top of the cask. The rest of the workers are standing well away from the cask in an extremely low radiation zone.

Moreover, these activities can talk place in parallel or in series. Fragments of each activity were produced to identify a realistic basis for the radiological exposure calculations.

Gantt charts were prepared for each alternative based on the durations built up from analyzing all of the steps necessary to accomplish a major activity. These were placed on an 8-hour shift basis with steps included for securing the work space at the end of the shift and a morning “Plan of the Day” meeting at the beginning of the shift. These schedules were then placed on a weekly schedule in series and the series were put in parallel to determine how many DPCs could be processed in a period of time necessary for the cycle to repeat itself. That was generally four weeks because the facility could process two three shift cycles at a time by staggering it one shift.

6.3.3 Time and Motion Evaluations of Storage Alternatives

6.3.3.1 C-PAD

It was determined that the C-PAD throughput with all of the assumptions is 5 full-sized DPCs placed into storage each week. Several observations came out of the Time and Motion Analysis. First, the CHB requires two railbays with the ability to shuffle railcars into and out of the railbay daily. This is necessary to get the throughput because it takes an entire shift to open a shipment and an entire shift to repackage a transport cask for reshipment. In between these two evolutions, there is an entire shift where the railbays are idle unless a new shipment is moved in for processing. This way, the shipments are processed through the facility in a staggered manner in order to assure continuous operation.

Second, with the CHB having two railbays, it is the OTB cranes that determine the maximum throughput of the CHB. Two overhead traveling bridge cranes service the railbays; one for each bay. These cranes are both on the same rails to reduce overhead space, but they typically operate in a dedicated railbay only. If one of the cranes becomes unavailable for any reason, it is moved into a maintenance position and the remaining crane can be used to maintain operations, albeit at a reduced throughput forced by the lack of crane availability.

Third, there needs to be four horizontal and three vertical cask transporters on site to develop and maintain full ISF throughput. These are extremely slow moving machines. Their size and mass make them destructive of the road bed if they move too rapidly. Moreover, they are restrained from moving too rapidly when carrying DPCs in order to limit the potential impact should there be a failure of any kind. They become critical path constraints if any one of them is out of service. In addition, they are currently designed for a limited amount of duty. The ISF would use these machines far more than their design. This could force a great deal of maintenance to keep them available. One or two spares are considered necessary for the long-term functionality of the ISF.

Three separate time motion study scenarios were considered: all vertical storage, all horizontal storage and a 50-50 mix of vertical and horizontal storage. In spite of small differences in the work scopes, the time motion studies showed a consistent 20 DPCs placed every four weeks, for an average of five DPCs per week or an equivalent of about 3,000, MTHM per year, assuming no outages.

6.3.3.2 C-STD

It was determined that the C-STD throughput with all of the assumptions is at best 5 full-sized DPCs placed into storage each week. Several observations came out of the Time and Motion Analysis. First, the CHB requires two railbays with the ability to shuffle railcars into and out of the railbay daily. This is necessary to get the throughput because it takes an entire shift to open a shipment and an entire shift to repackage a transport cask for reshipment. In between these two evolutions, there is an entire shift where the railbays are idle unless a new shipment is moved in for processing. This way, the shipments are processed through the facility in a staggered manner in order to assure continuous operation.

Second, with the CHB having two railbays, it is the OTB cranes that determine the maximum throughput of the CHB. Two overhead traveling bridge cranes service the railbays; one for each railbay. These cranes are both on the same rails to reduce overhead space, but they typically operate in a dedicated railbay only. If one of the cranes becomes unavailable for any reason, it is moved into a maintenance position and the remaining crane can be used to maintain operations, albeit at a reduced throughput forced by the lack of crane availability.

Third, there needs to be four horizontal and four vertical cask transporters on site operational on site to develop and maintain full ISF throughput. These are extremely slow moving machines. Their size and mass make them destructive of the road bed if they move too rapidly. Moreover, they are restrained from moving too rapidly when carrying DPCs in order to limit the potential impact should there be a failure of any kind. They become critical path constraints if any one of them is out of service. In addition, they are currently designed for a limited amount of duty. The ISF would use these machines far more than their design. This could force a great deal of maintenance to keep them available. One or two spares are considered necessary for the long-term functionality of the ISF.

Fourth, the use of the standardized overpacks for the storage of SNF adds several additional operations to the ISF and may actually cost more than procuring more traditional overpacks from the original vendors. Indeed, the overpacks would need to be large enough to accommodate the largest of all of the commercial DPCs so they would, in general, be larger and more expensive than the legacy storage casks. This coupled with the need to provide inserts/adaptors to ensure the protection of the confinement barrier and heat transfer capability of the original storage system, could well increase rather than decrease the cost of the overall system.

Separate time motion study scenarios were considered for each variant but the results were all very similar. In spite of some detailed differences, all C-STD cases result in a consistent ability to process 20 DPCs every four weeks week or an equivalent of about 3,000, MTHM per year. It can be seen that the standardized overpacks do not impact the throughput of the ISF.

6.3.3.3 C-UGS

It was determined that the C-UGS throughput with all of the assumptions is 5 full-sized DPCs placed into storage each week. Several observations came out of the Time and Motion Analysis. First, the CHB requires two railbays with the ability to shuffle railcars into and out of the railbay daily. This is necessary to get the throughput because it takes an entire shift to open a shipment and an entire shift to repackage a transport cask for reshipment. In between these two evolutions, there is an entire shift where the railbays are idle unless a new shipment is moved in for processing. This way, the shipments are processed through the facility in a staggered manner in order to assure continuous operation.

Second, with the CHB having two railbays, it is the OTB cranes that determine the maximum throughput of the CHB. Two overhead traveling bridge cranes service the railbays; one for each bay. These cranes are both on the same rails to reduce overhead space, but they typically operate in a dedicated railbay only. If one of the cranes becomes unavailable for any reason, it is moved into a maintenance position and the remaining crane can be used to maintain operations, albeit at a reduced throughput forced by the lack of crane availability.

Third, there needs to be four operable vertical cask transporters on site to develop and maintain full ISF throughput. These are extremely slow moving machines. Their size and mass make them destructive of the road bed if they move too rapidly. Moreover, they are restrained from moving too rapidly when carrying DPCs in order to limit the potential impact should there be a failure of any kind. They become critical path constraints if any one of them is out of service. In addition, they are currently designed for a limited amount of duty. The ISF would use these machines far more than their design. This could force a great deal of maintenance to keep them available. Two spares are considered necessary for the long-term functionality of the ISF.

Finally, this concept is especially susceptible to weather and other environmental conditions during the loading process. Precipitation or blowing dust may preclude activities for extended periods of time. If these adverse conditions persist through period of the day that the work is being performed, it could have a significant impact on the ISF throughput.

Three separate time motion study scenarios were considered: all vertical storage, all horizontal storage and a 50-50 mix of vertical and horizontal storage. Since both the vertical and the horizontal time motion studies require approximately three shifts to complete a cycle and four weeks to cycle two railcars through the railbay, the best way to see what the ISF's throughput would be is to lay out four weeks. In spite of small differences in the work scopes, the time motion studies showed a consistent 20 DPCs placed every four weeks, for an average of five DPCs per week or an equivalent of about 3,000, MTHM per year, assuming no outages.

6.3.3.4 C-BGV

It was determined that the Below Grade Vault throughput has two variants: Below Grade Vault with Integral CHB and Below Grade Vault with Separate CHB. In addition, there is the option for all vertical storage or for a combination of vertical and horizontal storage depending on the legacy storage concept used.

First, the concepts with integral CHBs were limited to an average throughput of 2.5 full-sized DPCs placed into storage each week. Several observations came out of the Time and Motion Analysis. First, the layout of this concept has placed a great deal of activities in series. A single railbay covered by OTB cranes on a single set of tracks limits the performance of the concept. In addition, the OTB cranes are used to place the DPCs into storage which puts an additional time constraint on the use of the OTB cranes. Most of the activities associated with DPC storage are associated with activities in the railbay. So, optimizing the activities in the railbay results in only a great deal of time where the crane in the vault is idle.

Second, doubling the number of rails in the railbay would have no impact on the throughput unless there additional OTB cranes could be utilized. Even so, the system would result in idle time for cranes either in the railbay or in the vault area. The OTB cranes are the most important device in this concept. Although they are extremely reliable devices, any outage of one of these cranes would have a significant impact on the throughput of this facility.

Third, this concept is easier for the security team to protect because it is concentrated and contained. External threats and internal threats are easier to identify and to defeat than is the case for an external facility.

Finally, this concept is unaffected by weather and other environmental conditions during the loading process. Therefore, DPC placement is not impacted by external conditions so the ISF can be sited anywhere without the throughput being impacted.

Three separate time motion study scenarios were considered for each variant: all vertical storage, all horizontal storage and a 50-50 mix of vertical and horizontal storage. There are no appreciable differences. The C-BGV designs with Integral CHB were only able to place about 10 DPCs every four weeks week or an equivalent of about 1,500 MTHM per year.

The second variation of the C-BGV solves many of these problems by the introduction of a standalone CHB. This approach eliminates the congestion in the railbay by separating the function of the cranes that support railbay activities from the cranes and other devices that transfer the DPC out of the Transport Cask and place it into storage. This study proposes the use of a Shielded Transfer Cask from the CHB to the Vault Building. This enables the return of the Transport Cask to the Railbay while the DPC is independently placed into storage. Further, the study assumes that the standalone CHB has two railbays and two OTB cranes servicing them. This successfully eliminates the problem of congestion in the railbay and the use of the Shielded Transfer Cask expedites the recycling of the Transport Cask. Unfortunately, the Vault Building only has two OTB cranes. It takes roughly two shifts to transfer the DPC into the Shielded Transfer Sleeve and to place it into the vault. Therefore, the Vault Building can only handle a throughput of 10 DPCs every four weeks week or an equivalent of about 1,500 MTHM per year.

6.3.3.5 C-AGV

There is no difference between the Above Grade Vault and the Below Grade Vault.

6.3.4 Study 2

6.3.4.1 C-OPS

It is determined that the commercial operations (C-OPS) can process approximately five full-sized DPCs placed into storage every four weeks. This assumes a single heavy lift overhead crane in the CHB and one cask transporter of each type (vertical and horizontal). The attractiveness of this concept is that it is linear. Two heavy lift cranes in the CHB coupled with two cask transporters of each type result in 10 DPCs every four weeks. It also can be employed without a great deal of infrastructure support. So, it provides a functional means of beginning operations at the ISF before the complete build out of all the systems.

The disadvantage of this approach is that it is labor intensive. In addition, it increases the radiation exposure necessary for each activity slightly over the more remote techniques. In addition, one crane is tied-up because the vertical DPCs are limited to a series operation so that the crane is required for the DPC transfer processes. It is also subject to weather conditions and environmental events that would not be as much of an issue if the CHB is used.

The horizontal DPCs would appear to have an advantage because the crane is available to unpackage the next Transport Cask while the HCT is delivering the DPC to the overpack on the pad. However, a problem arises when HCT returns with the empty Transport Cask. The Transport Cask on the railcar will be completely unpacked but will need to be positioned so that the crane can pick the emptied Transport Cask off of the HCT and place it on its railcar. So, a conservative sequence does not try to take advantage of the down time of the crane by staggering the processing of two railcars at the same time.

6.3.4.2 A-OPS

It was determined that the A-OPS alternate canister transfer system would represent a small improvement in ISF throughput and a slightly larger reduction to the exposures to workers involved. Most of that reduction was achieved by the reduction in the size of the Cask Handling Crew. Fewer workers associated with DPC transfers spending less time in the radiation resulted in less worker exposures. However, overall it did not represent a significant savings in overall dose reduction or in the overall time to put a vertical DPC into storage. While some marginal improvement may be possible, it was considered that the throughput of the ISF would remain at about five DPCs per week.

Second, addition of automated systems in a radiation environment raises the possibility of additional failure rates and extra maintenance activities. Due to the potential that the failure would occur when the system was transferring DPCs, any failure would result in an interruption in the ISF throughput. However, most of the transducers are employed when the shielding is in place, so this is judged to be a minor concern.

Third, there needs to be four horizontal and three vertical cask transporters on site to develop and maintain full ISF throughput. This conclusion is unchanged from the Base Case. These are extremely slow moving machines. Their size and mass make them destructive of the road bed if they move too rapidly. Moreover, they are restrained from moving too rapidly when carrying DPCs in order to limit the potential impact should there be a failure of any kind. They become critical path constraints if any one of them is out of service. In addition, they are currently designed for a limited amount of duty. The ISF would use these machines far more than their design. This could force a great deal of maintenance to keep them available. One or two spares are considered necessary for the long-term functionality of the ISF.

The crew size is reduced about ten FTEs over the Base Case. This reduction in cost would be the major improvement of this approach. The radiation exposures are also reduced slightly, which is a benefit, but the real tangible benefit of this approach is a reduction in the necessary Cask Handling Crew size from an average of 49 in the Base Case to an average of 39 for the A-OPS alternative.

6.3.4.3 R-OPS

Remote operations, that is DPC transfers from the Transport Cask to the Transfer Cask taking place in a hot-cell, was determined to system would represent a small improvement in ISF throughput and a slightly larger reduction to the exposures to workers involved. Most of that reduction was achieved by the reduction in the size of the Cask Handling Crew. Fewer workers associated with DPC transfers spending less time in the radiation resulted in less worker exposures. However, overall it did not represent a significant savings in overall dose reduction or in the overall time to put a vertical DPC into storage. While some marginal improvement may be possible, it was considered that the throughput of the ISF would remain at about five DPCs per week.

Second, addition of automated systems in a radiation environment raises the possibility of additional failure rates and extra maintenance activities. Due to the potential that the failure would occur when the system was transferring DPCs, any failure would result in an interruption in the ISF throughput. However, most of the transducers are employed when the shielding is in place, so this is judged to be a minor concern.

Third, there needs to be four horizontal and three vertical cask transporters on site to develop and maintain full ISF throughput. This conclusion is unchanged from the Base Case. These are extremely slow moving machines. Their size and mass make them destructive of the road bed if they move too rapidly. Moreover, they are restrained from moving too rapidly when carrying DPCs in order to limit the potential impact should there be a failure of any kind. They become critical path constraints if any one of them is out of service. In addition, they are currently designed for a limited amount of duty. The ISF would use these machines far more than their design. This could force a great deal of maintenance to keep them available. One or two spares are considered necessary for the long-term functionality of the ISF.

6.3.5 Study 3

6.3.5.1 S-PAD

Using STAD Canisters instead of DPCs has no impact on ISF throughput. The S-PAD design study used a CHB with a single railbay. Therefore, it is limited to placing 2.5 STAD Canisters into storage each week. This conclusion is independent of what size STAD Canisters were considered. So, while the movement of STAD Canisters is the same, the placement of SNF into storage is very different. **Table 6.3.5.1** below captures the differences among the STAD Canister options available.

Table 6.3.5.1
ISF Throughput Using STAD Canisters on S-PADs

Option	STAD Canister	STAD Canister Capacity		MTU per Year	5000 MTU Time
		PWR	BWR		
S-PADa	Small	12	27	702	7.1 years
S-PADb	Medium	12	32	702	7.1 years
S-PADc	Large	24	68	1404	3.6 years

Several observations came out of the Time and Motion Analysis. First, the use of "pillbox" overpacks that accommodate eight STAD Canisters in a single overpack has no impact on the ISF throughout. It has a negligible impact on dose rates and Cash Handling Crew size, but otherwise no significant impact on the cask handling operations.

Second, with the CHB having two rail lines, it is the OTB cranes that determine the maximum throughput of the CHB. The single OTB crane is the limiting element in the throughput of this alternative. It precludes increasing the throughput of the facility and should it fail or experience an outage, it would effectively prevent the CHB from functioning.

Third, there needs to be two overpack transporters on site to develop and maintain full ISF throughput. These are extremely slow moving machines. Their size and mass make them destructive of the road bed if they move too rapidly. Moreover, they are restrained from moving too rapidly when carrying STAD Canisters in order to limit the potential impact should there be a failure of any kind. They become critical path constraints if any one of them is out of service. In addition, they are currently designed for a limited amount of duty. The ISF would use these machines far more than their design. This could force a great deal of maintenance to keep them available. One or two spares are considered necessary for the long-term functionality of the ISF. If the “pillbox” design overpack is used, the transporter is less important in that it will have adequate down time between movements for maintenance. One transporter is probably adequate.

6.3.5.2 S-UGS

Using STAD Canisters instead of DPCs has no impact on ISF throughput. The S-UGS design study used a CHB with a single railbay. Therefore, it is limited to placing 2.5 STAD Canisters into storage each week. This conclusion is independent of what size STAD Canisters were considered. So, while the movement of STAD Canisters is the same, the placement of SNF into storage is very different. **Table 6.3.5.2** below captures the differences among the STAD Canister options available.

Table 6.3.5.2
ISF Throughput Using STAD Canisters in S-UGS

Option	STAD Canister	STAD Canister Capacity		MTU per Year	5000 MTU Time
		PWR	BWR		
S-PADa	Small	12	27	702	7.1 years
S-PADb	Medium	12	32	702	7.1 years
S-PADc	Large	24	68	1404	3.6 years

With the CHB having two rail lines, it is the OTB cranes that determine the maximum throughput of the CHB. The single OTB crane is the limiting element in the throughput of this alternative. It precludes increasing the throughput of the facility and should it fail or experience an outage, it would effectively prevent the CHB from functioning.

There needs to be two overpack transporters on site to develop and maintain full ISF throughput. These are extremely slow moving machines. Their size and mass make them destructive of the road bed if they move too rapidly. Moreover, they are restrained from moving too rapidly when carrying STAD Canisters in order to limit the potential impact should there be a failure of any kind. They become critical path constraints if any one of them is out of service. In addition, they are currently designed for a limited amount of duty. The ISF would use these machines far more than their design. This could force a great deal of maintenance to keep them available. One or two spares are considered necessary for the long-term functionality of the ISF. If the "pillbox" design overpack is used, the transporter is less important in that it will have adequate down time between movements for maintenance. One transporter is probably adequate.

6.3.5.3 S-BGV

Using STAD Canisters instead of DPCs has no impact on ISF throughput. The S-BGV design study used a CHB with a single railbay. Therefore, it is limited to placing 2.5 STAD Canisters into storage each week. This conclusion is independent of what size STAD Canisters were considered. So, while the movement of STAD Canisters is the same, the placement of SNF into storage is very different. **Table 6.3.5.2** below captures the differences among the STAD Canister options available.

Table 6.3.5.2
ISF Throughput Using STAD Canisters in S-BGV

Option	STAD Canister	STAD Canister Capacity		MTU per Year	5000 MTU Time
		PWR	BWR		
S-PADa	Small	12	27	702	7.1 years
S-PADb	Medium	12	32	702	7.1 years
S-PADc	Large	24	68	1404	3.6 years

Several observations came out of the Time and Motion Analysis.

First, with the CHB having two rail lines, it is the OTB cranes that determine the maximum throughput of the CHB. The single OTB crane is the limiting element in the throughput of this alternative. It precludes increasing the throughput of the facility and should it fail or experience an outage, it would effectively prevent the CHB from functioning. Adding another CHB OTB crane would have no impact on ISF throughput without massive redesign of the CHB.

Second, the Vault Building OTB cranes are fully utilized and possibly overextended. Using more cranes with more limited roles might make for a more reliable system, albeit at the price of complexity and the need for more operators. The need to swap out the lifting devices between picking the Shielded Transfer Cask and managing the complex Shielded Transfer Sleeve may be too daunting of a design challenge. However, as currently configured, the Cranes in the Vault Building are at the limits of their capability.

Third, there needs to be two VCTs on site to develop and maintain full ISF throughput. These are extremely complex machines and could be unreliable if used as much as this concept requires. One VCT would possibly be able to maintain the ISF throughput, but having two is seen as a necessary precaution.

Fourth, this concept is easier for the security team to protect because it is concentrated and contained. External threats and internal threats are easier to identify and to defeat than is the case for an external facility.

Finally, this concept is unaffected by weather and other environmental conditions during the loading process. Therefore, STAD Canister placement is not impacted by external conditions so the ISF can be sited anywhere without the throughput being impacted.

6.3.5.4 S-AGV

There is no difference operationally between Above Grade Vaults and Below Grade Vaults.

6.4 Occupational Dose / ALARA Analyses of Storage Alternatives

6.4.1 General

Radiological evaluations of storage alternatives must be performed to demonstrate compliance with the controlled area dose requirements given in 10CFR72.104(a)(2), the annual dose requirements for unmonitored workers given in 10CFR20.1502(a)(1), and annual occupational exposure limits for radiation workers given in 10CFR20.1201. Nuclear operations at Department of Energy sites typically adopt a more restrictive occupational dose limit equal to 0.1 times the limit specified in 10CFR20, as a good radiological practice. In addition, site activities where there is a potential for workers to be exposed to radiation must follow the principles of the As Low As Reasonably Achievable program described in 10CFR20.1101.

6.4.2 Owner Controlled Area Dose Evaluations

In accordance with 10CFR72.104(a)(2), SNF storage sites are subject to a limit of 25 mrem/year for the annual dose equivalent that a real person may receive at the owner controlled area boundary. The ability for a particular site to meet this limit is established during the design of the ISFSI by a bounding dose calculation of the entire storage array. In the calculations, DPCs are modeled as point sources and a dose field over a wide area is calculated by spatial integration of the dose from each point source. The dose results obtained at different distances from the point sources are used to determine the actual owner controlled area boundary.

In the Pilot and Expanded ISF, there are no constraints placed on the amount of land that the site may occupy. The general concept for site selection is that it be located away from major population centers where obtaining enough land would not be an issue. The overall site plan drawings show the site on a one square mile tract of land surrounded by a boundary fence. This fence is shown for comparison purposes, and may or may not coincide with the owner controlled area. Estimates of fence line setback distance for 5-year cooled, high burnup fuel in vertical storage arrays are on the order of 775 meters for the Pilot ISF SNF inventory, and 830 meters for the Expanded ISF SNF inventory. Therefore, even if the storage pads were located at the center of the one square mile site, the owner controlled area boundary for the Expanded ISF storing this type of fuel would extend beyond the reference fence by approximately 160 meters. Since much of the fuel to be stored will have been aging for 15 years or more when placed in the Pilot ISF and Expanded ISF, required fence line setbacks will be reduced, potentially to the reference boundary fence shown in the site plans.

6.4.3 Radiation Controlled Area Dose Evaluations

In accordance with 10CFR20.1502(a)(1), SNF storage sites are subject to a limit of 500 mrem/year for the annual dose equivalent that an unmonitored worker may receive. The boundary at which radiation monitoring of workers is required is defined as the radiation controlled area. The radiation controlled area boundary will be established differently for each storage alternative. For the alternatives with outside storage - C-PAD, C-STD, and C-UGS – the radiation controlled area will be defined by a fence, which surrounds the storage area. The same area dose calculations described in section 6.4.2 may be used to determine appropriate setback distances from the storage area for the radiation controlled area fence. For the underground storage alternative, the setback distance will be much less than for other pad storage alternatives, due to the radiation shielding provided by the lean concrete that underground silos are embedded in. For the vault options with integral cask handling, the radiation controlled area will encompass the vault building if the dose rates outside the building walls are low enough, or a fence surrounding the facility if the dose rates outside the building walls exceed the 500 mrem/year limit. For the vault options with a separate CHB, the radiation controlled area will include the CHB, the vault, and the haul path between the two buildings.

6.4.4 Occupational Dose Evaluations

Occupational radiation exposures to workers are subject to a legal limit of 5 rem/year specified in 10CFR20.1201, and a more restrictive operating goal of 500 mrem/year. adopted as a good practice measure in accordance with the ALARA principles. Operations at the Pilot and Expanded ISF involve close proximity to high dose SNF sources, so unless planning and continuous monitoring are performed, occupational exposures to workers can easily exceed annual limits. Radiation dose evaluations are performed for all cask handling operations for each storage alternative for both vertical and horizontal DPCs in order to determine the potential occupational exposure to workers on a unit basis. In the evaluations, individual task descriptions and durations from the time and motion studies discussed in section 6.3 are used along with dose rate information at various locations around the individual transport, transfer, and storage casks being handled to determine the dose rate to workers accumulated during the range of operations encompassing the time a transport cask is received at the ISF to the time the DPC is placed in storage. Since different types of workers are assigned different cask handling tasks, separate occupational doses are calculated for each different type of worker. The inputs and results of the evaluations are discussed in separate sections below.

6.4.4.1 Time and Motion Study Inputs

As described in section 6.3, the time and motion studies break down all operations required to move a DPC from the railcar to storage into discreet steps. For each step, the number and type of each worker involved in the task, and the total duration of the task are documented. The only time that workers are accumulating significant doses is when they are in close proximity to the casks. But the time and motion studies specify durations based on completion of the entire task, including the time spent when no one is occupying the dose field for activities such as lining up required tools and equipment, job briefings, and signing off work packages. Therefore, estimates are made for the percentage of time for each task that the workers are actually receiving significant doses. The dose recorded for each step for each given worker type is calculated by multiplying the step duration by the number of workers in the dose field by the percentage of time spent in the dose field time and finally by the dose rate. Note that all workers in the vicinity of the casks are receiving some level of dose. The evaluations assume that nuclear operations are conducted under the ALARA principles, and that workers who are required to participate in the task, but are not required to be in close proximity to casks remain at a distance from the operation where the dose field is insignificant.

6.4.4.2 Radiation Doses from Casks

The radiation dose emitted from a container of SNF varies as a function of location around the container due to variations in the internal and external shielding between the radiation source and the surface of the container. Transport casks are limited by 10CFR71 regulations to a maximum external dose rate of 200 mrem/hour on each point on the surface. This dose limit may be determined considering the impact limiters and personnel shields which comprise the licensed package. Storage and transfer casks are not subject to individual external limits on radiation. Rather, shielding for these containers is designed based on ALARA principles, trading off dose rates for ease of handling considerations. DPCs typically include plates to shield the top and bottom surfaces of the canisters, but have no extra shielding on the canister sides. Furthermore, there are known “hot spots” or gaps which typically occur in various containers, including the air vents at the bottom of storage casks and the access ports in transport casks where gas samples of the DPC are taken. The increased dose associated with these hot spots is not accounted for in the occupational exposure calculations, considering that workers will be advised of them and will be able to avoid them.

In **Figure 6.4.4.1** and **Table 6.4.4.1** below, the dose rates determined at various points around SNF containers are shown. Since it is likely that certain types of workers will reach the annual occupational exposure limits at some point during the year, the dose rates are calculated based on median aged fuel, rather than the using the maximum dose rates documented in the container SARs, in order to present a more accurate assessment of personnel requirements.

6.4.4.3 Occupational Exposure Evaluation Results

The results of the occupational exposure evaluations for Study 1 storage alternatives are presented in **Tables 6.4.4.2a, 6.4.4.2b, and 6.4.4.2c**. **Table 6.4.4.2a** shows the occupational exposures accumulated by each category of worker during placement of a single DPC into storage. Annual occupational exposures for each worker category (e.g. for each mechanic or rigger position on a crew) are shown in **Table 6.4.4.2b**. These annual doses are calculated by summing the exposures per DPC accumulated by all workers in a given category, dividing by the number of workers on a crew in a given category, and then multiplying them by the number of DPCs processed each year. These annual doses are then used to determine the total number of workers in each category required to meet the DOE administrative occupational exposure goal of 500 mrem/year, shown in **Table 6.4.4.2c**. Individual workers will be rotated into and out of cask handling crews as required to keep their occupational exposures below this administrative limit. The same data for Study 2 cask handling alternatives is shown in **Tables 6.4.4.3a, b, and c**.

To the extent possible, the dose rates have been based on median fuel which captures the effects of aging on source terms, and durations have been based on experience data from operating nuclear power plants. However, certain high-dose cask handling operations in the time and motion studies which have no precedent in the industry account for a significant portion of the occupational exposures calculated for each DPC. Industry experience indicates that theoretical dose studies typically over-estimate actual occupation exposures accumulated in practice. Further industry experience indicates that as cask handling workers become familiar with the operations, total exposures decrease as techniques for avoiding dose are refined and local shielding is employed for high-dose activities. Therefore, the occupational exposures shown in the tables are more useful as a basis for comparing the different storage and cask handling alternatives presented than as an indicator of actual exposures to be expected.

Figure 6.4.4.1
Dose Rate Locations around SNF Containers

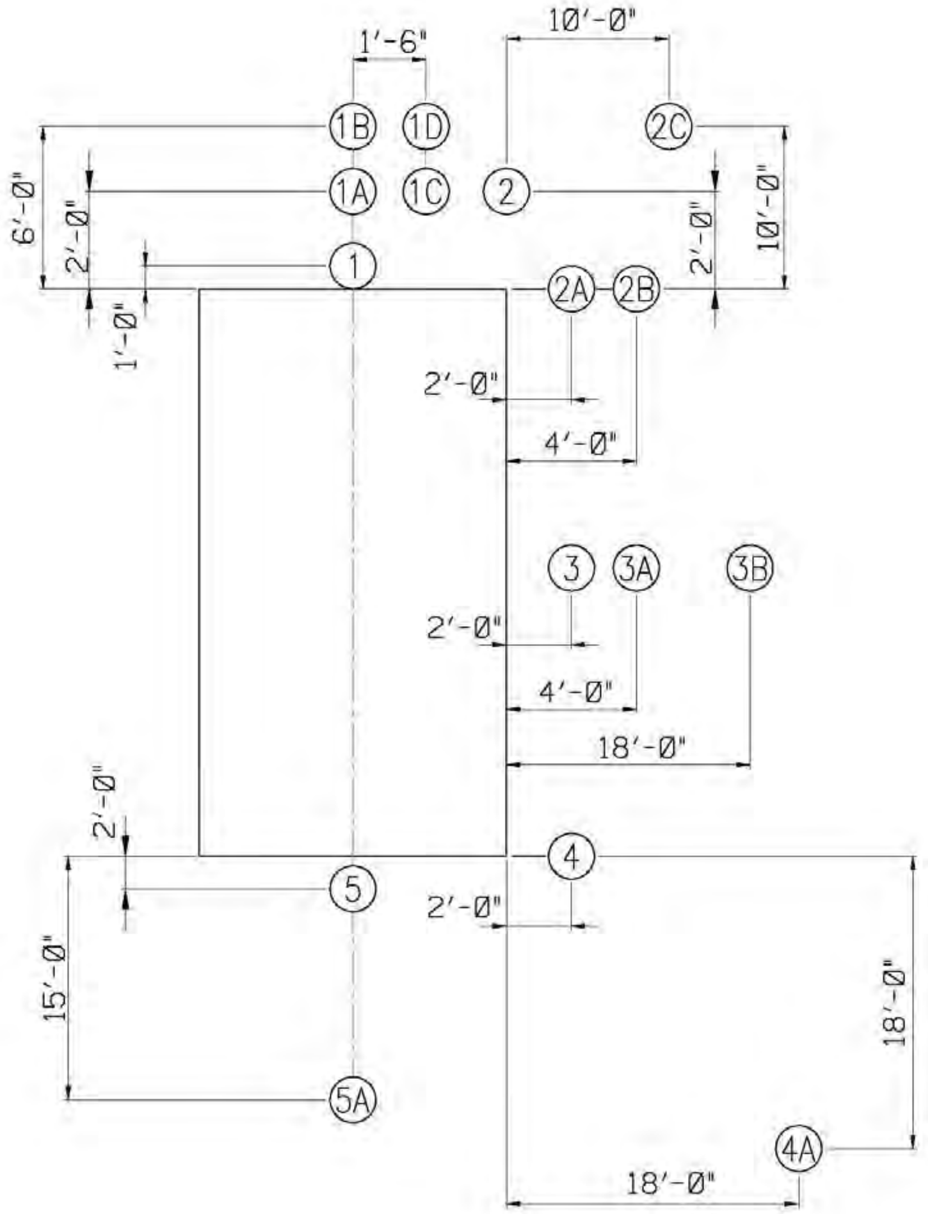


Table 6.4.4.1
Dose Rates for Median Fuel at Locations around SNF Containers

Dose ID	Location	Orientation	Container	mrem/hr	Notes:
1 V C	1	Vertical	DPC	512	no overpack lid
1A H C	1A	Horizontal	DPC	163.2	no overpack lid
1A H T	1A	Horizontal	Transport	18.4	transport cask lid installed
1A V C	1A	Vertical	DPC	254	no overpack lid
1A V T	1A	Vertical	Transport	15	impact limiters installed
1B V C	1B	Vertical	DPC	134	no transfer cask lid
1C V C	1C	Vertical	DPC	117	no transfer cask lid
1D V C	1D	Vertical	DPC	62	no transfer cask lid
2 V T	2	Vertical	Transport	150	transport cask lid removed
2A H T	2A	Horizontal	Transport	31.8	transport cask lid installed
2A V T	2A	Vertical	Transport	20	transport cask lid installed
2B V X	2B	Vertical	Transfer	125	no transfer cask lid
2C H T	2C	Horizontal	Transport	1.5	transport cask lid installed
2C H T	2C	Horizontal	Transport	7.1	transport cask lid removed
3 V T	3	Vertical	Transport	44	
3A V T	3A	Vertical	Transport	34	
3B V C	3B	Vertical	DPC	146	
4 H T	4	Horizontal	Transport	31.8	
4 V S	4	Vertical	Storage	111	
4 V X	4	Vertical	Transfer	177	
4A H H	4A	Horizontal	HSM	2.5	port cover installed
5 H H	5	Horizontal	HSM	8.5	port cover installed
5A H H	5A	Horizontal	HSM	3.2	port cover installed

Table 6.4.4.2a
Occupational Exposures per DPC by Worker Category for Study 1 Storage Alternatives

Study #1 Storage Alternative	Worker Category:	Dose per DPC to Worker by Category[1] (person-mrem/DPC)						
		Mechanics	Riggers	Health Physics	Operators	Security	Quality	Total per DPC
	No. of Workers:	2	2	2	1	1	1	
CPAD	Vertical	126	60	51	0	11	3	251
	Horizontal	80	47	51	0	11	8	198
CSTDa	Vertical	126	60	51	0	11	3	251
	Horizontal	69	60	50	0	13	0	192
CSTDb	Vertical	126	60	51	0	11	3	251
	Horizontal	80	47	51	0	11	8	198
CSTDc	Vertical	167	91	64	0	18	11	351
	Horizontal	80	47	51	0	11	8	198
CUGS	Vertical	176	68	54	0	11	3	313
	Horizontal	197	91	50	0	12	0	350
CAGVa, CBGVa	Vertical	72	42	46	0	11	3	173
	Horizontal	53	66	50	0	9	0	178
CAGVb, CBGVb	Vertical	72	42	46	0	11	3	173
	Horizontal	56	38	42	0	3	1	141
CAGVc, CBGVc	Vertical	92	58	56	0	11	3	220
	Horizontal	94	75	59	0	20	0	249
CAGVd, CBGVd	Vertical	92	58	56	0	11	3	220
	Horizontal	110	75	59	0	16	0	260

[1] Dose/DPC = (time in rad zone) * (no. of workers in rad zone) * (dose in rad zone)

Table 6.4.4.2b

Annual Occupational Exposures to Unit Worker by Category for Study 1 Storage Alternatives

Study #1 Storage Alternative	Worker Category:	Annual Dose to Unit Worker by Category[1] (rem/year)						
		Mechanics	Riggers	Health Physics	Operators	Security	Quality	Total Dose[2]
	No. of Workers:	1	1	1	1	1	1	
CPAD	Vertical	15.8	7.5	6.4	0.0	2.8	0.7	33.2
	Horizontal	10.0	5.8	6.4	0.0	2.8	2.0	27.1
CSTDa	Vertical	15.8	7.5	6.4	0.0	2.8	0.7	33.2
	Horizontal	8.6	7.4	6.3	0.0	3.3	0.0	25.6
CSTDb	Vertical	15.8	7.5	6.4	0.0	2.8	0.7	33.2
	Horizontal	10.0	5.8	6.4	0.0	2.8	2.0	27.1
CSTDc	Vertical	20.8	11.4	7.9	0.0	4.5	2.8	47.5
	Horizontal	10.0	5.8	6.4	0.0	2.8	2.0	27.1
CUGS	Vertical	22.0	8.5	6.8	0.0	2.8	0.7	40.8
	Horizontal	24.7	11.4	6.3	0.0	2.9	0.0	45.2
CAGVa, CBGVa	Vertical	9.0	5.2	5.8	0.0	2.8	0.6	23.4
	Horizontal	6.6	8.3	6.3	0.0	2.2	0.0	23.4
CAGVb, CBGVb	Vertical	9.0	5.2	5.8	0.0	2.8	0.6	23.4
	Horizontal	7.0	4.8	5.3	0.0	0.7	0.4	18.2
CAGVc, CBGVc	Vertical	11.5	7.3	7.0	0.0	2.8	0.6	29.2
	Horizontal	11.7	9.4	7.4	0.0	5.0	0.0	33.6
CAGVd, CBGVd	Vertical	11.5	7.3	7.0	0.0	2.8	0.6	29.2
	Horizontal	13.7	9.4	7.4	0.0	3.9	0.0	34.4

[1] Annual Dose = (time in rad zone) * (dose in rad zone) * (no. of DPCs per year)

[2] Based on 250 DPCs per year.

Table 6.4.4.2c
No. of Workers by Category at 500 mrem/year Limit for Study 1 Storage Alternatives

Study #1 Storage Alternative	Worker Category:	Number of Workers by Category Required to Meet 500 mrem/year Limit[1]						
		Mechanics	Riggers	Health Physics	Operators	Security	Quality	Total
CPAD	Vertical	32	16	13	0	6	2	69
	Horizontal	21	12	13	0	6	5	57
CSTDa	Vertical	32	16	13	0	6	2	69
	Horizontal	18	15	13	0	7	0	53
CSTDb	Vertical	32	16	13	0	6	2	69
	Horizontal	21	12	13	0	6	5	57
CSTDc	Vertical	42	23	16	0	10	6	97
	Horizontal	21	12	13	0	6	5	57
CUGS	Vertical	45	18	14	0	6	2	85
	Horizontal	50	23	13	0	6	0	92
CAGVa, CBGVa	Vertical	18	11	12	0	6	2	49
	Horizontal	14	17	13	0	5	0	49
CAGVb, CBGVb	Vertical	18	11	12	0	6	2	49
	Horizontal	15	10	11	0	2	1	39
CAGVc, CBGVc	Vertical	23	15	14	0	6	2	60
	Horizontal	24	19	15	0	11	0	69
CAGVd, CBGVd	Vertical	23	15	14	0	6	2	60
	Horizontal	28	19	15	0	8	0	70

[1] Number of workers = annual unit dose (from **Table 6.4.4.2.b**) / 500 mrem

Table 6.4.4.3a
Occupational Exposures per DPC by Worker Category for Study 2 Cask Handling Alternatives

Study #1 Storage Alternative	Worker Category:	Dose per DPC to Worker by Category[1] (person-mrem/DPC)						
		Mechanics	Riggers	Health Physics	Operators	Security	Quality	Total per DPC
	No. of Workers:	2	2	2	1	1	1	
COPS	Vertical	241	87	53	0	6	3	391
	Horizontal	80	47	55	0	13	8	203
AOPS	Vertical	126	60	51	0	11	3	251
	Horizontal	80	47	51	0	11	8	198
ROPS	Vertical	126	60	48	0	11	3	248
	Horizontal	-	-	-	-	-	-	-
SOPS	Vertical	269	98	75	0	10	5	458
	Horizontal	80	47	55	0	13	8	203

[1] Dose/DPC = (time in rad zone) * (no. of workers in rad zone) * (dose in rad zone)

Table 6.4.4.3b

Annual Occupational Exposures to Unit Worker by Category for Study 2 Cask Handling Alternatives

Study #1 Storage Alternative	Worker Category:	Annual Dose to Unit Worker by Category[1] (rem/year)						
		Mechanics	Riggers	Health Physics	Operators	Security	Quality	Total Dose[2]
	No. of Workers:	1	1	1	1	1	1	
COPS	Vertical	30.2	10.9	6.7	0.0	1.6	0.6	49.9
	Horizontal	10.0	5.8	6.9	0.0	3.3	2.0	28.0
AOPS	Vertical	15.8	7.5	6.4	0.0	2.8	0.7	33.2
	Horizontal	10.0	5.8	6.4	0.0	2.8	2.0	27.1
ROPS	Vertical	15.8	7.5	6.0	0.0	2.8	0.7	32.8
	Horizontal	-	-	-	-	-	-	-
SOPS	Vertical	33.6	12.3	9.4	0.0	2.5	1.3	59.1
	Horizontal	10.0	5.8	6.9	0.0	3.3	2.0	28.0

[1] Annual Dose = (time in rad zone) * (dose in rad zone) * (no. of DPCs per year)
[2] Based on 250 DPCs per year.

Table 6.4.4.3c
Number of Workers by Category at 500 mrem/year Limit for Study 2 Cask Handling Alternatives

Study #1 Storage Alternative	Worker Category:	Number of Workers by Category Required to Meet 500 mrem/year Limit[1]						
		Mechanics	Riggers	Health Physics	Operators	Security	Quality	Total
CPAD	Vertical	61	22	14	0	4	2	103
	Horizontal	21	12	14	0	7	5	59
CSTDa	Vertical	32	16	13	0	6	2	69
	Horizontal	21	12	13	0	6	5	57
CSTDb	Vertical	32	16	12	0	6	2	68
	Horizontal	-	-	-	-	-	-	-
CSTDc	Vertical	68	25	19	0	5	3	120
	Horizontal	21	12	14	0	7	5	59

[1] Number of workers = annual unit dose (from **Table 6.4.4.3.b**) / 500 mrem

6.5 Equipment

6.5.1 General

6.5.2 Equipment Descriptions

6.5.2.1 Cask Handling Bridge Crane
6.5.2.2 Universal Lift Yoke
6.5.2.3 Vertical Cask Transporter
6.5.2.4 Horizontal Cask Transporter with Tug
6.5.2.5 Transfer Cell Motorized Cart
6.5.2.6 Shielded Transfer Cart
6.5.2.7 Universal Lifting Lug Grapple
6.5.2.8 Horizontal DPC Lift Frame Grapple
6.5.2.9 Horizontal DPC Transfer Cart
6.5.2.10 Horizontal Cask Upender
6.5.2.11 Horizontal Transfer Docking Collar
6.5.2.12 Vertical Transfer Docking Collar
6.5.2.13 Shielded Transfer Sleeve
6.5.2.14 Horizontal Vault DPC Transfer Cart

6.5.3 Commodity Descriptions

6.5.3.1 Vertical DPC Lift Lug
6.5.3.2 Horizontal DPC Lift Frame
6.5.3.3 Vertical DPC Pulling Lug
6.5.3.4 Vertical Transfer Cask
6.5.3.5 Horizontal Transfer Cask

6.5.1 General

The storage alternatives call for a wide variety of material handling equipment to receive, transfer, and place SNF DPCs in the different storage configurations. This section provides descriptions, performance specifications, process and safety functions, overviews of operations, maintenance and testing requirements, and applicable design codes for the major pieces of material handling equipment associated with each alternative. Whereas many of the material handling operations are common to multiple storage alternatives, much of the equipment is likewise common to more than a single storage alternative. In **Table 6.5.1**, a list of the major pieces of material handling equipment appears, along with quantities required and the different storage alternatives in which they are used. The list includes both commercially available equipment and equipment which is custom designed for a specific application. The list only includes process equipment used in the receipt, transfer, and storage of SNF DPCs and overpacks. Equipment associated with ventilation, power, and utility systems common to all industrial facilities, such as fans, pumps, compressors, vessels, motors, switchgear, etc. is not included in the scope of this section.

To the extent practical, the storage alternative concepts are based on equipment which is commercially available and generally used for the intended application. The advantages of using this approach are minimization of risk by using proven technologies and lowered costs as a result of competition between vendors. Many of the material handling applications projected for the ISF are currently in use at nuclear power plants for storing SNF at ISFSI's, and much of the specialized equipment developed for handling casks can be directly utilized for the same purpose at the ISF. However, the material handling operations and equipment at nuclear power plants were developed under a different set of space constraints, and with different throughput goals than the ISF. Therefore, where warranted, existing equipment and material handling operations have been re-designed using the same basic concepts to achieve higher throughput rates, dose reductions, and more efficient use of personnel. The re-design of custom material handling equipment is based on the following principles: avoid unnecessary complexity; use commercially available parts; integrate safety features early in the design process; use adequate factors of safety, based on design codes where applicable; make provisions for functional testing; and consider maintenance and constructability.

Table 6.5.1
Material Handling Equipment List

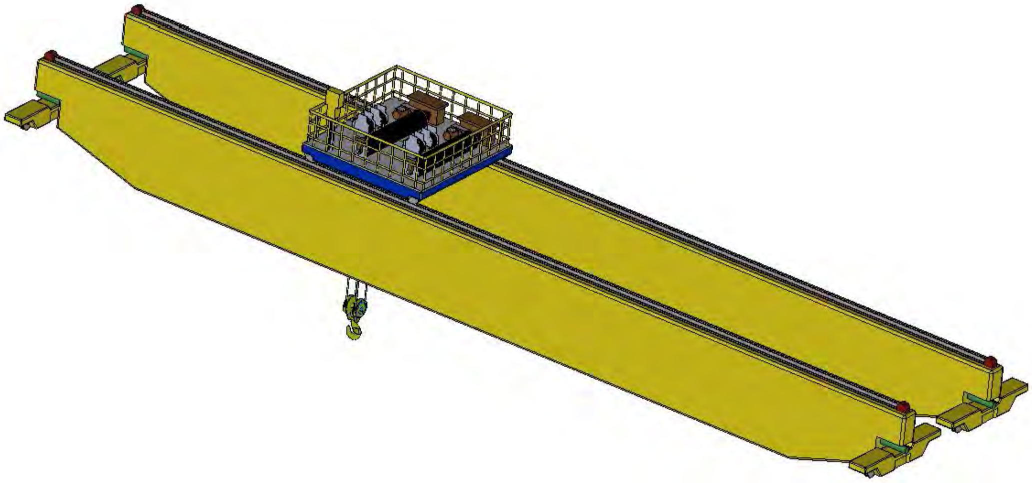
Storage Alternative Number / DPC Orientation	Section	STORAGE ALTERNATIVE													
		CPAD-V CSTDa-V CSTDb-V	CPAD-H CSTDb-H CSTDc-H	CSTDa-H	CSTDc-V	CUGS-V	CUGS-H	CAGVa-V CBGVa-V	CAGVb-V CBGVb-V	CAGVa-H CBGVa-H	CAGVb-H CBGVb-H	CAGVc-V CBGVc-V	CAGVd-V CBGVd-V	CAGVc-H CBGVc-H	CAGVd-H CBGVd-H
CASK HANDLING BUILDING															
Cask Handling Building Bridge Crane - 200T/25T - SFP	6.5.2.1	2	2	2	2	2	2	-	-	-	-	2	2	2	2
Universal Lift Yoke - 200T	6.5.2.2	2	2	2	2	2	2	-	-	-	-	2	2	2	2
Vertical Cask Transporter	6.5.2.3	4+2		4+2		4+2	4+2	-	-	-	-	2+1	2+1	2+1	2+1
Horizontal Cask Transporter	6.5.2.4		4+2		4+2			-	-	-	-				
Vertical Transfer Cask	6.5.3.4	2			2	2		-	-	-	-	2	2		
Horizontal Transfer Cask	6.5.3.5							-	-	-	-				
Transfer Cell Motorized Cart	6.5.2.5	2			2	2		-	-	-	-	2	2		
Shielded Transfer Cart	6.5.2.6	2			2	2		-	-	-	-	2	2		
Universal Lift Lug Grapple - 60T	6.5.2.7	2			2	2		-	-	-	-	2	2		
Horizontal DPC Lift Frame Lifting Device - 55T	6.5.2.8			2			2	-	-	-	-			2	
Vertical Transport Cask Lid Removal Stations Platform		2			2	2		-	-	-	-	2	2		
Horizontal Transport Cask Unloading Stand				2			2	-	-	-	-			2	
Horizontal Cask Lid Removal Jib Crane - 10T			2	2			2	-	-	-	-			2	2
Transport Cask Hydraulic Lid Bolt Wrench		4	4	4	4	4	4	-	-	-	-	4	4	4	4
Horizontal DPC Transfer Cart - 150T	6.5.2.9			2	2		2	-	-	-	-			2	
Railway Turntable				1			1	-	-	-	-			1	
Vertical Storage Cask Up/Down-ender - 210T	6.5.2.10			2	2		2	-	-	-	-			2	
Horizontal Transfer Docking Collar	6.5.2.11			2	2		2	-	-	-	-			2	
Lift Frame Forklift - 10T				2			2	-	-	-	-			2	
Mobile Storage Cask Unloading Gantry Crane - 150T		1	1	1	1	1	1	-	-	-	-				
Horizontal Transfer Jib Crane - 10T				2			2	-	-	-	-			2	
Lifting Cage Jib Crane - 10T				2			2	-	-	-	-			2	
UNDERGROUND STORAGE VAULT															
Vertical Transfer Docking Collar	6.5.2.12					2	2								
Portable Docking Collar Crane - 10T						2	2								

Storage Alternative Number / DPC Orientation	Section	STORAGE ALTERNATIVE													
		CPAD-V CSTDa-V CSTDb-V	CPAD-H CSTDb-H CSTDc-H	CSTDa-H	CSTDc-V	CUGS-V	CUGS-H	CAGVa-V CBGVa-V	CAGVb-V CBGVb-V	CAGVa-H CBGVa-H	CAGVb-H CBGVb-H	CAGVc-V CBGVc-V	CAGVd-V CBGVd-V	CAGVc-H CBGVc-H	CAGVd-H CBGVd-H
HORIZONTAL STORAGE PAD															
HSM Loading Portable Crane - 10T			1		1										
HSM Loading Portable Man Lift			2		2										
Portable Transport Cask Hydraulic Lid Bolt Wrench			2		2										
VAULT BUILDING															
Vault Building Cask Unloading Bridge Crane - 200T/25T	6.5.2.1							1	1	1	1	1	1	1	1
Universal Lift Yoke - 200T	6.5.2.2							1	1	1	1	1	1	1	1
Vault Building DPC Transfer Bridge Crane - 200T/25T	6.5.2.1							1	1	1	1	1	1	1	1
Vault Building Shielded Transfer Sleeve	6.5.2.13							1	1	1	1	1	1	1	1
Universal Lifting Lug Grapple - 60T	6.5.2.7							2	2			1	1	1	1
Horizontal DPC Lift Frame Lifting Device - 55T	6.5.2.8									2				1	
Transfer Cell Motorized Carts	6.5.2.5							2	2			2	2	2	2
Vertical Transport Cask Lid Removal Stations Platform								2	2						
Horizontal Cask Lid Removal Portable Man Lift										2	2			-	4
Vertical Transport Cask Lid Removal Stations Jib Crane								2	2						
Horizontal Cask Lid Removal Jib Crane - 10T											4				4
Hydraulic Transport Cask Lid Bolt Wrench								4	4	4	4	4	4	4	4
Horizontal DPC Shuttle Cart - 150T	6.5.2.9									2				2	
Railway Turntable										2				2	
Horizontal DPC Transfer Cart - 150T	6.5.2.9										4				4
Vertical Storage Cask Up/Down-ender - 210T	6.5.2.10									2				2	
Horizontal Transfer Docking Collar	6.5.2.11										4				4
Horizontal Vault DPC Transfer Cart - 55T	6.5.2.14										4				4
LIFTING DEVICES															
Vertical DPC Lifting Lug - 60T	6.5.3.1	2		2		2		*	*			*	*		
Horizontal DPC Lift Frame - 55T	6.5.3.2						**			**				**	
Vertical DPC Pulling Lug – 40T	6.5.3.3				*										

* One per Vertical DPC ** One per Horizontal DPC

6.5.2.1

Cask Handling Bridge Cranes



Storage Alternatives: All

Design Specs:	Hoisting Capacity (Main):	200T	
	Hoisting Capacity (Aux):	25T	
	Hook Height above Floor:	Main Hook – 34’–8”	Aux Hook – 40’–1”
	Maximum Velocity (Bridge):	design load – 25 FPM	no load – 100 FPM
	Maximum Velocity (Trolley):	design load – 25 FPM	no load – 80 FPM
	Hoisting Speed:	design load – 3 FPM	no load – 11 FPM
	Bridge Span:	100 ft.	
	Approach (Trolley Main):	7’-6”	
	Approach (Trolley Aux):	5’-0”	
	Weight (Bridge):	400T	
	Weight (Trolley):	120T	

Process Functions: The cask handling bridge cranes in the CHB are used to unload inbound transport casks from railway cars and transfer them to other equipment for DPC removal, and load outbound transport casks onto railcars for shipment out of the facility. In the vaults, they unload and load transport casks onto railcars for those vault options with integral rail bays, and hoist and re-position transfer casks to other equipment for those vault options without integral rail bays. Vault options which include vertical storage of DPCs also have separate cask handling bridge cranes which are dedicated to placement of DPCs into vault storage using shielded transfer sleeves.

Safety Functions: The primary safety function for the cask handling bridge crane is to retain the cask or transfer sleeve with the DPC throughout the hoisting, transfer, and placement process to maintain the integrity of the SNF confinement boundary. Event scenarios for which the cranes must be qualified to retain the load include operational accidents, machine malfunctions, loss of power, and earthquakes. Single failure proof safety features incorporated into the crane design to mitigate the consequences of these events are prescribed by NUREG-0554, including higher safety factors on wire rope and vertical hoisting components, double reeving, double hooks, hoist overtravel protection, redundant drive trains, redundant hoist drum holding brakes, seismic rail clips for bridge and trolley wheels, and overtravel and overspeed limit devices for the bridge and trolley drives.

Description: Cask handling and DPC transfer bridge cranes in the CHB and in the vault are double girder, top running bridge, top running trolley, overhead bridge cranes used to hoist transport, transfer, and storage casks and transfer them from one piece of material handling equipment to another. All bridge cranes have a rated capacity of 200T on the main hook, and an auxiliary hook with a rated capacity of 25T. All bridge cranes also have a bridge girder span of 100'. The CHB and vault designs all have two bridge cranes running on a common runway. The cranes will be controlled from local wireless control panels, by operators on the ground.

The cask handling bridge cranes will be required to hoist a variety of different transport casks received at the facility, each with a different configuration of lifting trunnions. In order to avoid the expense, laydown space requirements, and change out times associated with having different lifting yokes for each cask, the conceptual design calls for a universal lifting device to be developed which is capable of being adjusted to accommodate most, if not all, cask lifting trunnion configurations. This lifting device is described in further detail in section 6.3.1.

Operations: During transport cask unloading operations, a railcar with an inbound transport cask is transferred to the railbay and locked into position. The bridge crane auxiliary hook is used to hoist and transfer impact limiters and personnel barriers removed from the transport cask during unpackaging. When the transport cask is ready to be transferred, the universal lifting device on the main hook is adjusted to engage the upper lifting trunnions on the cask, and the cask is upended and hoisted off of the railcar. Transport casks containing vertical DPCs are transferred and placed vertically on a motorized cart. Transport casks containing horizontal DPCs are transferred and downended onto their trunnions on a fixed frame which is adjustable to engage both sets of trunnions on the casks. The universal lift device is then disengaged from the cask to allow it to be opened and the DPC to be removed. Transport casks are repackaged using the reverse set of operations after the DPCs have been removed.

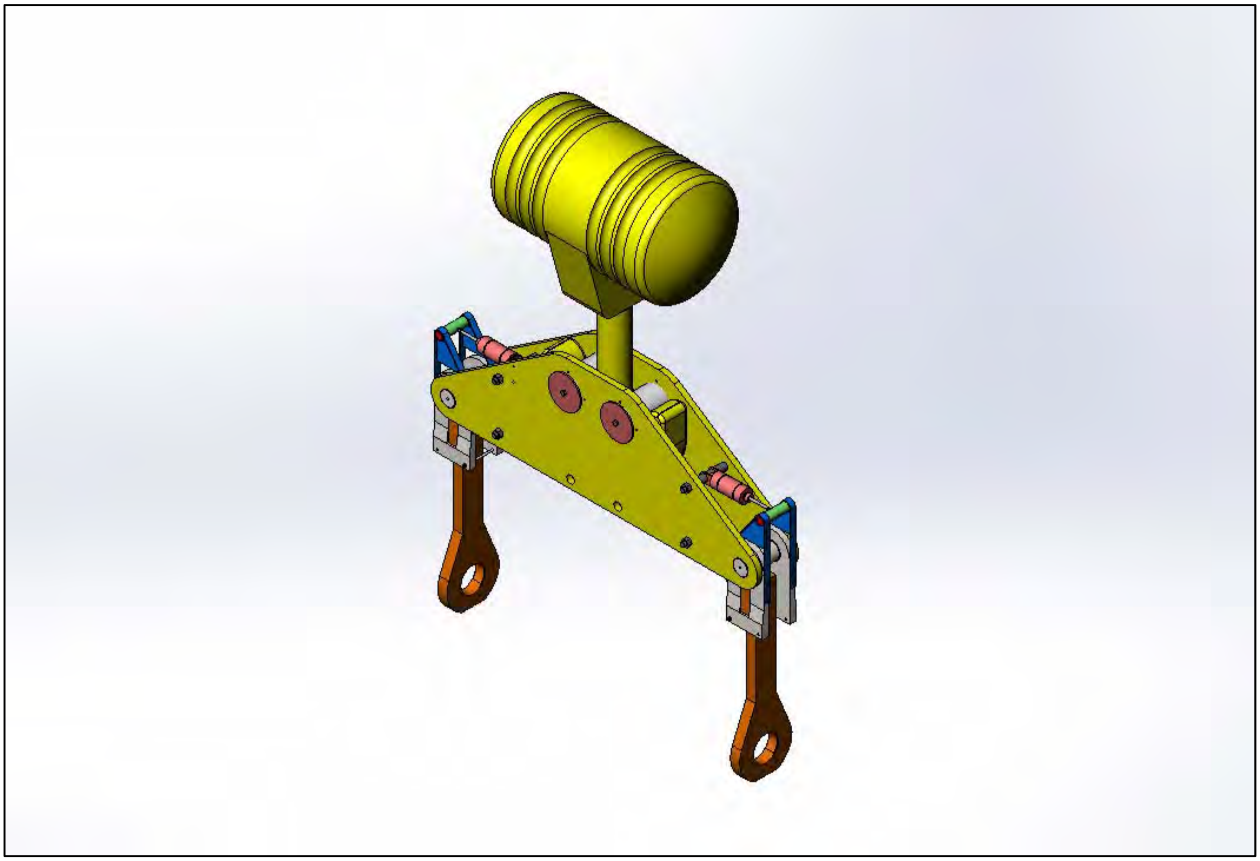
The cask handling cranes in the vault either handle transport casks as described above, or they handle transfer casks transferred from the CHB to the vault by cask transporters. The general hoisting operations are the same for transfer casks as they are for transport casks.

Maintenance: Bridge cranes are complex pieces of equipment which incorporate multiple mechanical drive systems, electric motors, and controls. Preventive maintenance activities include periodic lubrication of shafts and bearings, overhauling brakes on hoist, trolley, and bridge drives, rebuilding motors, and inspecting and potentially replacing hoisting ropes and reeving systems.

Testing: The ASME NOG-1 design code requires a prescribed set of functional tests, including a no-load test in the shop and a no-load test, full load test, and 125% rated load test in the field. NUREG-0554 requires a 200% Maximum Credible Load test for single failure proof cranes. Rated load test shall also be performed after major corrective maintenance evolutions.

Design Codes:		
	Crane Design:	ASME NOG-1, Type I NUREG-0554
	Operations:	ASME B30.2

6.5.2.2
Universal Lift Yoke



Storage Alternatives: All

Design Specs:	Capacity:	200T
	Width Between Arms:	minimum - 7’– 0”
	Clearance Above Arm Hole CL:	height - 3’– 4”
	Weight:	3450 lbs.
Process Functions:	The universal lift yoke is used to connect transport casks in the CHB, and transport, storage, and transfer casks in the vault to the bridge crane in order to lift and relocate the casks as required to support DPC removal operations.	
Safety Functions:	The primary safety function for the universal lift yoke is to retain casks containing DPCs during hoisting operations in order to prevent load drops which could threaten the integrity of the SNF confinement boundary provided by the DPC.	

Event scenarios for which the lifting yoke must be qualified include operational accidents, load excursions, machine malfunctions, and earthquakes.

Description: The universal lift yoke is a below-the-hook lifting device attached to the bridge crane main hook which is designed to engage the upper pair of trunnions on transport, storage, and transfer casks. Since trunnion configurations vary among the different types of casks hoisted, the span between lift yoke arms adjusts to accommodate a range of cask diameters. The adjustment mechanism is actuated by a screw drive which keeps the arms equi-distant from the lift point. An electric brake locks the screw in position whenever the drive is not actuated. The lift arms are fixed in length, with closed rings on the ends which fit over the trunnions. Closed rings transfer loads primarily in tension, therefore they are much stronger for a give weight than open hooks which transfer loads primarily in bending. However, in cask support configurations where the casks are downended onto their upper trunnions - e.g. railway cars and horizontal transfer carts – the closed rings will not fit over the other supports, and must engage the trunnions outside of them. The lift arms are designed to be replaceable, in the event that a single arm design suitable for hoisting all casks proves to be impractical. Additional lift yokes may also be considered, although it is preferable to minimize the number of lift yokes required in the interest of cost and laydown space.

Operations: In preparation for hoisting casks, the universal lift yoke arms will be moved to the full open position by the screw drive mechanism. The closed rings on the ends of the lift arms will be manually aligned with the upper trunnions on the cask using the overhead crane bridge, trolley, and main hoist. The lift arms will then be moved closer together until the arms are at the correct lifting location on the cask trunnions. The yoke will then be raised until the lift arms engage the trunnions.

Dis-engagement of the universal lift yoke is performed in the reverse sequence of engagement. The lift yoke will be lowered until the full weight of the payload is transferred from the yoke to the other trunnion supports (cask horizontal orientation) or the base of the cask (cask vertical orientation). The unweighting will be verified by load cell. The yoke will be lowered further to provide radial clearance between the closed rings on the lifting arms and the trunnions. Then the arms will be opened until they fully clear the trunnions.

Maintenance: Preventive maintenance activities for the universal lift yoke include lubricating mechanical drive components, overhauling electric motors and brakes, calibrating load cells, and performing periodic NDE on the lift arms.

Testing: The universal lift yoke is subject to an initial functional test of all drives, brakes, and indicators prior to service, and after major corrective maintenance. The yoke is also subject to a 125% rated load test before service and after corrective maintenance, per ASME B30.20. ANSI N14.6 also requires a 150% Maximum Credible Load lift test before service, and annually thereafter.

Design Codes:
Mechanical Drive Components – ASME BTH-1
Structural Framing and Welds – ASME BTH-1
Testing and Operations – ASME B30.20, ANSI N14.6

6.5.2.3
Vertical Cask Transporter

Storage Alternatives: CPAD, CSTDa, CSTDb, CUGS, CAGVc, CAGVd, CBGVc, CBGVd

Design Specs:	Capacity:	180T	
	Transporter Widths:	outside - 18’–11.5”	inside clearance - 12’– 2”
	Overall Dimensions:	length - 26’– 7.5”	height – 27’-6.5”
	Link Pin Elevation:	minimum - 16’-8”	maximum – 38’– 4”
	Link Pin Span:	minimum - 5’-8”	maximum – 8’– 6”
	Maximum Velocity:	design load – 35 fpm	no load – 35 fpm
	Total weight:	design load – 285T	no load - 105T

Process Functions: The vertical cask transporters are used to shuttle vertical transport casks between the CHB and the vaults, to move vertical storage casks to the pads, and to move vertical transfer casks to the underground storage vaults. They may also be used to stack transfer casks on top of storage or transport casks and raise and lower DPCs between them, performing stackup transfers without any other handling equipment required. For shuttle applications where there are hoisting devices at either end of the transfer, heavy-haul trailers (e.g., Goldhofer) will perform the same function and may prove more cost effective.

Safety Functions: The primary safety function for the vertical cask transporter is to support casks containing DPCs in order to prevent load drops which could threaten the integrity of the SNF confinement boundary provided by the DPC. Event scenarios for which the vertical cask transporters must be qualified include operational accidents, machine malfunctions, and earthquakes. Earthquakes are mitigated by designing the hoisting load path to be single failure proof.

Description: The vertical cask transporter is a multi-purpose tracked vehicle used to perform a variety of vertical cask loading and unloading, transfer, and upending and downending functions. The transporter consists of the vehicle main frame, two extendable lifting towers, an overhead beam that spans between the lifting towers, two wheel tracks directly beneath the lift towers, and cask restraint and lifting system attachments. Power for both the hoisting and tractor drives is provided by a diesel engine. The vehicle is commercially available and is in service at several nuclear power plants.

Cask hoisting functions primarily use the lift beam supported by two towers. The towers have a total vertical extension of over 21’, which allows the transporter to raise casks high enough to stack a transfer cask on top of a storage cask. The lift beam has both static lift links which attach to cask trunnions and a wire rope hoisting capability where loads suspended below the beam can be raised and lowered independent of the vertical motion of the lift beam. The dual hoisting capability permits the transporter to accomplish a complete stack-up transfer operation by itself, with no other hoisting equipment required.

Cask transfers are performed by picking up and carrying casks suspended from the lift beam on the static links. Cask bumpers on the main frame limit the cask swing induced by uneven terrain or inclined haul pathways. Grades up to 5% can be negotiated when carrying a storage overpack, and grades up to 10% can be negotiated when carrying a transfer cask. Normal cask carrying heights range between 6 and 12 inches. Since the hoisting capability is single failure proof, there is no maximum carrying height limit based on load drop.

Operations: VCTs are used in all storage alternatives with Cask Handling Buildings to acquire DPCs placed in storage or transfer casks and transfer them to pads, underground storage vaults, or the above or below grade main vaults.

The acquisition process starts by using the VCT to pick up an empty storage overpack or transfer cask from the storage area outside the CHB and transfer it to the exterior rollup door outside the appropriate CHB receiving transfer cell. The lid bolts on the cask are removed, the lid is rigged to the auxiliary hoist on the VCT, and the cask is transferred into the cell. For vertical DPCs, the cask is transferred into the cell by motorized cart. For horizontal DPCs, the VCT transfers the cask into the receiving cell, positions it on the upender, and backs out of the cell. In both cases, the cask lid is retained on the VCT aux hoist. After the DPC is loaded into the cask, the receiving cell doors are opened and the cask and VCT are re-united. The cask lid is lowered into position and bolted into place. The VCT then picks up the cask and carries it to its storage location.

Vertical storage overpack placement operations on a pad are straightforward. The VCT navigates to the designated storage location, aligns the overpack with the appropriate coordinates, and sets the overpack down. If the overpack must be seismically restrained, the holes in its lower flange are aligned with the studs embedded in the pad before lowering. After the overpack is set, the nuts are placed on top of the studs and are torqued into place. At this point, if no other provisions to replenish the store of empty casks at the CHB are in place, the VCT can be used to stop by the cask fabrication pad outside the Protected Area to retrieve a fabricated storage overpack before returning to the CHB.

Vertical DPC placement operations into an individual underground storage vault are more complex, due to the preparation of the designated storage location to receive the DPC that must occur. The underground vaults are each capped by a heavy concrete lid that must be removed. Next, a docking collar and adaptor are bolted into place on top of the vault. Then, the VCT with the transfer cask is rolled into position over the vault and lowers the transfer cask on top of the shielding adaptor. The cask is bolted to the adaptor and the DPC is rigged to the lift beam and slightly raised. The bottom flange on the transfer cask is unbolted and removed, clearing the path to lower the DPC into the vault. Once the DPC is placed, the rigging is removed from the DPC and retracted. The bottom lid on the transfer cask is bolted back into place. The transfer cask is unbolted from the shielding adaptor and docking collar, which are in turn unbolted and removed. Finally, the concrete lid is placed over the silo. The VCT returns the transfer cask to the CHB for reloading.

Vertical DPC transfer to the above or below grade main vaults, either in a transfer cask or a transport cask is also a direct process where casks are picked, shuttled out to the vaults, and set down at the destination for further handling by hoisting equipment local to the vault. On the return trip back to the CHB, the VCT will bring back an empty transfer or storage cask for re-loading.

Maintenance: Preventive maintenance activities for the VCT's include lubricating mechanical drive components, overhauling electric motors and brakes, powertrain systems, and hydraulic systems, and running required inspections on hoisting systems.

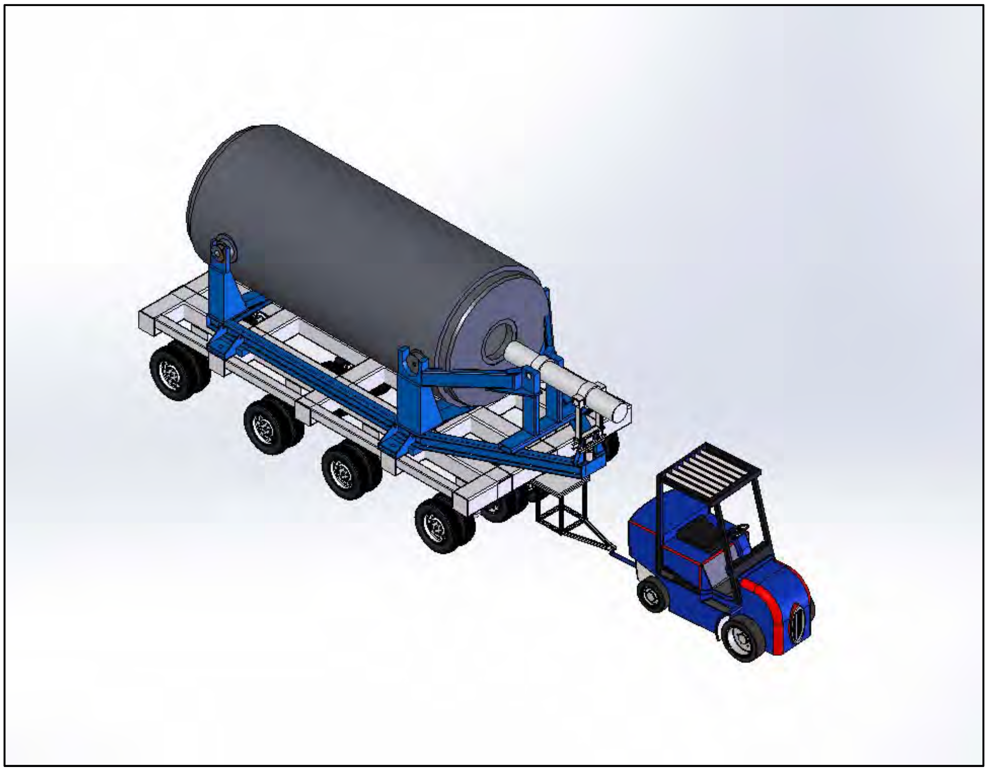
Testing: The design code based tests directly applicable to the VCT's are those required for compliance with ANSI N14.6, for heavy lifting, and those periodic surveillances and inspections required to verify that single failure proof features will perform their intended functions.

Design Codes:

Mechanical Drive Components - CMAA-70
Structural Framing and Welds - AISC Manual of Steel Construction
Heavy Lifting – ANSI N14.6

6.5.2.4

Horizontal Cask Transporter w/ Tug



Storage Alternatives: CPAD, CSTDb, CSTDc

Design Specs:	Capacity:	132T	
	Trailer Dimensions:	width - 10’– 6”	length - 22’– 0”
	Trailer Height:	maximum - 3’– 6”	minimum – 2’-11”
	Turning Radius:	outside – 21’ – 3”	
	Velocity:	design load – 5 mph	
	Total weight:	design load – 330,200 lbs.	no load - 66,200 lbs.
	Wheels / wheel load:	32 wheels	8250 lbs.

Process Functions: The horizontal cask transporter is used to receive horizontal transport casks off-loaded from railcars, move them to and from the horizontal storage modules (HSM) on the pads, align and dock the cask and the DPC inside with the port on the HSM, and push the DPC into the HSM using the on-board hydraulic ram.

Safety

Functions: The primary safety function for the horizontal cask transporter is to support casks containing DPCs in order to prevent load drops which could threaten the integrity of the SNF confinement boundary provided by the DPC. Event scenarios for which the horizontal cask transporters must be qualified include operational accidents, machine malfunctions, and earthquakes. Earthquakes are mitigated by designing the transporters to remain upright under lateral seismic loads.

Description: The horizontal cask transporter is a rubber-tired trailer pulled by a tractor which is used to receive horizontal transport casks unloaded off of railcars and downended onto trunnion supports and transfer them to pads or to above and below grade vaults for unloading. The transporter consists of the main trailer frame, a removable support skid for horizontal transport casks, axles and tires, jacking pads, and a large, hydraulic ram used to slide DPCs into and out of the transport cask. The trailer is towed around by a diesel powered tractor. Power to actuate the hydraulic ram is supplied by a portable power unit. The horizontal cask transporter is commercially available and is in service at nuclear power plants.

Operations: Horizontal cask transporters are used in all storage alternatives where horizontal transport casks are off-loaded from railcars and transferred to other site areas for DPC removal and storage. The off-loading process includes removing impact limiters and personnel barriers, upending the transport cask, placing it on the cask transporter, and downending it on its trunnions. For pad storage in HSMs, the transport cask remains on the transporter all the way to the pad, during DPC transfer, and all the way back to the railhead. For placement of horizontal DPCs into the above or below grade vaults, the transport cask is hoisted off of the transporter and placed in a transfer rack for DPC removal. After the DPC is removed, the transport cask is placed back on the transporter for the return trip back to the railhead.

Maintenance: Preventive maintenance activities for the horizontal cask transporter include lubricating mechanical drive components, overhauling electric motors and brakes, replacing tires and wheel bearings, replacing pneumatic cylinder seals and running required inspections on jacking systems.

Testing: The only design code based tests directly applicable to the horizontal cask transporter is pressure testing of the hydraulic systems which power the ram.

Design Codes:

Mechanical Drive Components - CMAA-70
Structural Framing and Welds - AISC Manual of Steel Construction
Hydraulic Drive Components – SAE J series

6.5.2.5
Horizontal Cask Transporter – Omniloader (Alternate)

Storage Alternatives: CPAD, CSTDb, CSTDc

Design Specs:	Capacity:	135T	
	Trailer Dimensions:	width - 10’– 0”	length - 36’– 6”
	Trailer Height:	minimum – 27”	maximum– 37”
	Turning Radius:	outside – 0”	
	Velocity:	design load – 60 fpm	no load – up to 110 fpm
	Total weight:	design load – 520,000 lbs.	no load – 60,000 lbs.
	Wheels / wheel load:	14 axles - 14 wheels	

Process Functions: The omni-loader is used to receive horizontal transport casks off-loaded from railcars, move them to and from the horizontal storage modules (HSM) on the pads, align and dock the cask and the DPC inside with the port on the HSM, and push the DPC into the HSM using the on-board hydraulic ram.

Safety Functions: The primary safety function for the horizontal cask transporter is to support transport casks containing DPCs in order to prevent load drops which could threaten the integrity of the SNF confinement boundary provided by the DPC. Event scenarios for which the transporters must be qualified include operational accidents, machine malfunctions, and earthquakes. Earthquakes are mitigated by designing the transporter to resist the overturning moments caused by the seismic excitation.

Description: The omni-loader is a vehicle which is designed for transporting horizontal DPCs and placing or retrieving them from storage in horizontal storage modules. The vehicle has (14) wheels mounted on (14) independently rotatable axles. Coordinated positioning of the axles allows the vehicle to be driven in any direction from front to back to directly sideways by individual electric motors on each wheel. The axles are mounted on hydraulic cylinders which have a vertical travel of 10 inches, to enable the vehicle to navigate uneven terrain and vertically align itself with the loading port on the HSM’s. Vehicle systems are powered by a diesel engine.

The omni-loader carries horizontal transport casks in a horizontal orientation, on a skid supported on its trunnions. During loading, the vehicle is lowered such that trunnion supports bear directly on the ground via bracket extensions. This protects the drive mechanisms from any impacts caused by loading and downending the transport casks on the skids. The DPC is pushed out of, or drawn into the transport cask by a large hydraulic ram mounted on the back of the skid. The ram engages a grapple ring on the bottom of the DPC through a port in the bottom of the transport cask. The ring is designed to transfer the friction forces associated with pushing and pulling between the ram and the DPC. The omni-loader is commercially available and is in service at nuclear power plants.

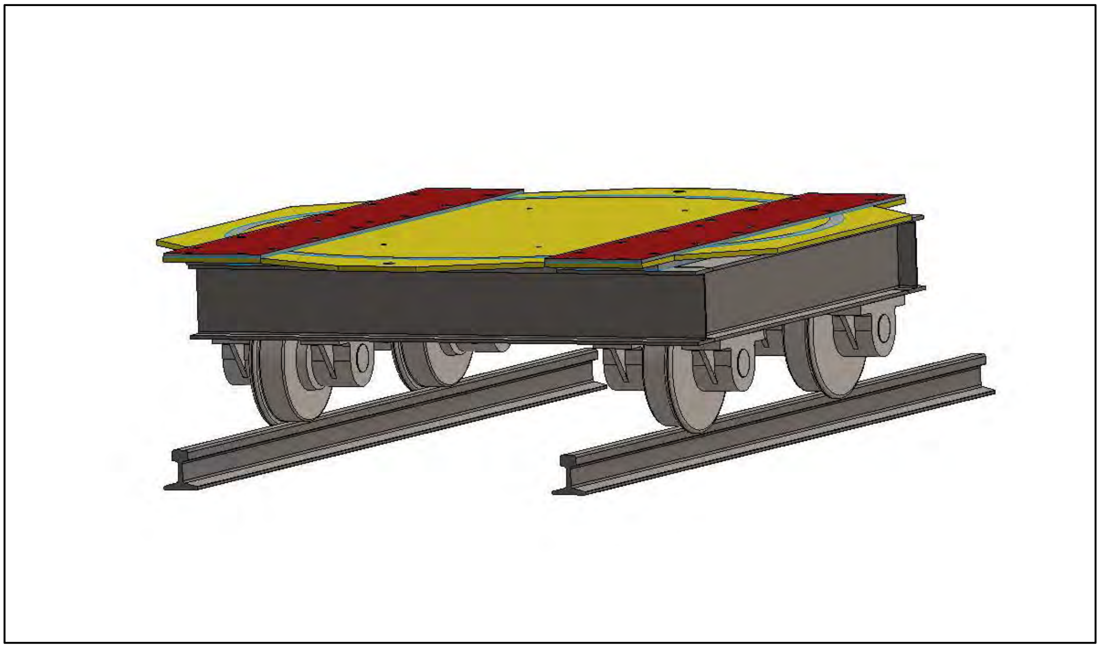
Operations: Horizontal cask transporters are used in all storage alternatives where horizontal transport casks are off-loaded from railcars and transferred to other site areas for DPC removal and storage. The off-loading process includes removing impact limiters and personnel barriers, upending the transport cask, placing it on the cask transporter, and downending it on its trunnions. For pad storage in HSMs, the transport cask remains on the transporter all the way to the pad, during DPC transfer, and all the way back to the railhead. For placement of horizontal DPCs into the above or below grade vaults, the transport cask is hoisted off of the transporter and placed in a transfer rack for DPC removal. After the DPC is removed, the transport cask is placed back on the transporter for the return trip back to the railhead. The omni-loader is controlled locally by an operator who walks beside the vehicle.

Maintenance: Preventive maintenance activities for the horizontal cask transporter include lubricating mechanical drive components, overhauling electric motors and brakes, replacing tires and wheel bearings, replacing pneumatic cylinder seals and running required inspections on jacking systems.

Testing:	The only design code based tests directly applicable to the horizontal cask transporter is pressure testing of the hydraulic systems which power the ram.
Design Codes:	Mechanical Drive Components - CMAA-70 Structural Framing and Welds - AISC Manual of Steel Construction Hydraulic Drive Components – SAE J series

6.5.2.6

Transfer Cell Motorized Carts



Storage Alternatives: CPAD, CSTDa-c, CUGS, CAGVc, CAGVd, CBGVc, CBGVd

Design Specs:	Capacity:	60T	
	Table Dimensions:	width - 8’– 0”	length - 9’– 0”
	Rail Width:	width - 5’– 0”	
	Velocity:	design load – 15 fpm	no load – 25 fpm
	Total weight:	design load – 123,725 lbs.	no load - 3725 lbs.
	Maximum wheel load:	design load – 31,000 lbs.	

Process Functions: The transfer cell motorized carts are used to move vertical transport, storage, and transfer casks to and from cask maintenance platforms and into and out of concrete transfer cells in the CHB and vault cask handling areas.

Safety Functions: The primary safety function for the transfer cell motorized cart is to support casks containing DPCs in order to prevent tip-over which could threaten the integrity of the SNF confinement boundary provided by the DPC. Event scenarios for which the motorized carts must be qualified include operational accidents, machine malfunctions, and earthquakes. Earthquakes are mitigated by anchoring the casks to the motorized cart table and using seismic rail clips or outriggers to prevent cart tip-overs.

Description: The transfer cell motorized carts are flat topped, fixed-rail, vehicles used to move vertical casks between stations where different unloading and loading operations are performed. The carts are used to shuttle inbound vertical transport casks in both the CHB and vault between cask maintenance platforms and unloading transfer cells. They are also used to move storage and transfer casks into and out of receiving transfer cells in the CHB. The CHB has (4) units, two of which are used for indoor service, and the other two for indoor/outdoor service. Vault storage alternatives where transport cask unloading is performed require (2) units, both of which are for indoor service.

The motorized carts are driven by electric motors and are equipped with electric brakes. The (4) CHB units have fixed table tops, which have targets painted on them to aid in placing casks directly in the center of the cart. The table tops in the (2) units in the vault must be capable of lateral movement with respect to the rails, due to the fact that the shield sleeve which does the hoisting in the vault has no lateral translational capability. Even though the table tops can move laterally, the transport casks must be centered on the cart within a certain tolerance to ensure that hoisting operations can be aligned properly and seismic restraints to keep the cask from tipping over can be installed, as required. For earthquakes above 0.25G, seismic restraints are also required to keep the cart on the rails. Power to the carts is provided by a cable-trac system which runs beneath the cart and is embedded into the CHB floor. The carts are controlled using local panels, by operators who continuously monitor cart motions.

Operations: Once the inbound vertical transport casks are removed from the railcar, they are placed on the motorized carts, which perform all cask movements required to de-lid, unload, and re-lid the cask for placement back on the railcar. This frees up the bridge crane for packaging and unpackaging duties on other transport casks. When the transport cask is first placed on the motorized cart, it is moved into position adjacent to a cask maintenance platform located on the opposite side of the CHB from the concrete transfer cells. This platform provides access to the top of the cask for untorquing lid bolts, removing the cask lid, and installing a lifting lug fixture on top of the DPC. A nearby jib crane is used to raise and lower the cask lids and lifting lugs from the ground to the top of the cask, and swing them into position over the cask. After the lift fixture is attached to the DPC, the motorized cart moves the transport cask with the DPC inside across the CHB and into the unloading concrete transfer cell. The cart is used to longitudinally center the DPC underneath the lifting port in the transfer cell ceiling and is locked in place in preparation for hoisting.

After the DPC is hoisted out of the transport cask and the shielded transfer cart has moved it over the adjacent receiving cell, the empty transport cask is available for repackaging. The shield doors to the unloading cell are opened and the motorized cart moves the transport cask back across the CHB to the maintenance platform. The cask lid is hoisted and swung into place on top of the cask, and the lid bolts are installed and torqued. The final movement of the motorized cart returns the transport cask to the middle of the crane bay, where it is rigged to the bridge crane, hoisted, and downended on the railcar.

The same sequence of operations is performed for transport casks unloaded in the vault, for those storage alternatives which have cask handling operations integral to the vault.

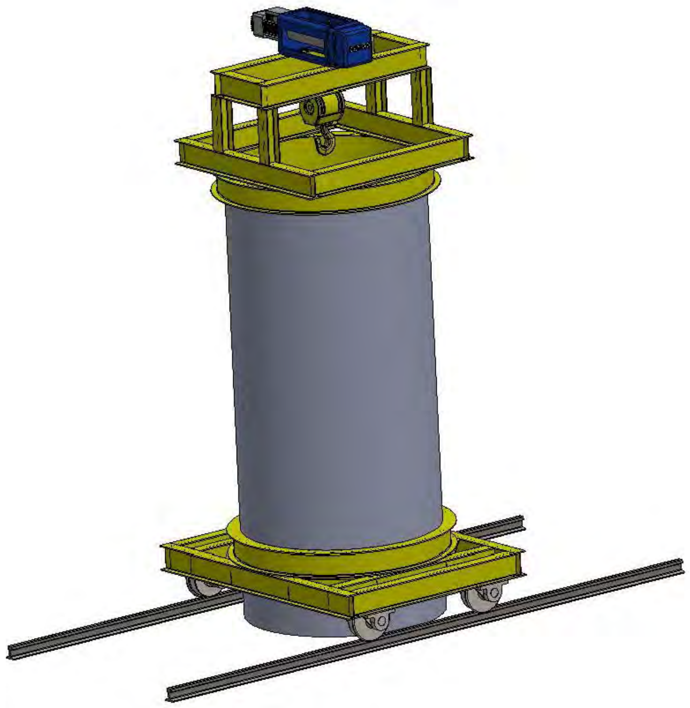
Maintenance: Preventive maintenance activities for the motorized carts include lubricating mechanical drive components, overhauling electric motors and brakes, and servicing the cable-trac system.

Testing: There are no design code based tests directly applicable to the carts, however they will be subject to standard pre-operational function testing including checkout tests on all major systems, and no-load and full load operational tests in the field. Full load functional testing shall also be performed after major corrective maintenance.

Design Codes:
Mechanical Drive Components - CMAA-70
Structural Framing and Welds - AISC N690

6.5.2.7

Shielded Transfer Cart



Storage Alternatives: CPAD, CSTDa-c, CUGS, CAGVc, CAGVd, CBGVc, CBGVd

Design Specs:	Hoist Capacity:	60T	
	Maximum Hook Height:	17’– 0”	
	Hoist Velocity:	design load – 3 fpm	no load – 11 fpm
	Travel velocity:	design load – 15 fpm	no load – 25 fpm
	Rail span:	8’– 10”	
	Housing inner diameter:	7’– 0”	
	Shielding material:	1” steel + 12” concrete	
	Total weight:	design load – 139,825 lbs.	no load - 19,825 lbs.
	Maximum wheel load:	design load – 35,000 lbs.	

Process Functions: The shielded transfer cart located in the CHB is used to hoist vertical DPCs out of transport casks and lower them into transfer casks or storage overpacks. Bare DPCs emit extremely high levels of radiation from the sides, therefore the cart must provide the shielding required while the DPC is outside of a cask or transfer cell. In order to keep occupational exposures low, the cart is designed to perform the entire DPC transfer operation, from grappling to decoupling, remotely. The shielded transfer cart is also used to load lift frames into storage and transfer casks for those storage alternatives where horizontal DPCs are to be stored vertically.

Safety Functions: The primary safety function for the shielded transfer cart is to retain the DPC throughout the hoisting, transfer, and lowering process in order to maintain the integrity of the SNF confinement boundary provided by the DPC. Event scenarios for which the transfer cart must be qualified include operational accidents including load drops, machine malfunctions, loss of power, and earthquakes. Load drops are mitigated by designing the hoist on the transfer cart to be single-failure proof. Single-failure proof design requirements for Type I hoists are identified in ASME NOG-1, including dual load paths for reeving and drive trains, redundant holding brakes, hoist overtravel protection, and overspeed limit devices for the motor. Remote lifting devices are also equipped with sensors to ensure proper engagement of lifting lugs and load sensing. Safety features required by the design to mitigate the consequences of events other than load drops include redundant controls to prevent cart travel during hoisting, over-travel stops for the cart and seismic rail clips to prevent overturning during earthquakes.

The transfer cart must also provide shielding for the DPCs during transfer operations to reduce occupational exposures to the limits specified in 10CFR20.

Description: The shielded transfer cart a steel-framed, rail-based, vehicle which is capable of remotely grappling, hoisting, transferring, lowering and releasing DPCs with or without lift frames that weigh up to 60 tons. There are two, identical transfer carts which run on a common set of rails above the row of concrete cask transfer cells in the CHB. The railway includes a maintenance area at each end where a cart can be maintained while allowing the other cart to service all transfer cells.

The carts raise and lower payloads through ports in the ceilings of the concrete transfer cells using a single-failure proof hoist which is mounted on top of the cylindrical shield housing. Remote grappling of vertical DPCs is accomplished by the use of a self-centering grapple which actuates to engage a centrally located cylindrical lifting lug bolted to the top of the DPC. Whereas the tops of horizontal DPCs are not designed for vertical lifting, lift frames which completely enclose the DPC are used for vertical transfer and storage of horizontal DPCs. Lift frames are grappled remotely using a lifting device where pins rotate in opposite directions to engage the lifting lugs which are distributed around the periphery of the top of the frame, The different lifting devices may be exchanged to match the type of DPC – vertical or horizontal – being processed.

Shielding is provided by the 1” thick steel cylindrical housing that the DPC is raised into, which is augmented by an additional 12” layer of concrete placed externally. There is a small gap between the bottom of the housing and the top of the concrete ceiling over the cells. In order to prevent streaming through this gap from exposing personnel occupying the main floor of the CHB, a 12” high concrete parapet runs along the crane bay side of the transfer cart railway.

The carts are motorized and equipped with electric brakes, with power being supplied by a conductor bar system. The carts are controlled locally using a wireless panel by an operator on the ground floor of the CHB. Cart movements are automated, both to limit accelerations and decelerations in order to prevent the payloads from swinging and contacting the housing, and to ensure precise cart positioning over transfer ports. Hoisting and grappling activities are monitored by cameras in the cells and on board the lifting devices to detect abnormal operations.

Operations: During DPC transfer operations, inbound transport casks are brought into the vertical cask unloading cell on a motorized cart and centered directly underneath the port in the cell ceiling. The cell is then evacuated and the shield doors to the cell are closed. The shielded transfer cart, equipped with the appropriate lifting device, is positioned over the port. The lifting device is lowered into position by the hoist, guided by visual observations from the cameras. The lifting device is aligned with the lifting lug on the DPC by small movements of the motorized cart in one direction and the shielded cart in the other. When alignment is achieved, the carts are locked into position, and the lifting device is lowered and actuated to grapple the lifting lug on the DPC. The success of the grappling operation is verified visually and by sensors on the lifting device. The DPC is then raised up through the port and into the shield housing on the transfer cart. During the hoisting operation, the exposed surface of the DPC is visually inspected for condition and damage using the cameras. Once the DPC is verified to be fully raised by sensors and by visual observation, the brakes on the cart are released and the cart is moved into position above the port in the receiving cell ceiling.

In the meantime, while the transfer cart is acquiring the DPC, the storage or transfer cask into which the DPC will be placed is being staged in the receiving cell. The cask is transferred in from its storage location outside the CHB on a motorized cart, which centers it underneath the port in the receiving cell ceiling. The staging operation is completed and the receiving cell evacuated and shield doors closed before the transfer cart moves the DPC into position over the port. The DPC is then lowered into the cask, pausing as required to visually align the DPC with the cask using the same procedure as during lifting. When the DPC is fully seated in the cask, and verified to be by load sensor, the lifting device is released and the hoist retracted.

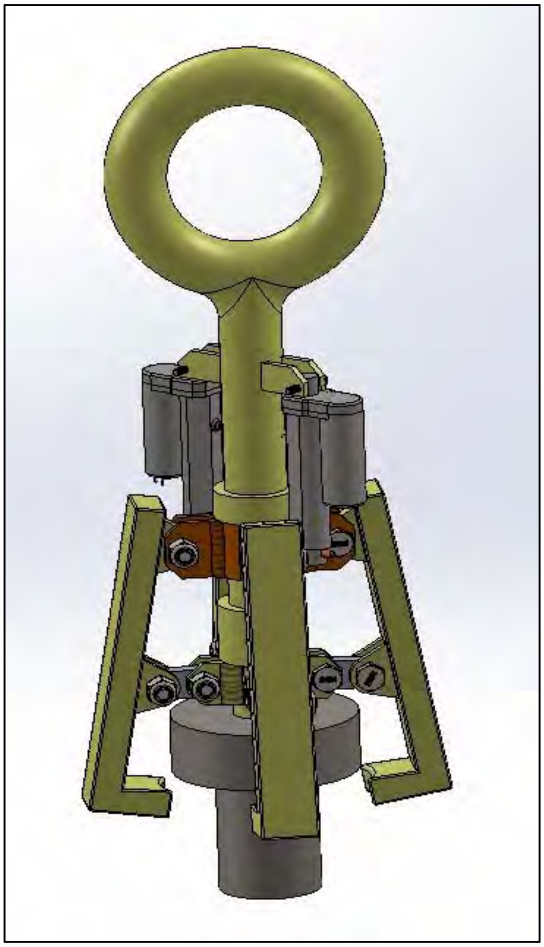
Maintenance: Preventive maintenance activities for the cart include periodic lubrication of the shafts, bearings and drives, overhauling the motors and brakes, servicing the power system conductor bars and collectors, calibrating the motion control system and lifting device sensors, and servicing the electric actuators and replacing cameras on the lifting devices. Preventive maintenance activities for the hoist include inspecting the wire rope and replacing it as required, lubricating mechanical drive components, and overhauling electric motors and brakes.

Testing: The ASME NOG-1 design code requires a prescribed set of functional tests which are applicable to hoisting equipment, including a no-load test in the shop and a no-load test, full load test, and 125% rated load test in the field. NUREG-0554 requires a 200% Maximum Credible Load test for single failure proof hoisting equipment, which would be applied in this case. Rated load testing shall also be performed after major corrective maintenance.

Design Codes:
Hoisting Equipment – ASME NOG-1, Type I
– NUREG-0554
Mechanical Drive Components - CMAA-70
Structural Framing and Welds - AISC N690

6.5.2.8

Universal Lifting Lug Grapple



Storage Alternatives: CPAD, CSTDa-c, CUGS, CAGVc, CAGVd, CBGVc, CBGVd

Design Specs:	Capacity:	60T	
	Overall Height:	0’– 4.25”	
	Jaw Opening:	minimum – 3” Ø	maximum – 8” Ø
	Weight:	125 lbs.	

Process Functions: The vertical DPC lifting lug grapple is used to remotely grapple the vertical DPC lifting lug presented in section 6.3.1, hoist vertical DPCs attached to the lug, and release the lug after the hoisting operation is finished. The grapple is installed on cart mounted shielded transfer sleeve hoists in the CHB and suspended shielded transfer sleeve hoists in the above and below grade vaults.

Safety Functions: The primary safety function for the vertical DPC lifting lug grapple is to retain DPCs during hoisting operations in order to prevent load drops which could threaten the integrity of the SNF confinement boundary provided by the DPC. Event scenarios for which the lift frame lifting devices must be qualified include operational accidents, load excursions, load drops, and earthquakes.

Description: The vertical DPC lifting lug grapple is a below-the-hook, steel grapple suspended below the shielded transfer cart in the CHB and the shielded transfer sleeve in the vault. The device is designed to remotely engage the vertical DPC lifting lugs bolted to the top of vertical DPCs. The grapple arms engage the head of the lug concentrically. Actuation of the grapple arms by a pair of electric actuators will self-center the grapple on the lug. The fingers on the grapple arms have a 4 degree relief that matches the relief on the bottom of the lifting lug head, which prevents the arms from opening up under load. Position sensing on the arms is interlocked with the hoisting function to ensure the arms fully engage the lug prior to hoisting. The engagement will also be visually verified remotely by camera by an operator who will continuously monitor all hoisting operations.

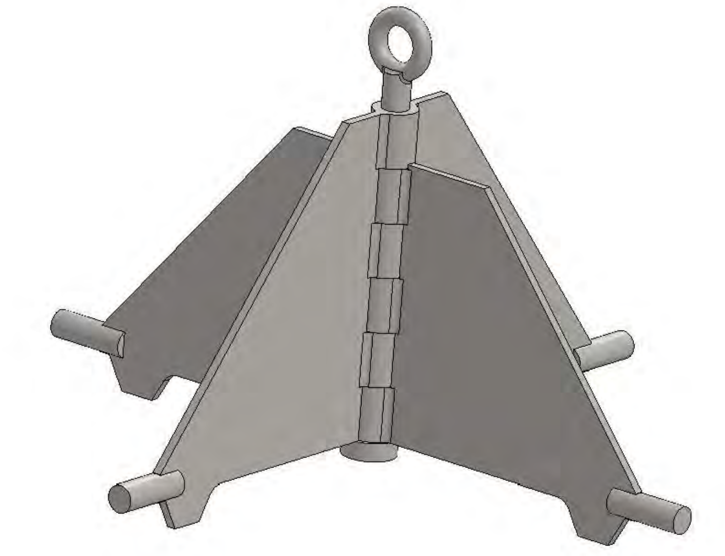
Operations: In preparation for vertical hoisting of DPCs, a vertical DPC lifting lug is bolted to the top of the vertical DPC to be hoisted. The DPC is then rolled into a concrete transfer cell on a motorized cart and placed directly below the opening in the cell ceiling. The shielded transfer cart or sleeve equipped with a vertical DPC lifting lug grapple is positioned over the opening, lowers the lifting device, and engages and raises the DPC. The cart or sleeve is then positioned over the opening in the adjacent receiving cell ceiling and lowers the DPC into a storage or transfer cask which has been staged in the receiving cell. Once the DPC is placed in the cask, the grapple is released and the hoist retracted.

Maintenance: Preventive maintenance activities for the vertical DPC lifting lug grapple lubrication of mechanical components and actuators.

Testing: The lift frame lifting device is subject to an initial 125% rated load test before service and after corrective maintenance. ANSI N14.6 requires a 150% Maximum Credible Load test prior to service, and annually thereafter.

Design Codes:
Structural Framing and Welds – ASME BTH-1
Pneumatic System Design - SAE J series Standards
Testing and Operations – ASME B30.20, ANSI N14.6

6.5.2.9
Horizontal DPC Lift Frame Lifting Device



Storage Alternatives: CSTDa, CUGS, CAGVa, CAGVc, CBGVa, CBGVc

Design Specs:	Capacity:	55T
	Overall Height:	4’– 0”
	Rotational Range:	360°
	Weight:	1,125 lbs.

Process Functions: The horizontal DPC lift frame lifting device is used to hoist horizontal DPCs which have been loaded into lift frames, for storage in a vertical orientation in the above or below grade vaults (C-AGV, C-BGV) or in individual underground storage vaults (C-UGS). The grapples are also used to lower empty lift frames into storage and transfer casks staged on upenders in the CHB and vault, in preparation for downending and inserting horizontal DPCs.

Safety Functions: The primary safety function for the horizontal DPC lift frame lifting device is to retain DPCs during hoisting operations in order to prevent load drops which could threaten the integrity of the SNF confinement boundary provided by the DPC.

Event scenarios for which the lift frame lifting devices must be qualified include operational accidents, load excursions, load drops, and earthquakes.

Description: The lift frame lifting device is a below-the-hook, steel grapple suspended below the shielded transfer cart in the CHB and the shielded transfer sleeve in the vault. The device is designed to remotely engage the lifting lugs on the horizontal DPC lift frame. The lift frame lifting lugs are open hooks with the openings on adjacent lugs facing each other. The lifting device has two plates with pins on the ends which when actuated, rotate in opposite directions about a central hinge. The pins engage the lifting lugs on the frame in the circumferential direction through the open part of the hook. The plate are rotated by an electric actuator which forces the pins into the hooks as the lifting device is raised. When the lifting device is released and lowered, the sloping shape on the base of the lifting lugs automatically causes the pins to disengage from the lugs, aided by the actuated rotation of the plates in the reverse direction. Successful remote engagement of the lifting device requires that the lifting device be centered on the lift frame in a specific rotational orientation. Centering is achieved via a lead-in fabricated on the bottom of the lifting device plates. In order to achieve the required rotational orientation, the grapple is equipped with motorized rotation of its position relative to the hook, which is manually controlled using visual feedback by camera.

Operations: In preparation for vertical storage of horizontal DPCs, a horizontal DPC lift frame is transferred by forklift to an empty concrete transfer cell adjacent to an upender cell and placed directly below the opening in the cell ceiling. The shielded transfer cart or sleeve equipped with a lift frame lifting device is positioned over the opening, lowers the lifting device, and engages and raises the lift frame. The cart or sleeve is then positioned over the opening in the upender cell ceiling and lowers the lift frame into a staged storage or transfer cask sitting on the upender. Before final placement of the lift frame in the cask, the frame is rotated to the orientation where the v-rollers will be directly at the bottom of the cask when the cask is upended, using the rotational motor drive. Once the lift frame is placed in the cask, lift frame hoisting activities in the CHB are complete. However, in the vault, the lift frame with the DPC inside must still be hoisted up off of the upender and into the shield sleeve for transfer and placement in storage on the vault floor.

Maintenance: Preventive maintenance activities for the lift frame lifting device include lubrication of mechanical components and installing seal kits in the pneumatic cylinder actuators.

Testing:	The lift frame lifting device is subject to an initial 125% rated load test before service and after corrective maintenance. ANSI N14.6 requires a 150% Maximum Credible Load test prior to service, and annually thereafter.
Design Codes:	Structural Framing and Welds – ASME BTH-1 Pneumatic System Design - SAE J series Standards Testing and Operations – ASME B30.20, ANSI N14.6

6.5.2.10

Horizontal DPC Transfer Cart w/ or w/o Transfer Sleeve

Storage
Alternatives: CSTDa, CSTDc, CUGS, CAGVa, CBGVa, CAGVb, CAGVd, CBGVb, CBGVd

Design Specs:	Load Capacity:	275,000 lbs.	
	Drive Velocity:	10 fpm	
	Cask Positioning System	vertical: +/- 6”	lateral: +/- 4”
	Cask Positioning System	pitch: +/- 2 degrees	
	Total weight:	design load – 301,700 lbs.	no load - 26,700 lbs.
	Maximum wheel load:	design load –50,300 lbs.	

Process
Functions: There are two versions of the horizontal DPC transfer cart – one that is used to transfer horizontal DPCs for vertical storage and vertical DPCs for horizontal storage (CSTDa, CSTDc, CUGS, CAGVa, CBGVa), and one that is used to transfer horizontal DPCs into the vaults for horizontal storage (CAGVb, CAGVd, CBGVb, CBGVd). The first version (I) shuttles DPCs between downended transport casks staged on fixed stands and transfer casks staged on an upender in

the horizontal position. This version features a permanently mounted transfer sleeve which shields the DPC during transfer operations.

The second version (II) receives horizontal transport casks which have been offloaded from railway cars or horizontal transporters and stages them for removal and transfer of the DPC to horizontal vault storage. The transport casks are downended on the cart, which allows access to the lid for removal. With the lid removed, the transfer cart is rolled into position, aligned, and docked with the port in the concrete wall of the vault. The DPC is pushed out of the transport cask, through the port, and onto a horizontal DPC transfer cart which services the vault by a hydraulic ram mounted to the cart. The ram engages the DPC through a port in the bottom of the transport cask. Once the DPC transfer into the vault is complete, the transfer cart is rolled back from the port, and the transport cask is re-assembled, transferred to a railcar for removal from the cask handling area in the vault.

Safety Functions: The primary safety function for the horizontal DPC transfer cart is to support the cask containing the DPC throughout the cask loading and unloading process to maintain the integrity of the SNF confinement boundary. Event scenarios for which the transfer cart must be qualified include operational accidents, machine malfunctions, loss of power, and earthquakes. Safety features incorporated in the design to mitigate the consequences of these events include retention straps for the casks, over-travel stops and fail-safe electric brakes for the cart, and load sensing on the hydraulic ram which performs the DPC transfer.

Description: The horizontal DPC transfer cart is a steel-framed, rail-based, motorized cart which is capable of receiving either DPCs transferred from other casks into a shield sleeve on the cart (I) or transport casks downended on a set of trunnion supports (II). The cart is capable of aligning and positioning the DPCs for transfer, and providing the force required to push the DPCs out of casks on the cart and into adjacent casks.

Storage alternatives with version I transfer carts have two redundant horizontal DPC transfer lines, each with its own transfer cart. The carts are located in the CHB or vault cask handling areas within access of the main bridge cranes. They are mounted on a set of rails which run from a fixed transport cask stand on one side of the cask handling area, across a turntable located midway along the railway, to a concrete transfer cell which houses an upender mechanism on the other side. The rails allow the transfer cart to load a horizontal DPC from a transport cask, turn it end-for-end, and unload it into a transfer cask sitting on the upender. The end-for-end maneuver is required to ensure that when the horizontal DPC is upended for vertical storage, the fuel assemblies inside the DPC are sitting on their bases.

Storage alternatives with version II transfer carts have four carts, each of which services its own vault storage line. In the version II carts, transport casks are supported in a horizontal orientation on their trunnions. The trunnions engage stanchions on the cart which are adjustable both lengthwise and widthwise to accommodate the range of trunnion configurations on the different transport casks received by the facility. The stanchions are mounted on a steel frame which attaches to the cart by a set of hydraulic cylinders which provide relative movement between the frame and cart in the vertical and lateral translational directions and two axes of rotation. The cylinders are actuated by a laser alignment system which automatically aligns the transport cask and storage cask via a set of targets placed on the storage cask. The base of the cart rolls on a set of rails, with electric motors driving the wheels. Hydraulic fluid is pumped from one of two redundant skids located in a maintenance area of the vault. The skids are cross-tied so that either skid may power either or both of the transfer carts. Hydraulic fluid, along with electric power, is delivered to the carts by a cable-trac system which runs beneath the carts and is recessed into the vault cask handling area floor. The cart is locally controlled by an operator who continuously monitors operations. The nominal capacity of the version II horizontal DPC transfer cart is 260,000 lbs., which envelopes the combined weight of the heaviest horizontal transport cask and DPC.

Operations: For DPC transfers to version I carts, inbound transport casks are loaded onto the fixed stand using the cask handling bridge crane. Once the transport cask is placed and secured, the lid bolts are removed using a hydraulic tensioner. The lid is then hoisted out of the way using an overhead jib crane. The transfer cart with a docking collar is then rolled into position, aligned, and docked with the transport cask, and the slings are tightened around the transport cask trunnions. The port in the base of the transport cask is removed, and the hydraulic ram on the transfer cart is inserted to engage the bottom of the DPC. The DPC is transferred into the shield sleeve on the transfer cart by the hydraulic ram. The door on the shield sleeve is closed, and the cart is rolled onto the turntable, turned end-for-end, and positioned at the upender. The door on the shield sleeve is opened and the cart is docked with a storage/ transfer cask into which a lift frame has been installed, which is staged on the upender in a horizontal orientation. The transfer cart and upender are locked into position, and the hydraulic ram forces the DPC out of the transport cask and into the lift frame inside the storage/transfer cask.

After the DPC transfer is complete, the transfer cart is rolled out of the upending cell and the cell doors closed. The docking collar is unbolted and removed, and the transport cask lid is installed and bolted into place.

For DPC transfers to version II carts, inbound transport casks are loaded directly onto the carts using the cask handling bridge crane. Once the transport cask is placed and secured, the lid bolts are removed using a hydraulic tensioner. The lid is then hoisted out of the way using an overhead jib crane. The transfer cart is then rolled into position, aligned, and docked with the port in the concrete vault wall. The transport cask is secured to the vault concrete wall using slings which engage the trunnions on the transport cask. The port in the base of the transport cask is removed, and the hydraulic ram on the transfer cart is inserted to engage the bottom of the DPC. The DPC is transferred through the port onto a vault horizontal DPC transfer cart by the hydraulic ram. After the DPC transfer is complete, the transfer cart is rolled away from the port and the port door is closed. The transport cask lid is installed and bolted into place, and the transport cask is hoisted and transferred to a railcar or transporter for removal from the vault.

Maintenance: Preventive maintenance activities include periodic lubrication of cart bearings, overhauling the motors and brakes on the drives, replacing hydraulic cylinder seals, and changing filters and rebuilding pumps and motors on the hydraulic skid. Consumables in the transfer cart design include local filters and seal kits for the hydraulic cylinders.

Testing: After construction, transfer cart hydraulic and power systems are subject to individual leak, pressure, and continuity tests, as required by the applicable design codes. The entire transfer cart system will undergo integrated no-load and load testing during initial functional acceptance testing. Load testing should also be performed after corrective maintenance. There are no code-related periodic test requirements after the initial acceptance tests are complete.

Design Codes:

Structural Framing and Welds - AISC N690
Mechanical Drive Components – CMAA-70
Hydraulic Drive Components – SAE J series

6.5.2.11
Horizontal Cask Upender

Storage Alternatives: CSTDc, CUGS, CAGVa, CBGVa

Design Specs:	Payload Capacity:	raising - 365,000 lbs.	lowering – 425,000 lbs.
	Total Weight:	design – 483,800 lbs.	no load – 58,800 lbs.
	Total travel:	90 degrees	
	Total travel time:	45 seconds	

Process Functions: The horizontal DPC upender reorients storage or transfer casks loaded with horizontal DPC lift frames from vertical position to horizontal position so horizontal DPCs can be inserted from adjacent transport casks. Once the DPCs are loaded, the upender rotates to return the storage/transfer cask to the vertical position with the bottom of the cask at floor level, to allow transfer by Vertical Cask Transporter to vault or underground storage location. The upender is also used to reorient vertical DPCs inside of transfer casks from a vertical position to a horizontal position for subsequent transfer onto a horizontal DPC transfer cart, in preparation for pad storage in a horizontal storage module.

Safety Functions: The primary safety function for the upender is to support the DPC throughout the loading and cask repositioning process to maintain the integrity of the SNF confinement boundary. Event scenarios for which the upender must be qualified include operational accidents, machine malfunctions, loss of power, and earthquakes. Safety features incorporated in the design to mitigate the consequences of these events include retention straps for the casks, over-travel stops for the frame, fail-safe electric brakes, and flow-limiting orifices for the hydraulic system to limit the speed of rotation in the event of a malfunction.

Description: Horizontal DPC upender is a steel-framed, hydraulically-actuated mechanism which is capable of rotating storage and transfer casks from vertical-to-horizontal for loading and from horizontal-to-vertical for transfer. The design calls for two upenders, each located in its own transfer cell in the CHB or integral vault. One side of each cell has doors which open to the building interior, through which the horizontal DPCs are introduced on a rolling cart which docks with the upender. The other side of each cell in the CHB has shielded doors opening to the exterior of the CHB, which permit access to the cell by Vertical Cask Transporters to introduce empty casks and retrieve loaded casks. The upender transfer cells in the vaults have ports in the roof where the shielded transfer sleeves acquire and hoist lift frames loaded with DPCs for transfer to a vault storage location.

The casks are supported by an L-shaped frame which pivots on a central shaft. The shaft is supported by a steel frame pedestal, which is anchored to a recessed foundation in the transfer cell floor. The flat base of the L supports the entire base of the storage or transfer cask in the vertical position. The back of the L is a V-shaped cradle which supports and centers the cask when in the horizontal position. The lifting capacity of the upender is 365,000 lbs., which envelopes the combined weight of the lift frame and the heaviest empty storage cask. The lowering capacity of the upender is 425,000 lbs., which envelopes the combined weight of the heaviest horizontal DPC, lift frame, and storage cask.

The upender is positioned by three dual-acting hydraulic cylinders, each with a nominal capacity of 135,000 lbs. Each cylinder is powered by an independent hydraulic circuit. The hydraulic fluid is supplied at a nominal pressure of 3000 psi from one of two redundant supply skids which are located in a separate equipment room in the CHB. The skids are cross-tied, so either skid can supply either or both of the upenders. Each upender is controlled from a local panel by an operator who continuously monitors upending operations.

Operations: During operations, empty casks are brought into the cell by a VCT and centered on the frame in the vertical position. The cask lid is removed and retained on the VCT, which then withdraws from the cell. A lift frame is lowered into the empty cask through a hole in the cell roof directly above the cask. The cask is then strapped to the frame and rotated into the horizontal position. The doors on the CHB side are opened and a transfer cart with a transport cask which has been downended and de-lidded is rolled into the cell. The transport cask is aligned and docked with the cask/frame on the upender. The DPC is pushed out of the transport cask and into the cask/frame by a hydraulic ram installed on the transfer cart. When the DPC is fully loaded into the cask/frame, the transfer cart is undocked and removed from the cell and the upender rotates the cask/frame back to the vertical position. The VCT then re-enters the cell, the lid on the cask/frame is installed, and the VCT transfers the cask/frame to storage.

Upender operations in the vault are similar, except that the transfer cask is permanently mounted to the upender. Lift frames are installed in the transfer cask by the transfer sleeve through the port in the cell roof. After the upender is loaded and rotated from horizontal to vertical, the lift frame is hoisted out of the cell by the transfer sleeve hoist and transferred to a storage location in the vault.

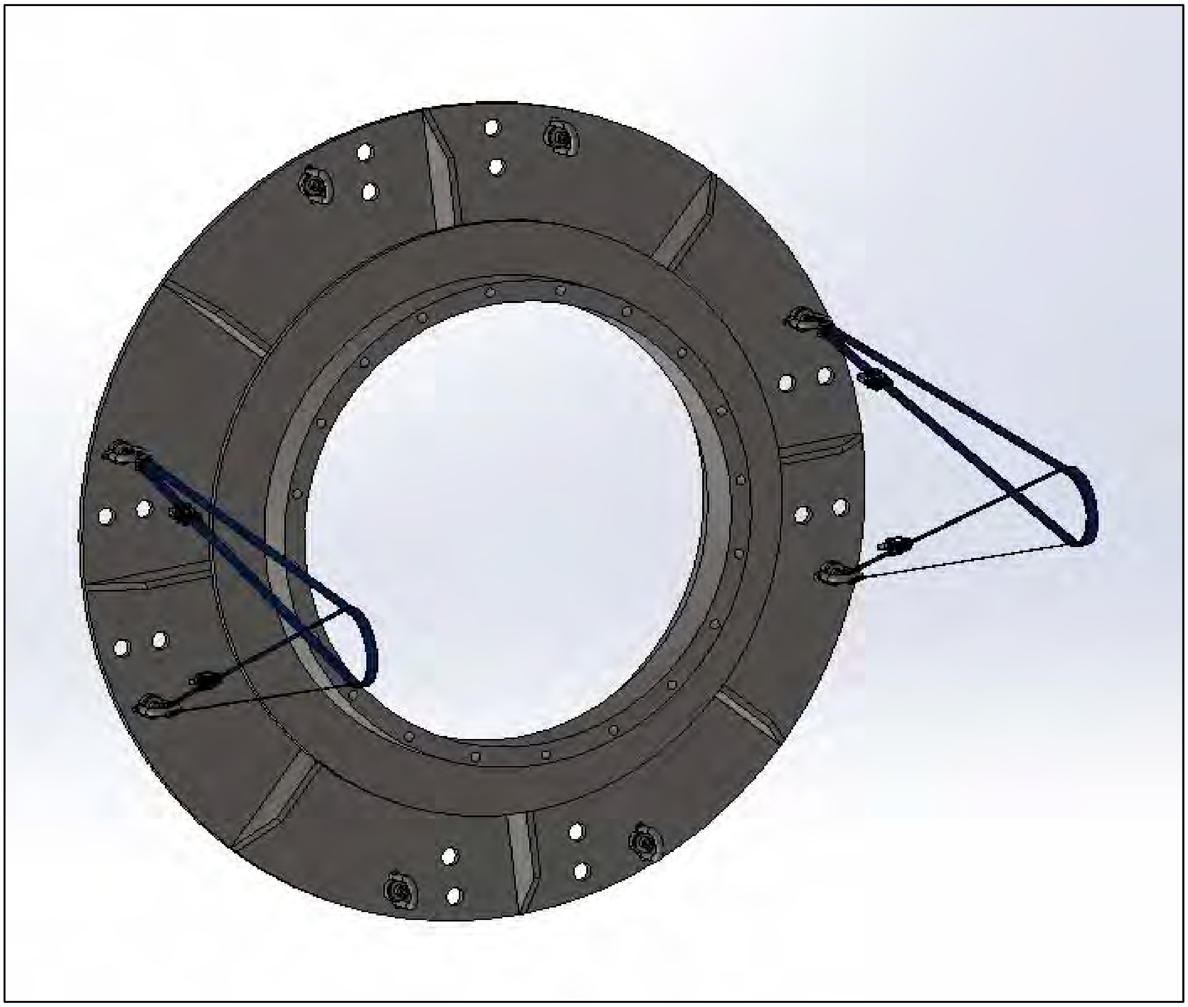
Maintenance: Preventive maintenance activities include periodic lubrication of shafts and bearings and overhauling the brakes on the frame, replacing hydraulic cylinder seals, and rebuilding pumps and motors on the hydraulic skid. Upender consumables include local filters and seal kits for the hydraulic cylinders.

Testing: After construction, upender hydraulic and power systems are subject to individual leak, pressure, and continuity tests, as required by the applicable design codes. The entire upender system will undergo integrated no-load and load testing during initial functional acceptance testing. Load testing should also be performed after corrective maintenance. There are no code-related periodic test requirements after the initial acceptance tests are complete.

Design Codes:
Structural Framing and Welds - AISC N690
Mechanical Drive Components – CMAA-70
Hydraulic Drive Components – SAE J series

6.5.2.12

Horizontal Transfer Docking Collar



Storage Alternatives: CSTDa, CSTDc, CUGS, CAGVd, CBGVd

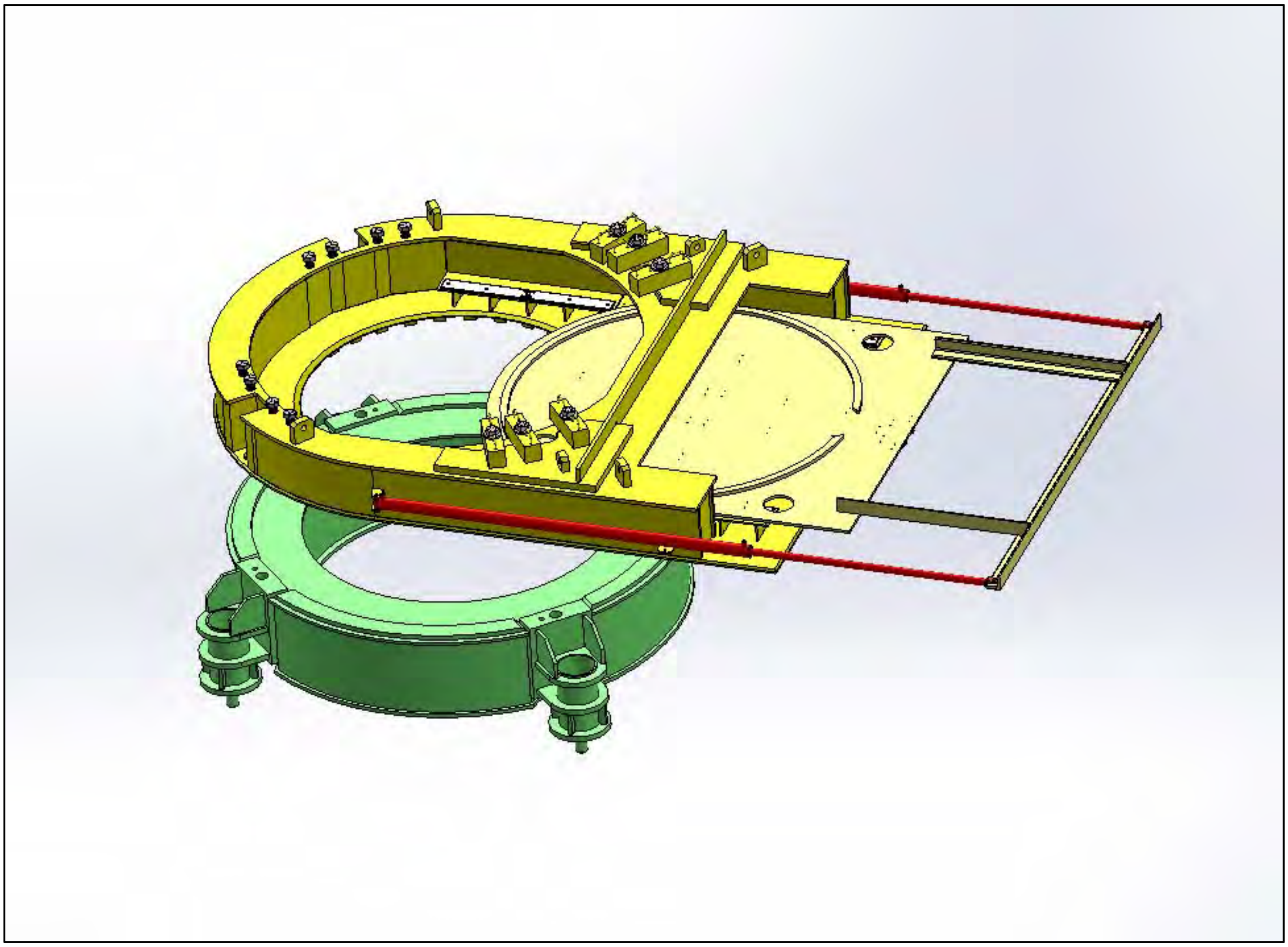
Design Specs:	Axial Capacity:	80,000 lbs.
	Outer Diameter:	9’– 6”
	Inner diameter:	5’– 2.5”
	Overall Height:	1’ - 2”
	Total weight:	4,350 lbs.

Process Functions: The horizontal transfer docking collar in the CHB and vault is used to provide the alignment and force transfer interface between horizontal transport casks which contain horizontal DPCs and the vertical storage overpacks and transfer casks into which the DPCs will be transferred.

Description:	The horizontal transfer docking collar is a removable mating device used to couple horizontal transport casks to vertical storage overpacks or transfer casks during DPC transfer operations. The collar bolts to the top face of a receiving overpack or cask, and inserts into the bore created by removing the lid on the transport cask. The collar is attached to the transport cask by straps which wrap around the upper trunnions on the cask, which are then tensioned. This method of attachment avoids the high doses associated with installing and removing bolts in the dose field immediately adjacent to the exposed top of the DPC. During the DPC transfer, the collar transmits the frictional forces applied by sliding the DPC into the receiving cask back to the transport cask, so there are no net reactions on either the upender which supports the receiving cask or the horizontal transfer cart which supports the transport cask. The straps are sized to carry the full 80,000 lb. force delivered by the hydraulic ram which drives the DPC. After the DPC is transferred into the receiving cask, the ram is withdrawn and the collar is unbolted from the receiving cask. The collar remains strapped to the transport cask as it is rolled back away from the upender and is subsequently removed using the jib crane which is also used to remove and install the lid on the transport cask.
Design Codes:	Structural Framing and Welds - AISC N690

6.5.2.13

Vertical Transfer Docking Collar



Storage Alternatives: CUGS

Design Specs:	Outer Diameter:	base: 10’– 0”	lid removal: 10’ – 3”
	Inner diameter:	base: 6’– 9”	lid removal: 6’ – 9”
	Overall Height:	base: 2’ - 1”	lid removal: 1’ – 10”
	Total weight:	base: 19,550 lbs.	lid removal: 22,725 lbs.

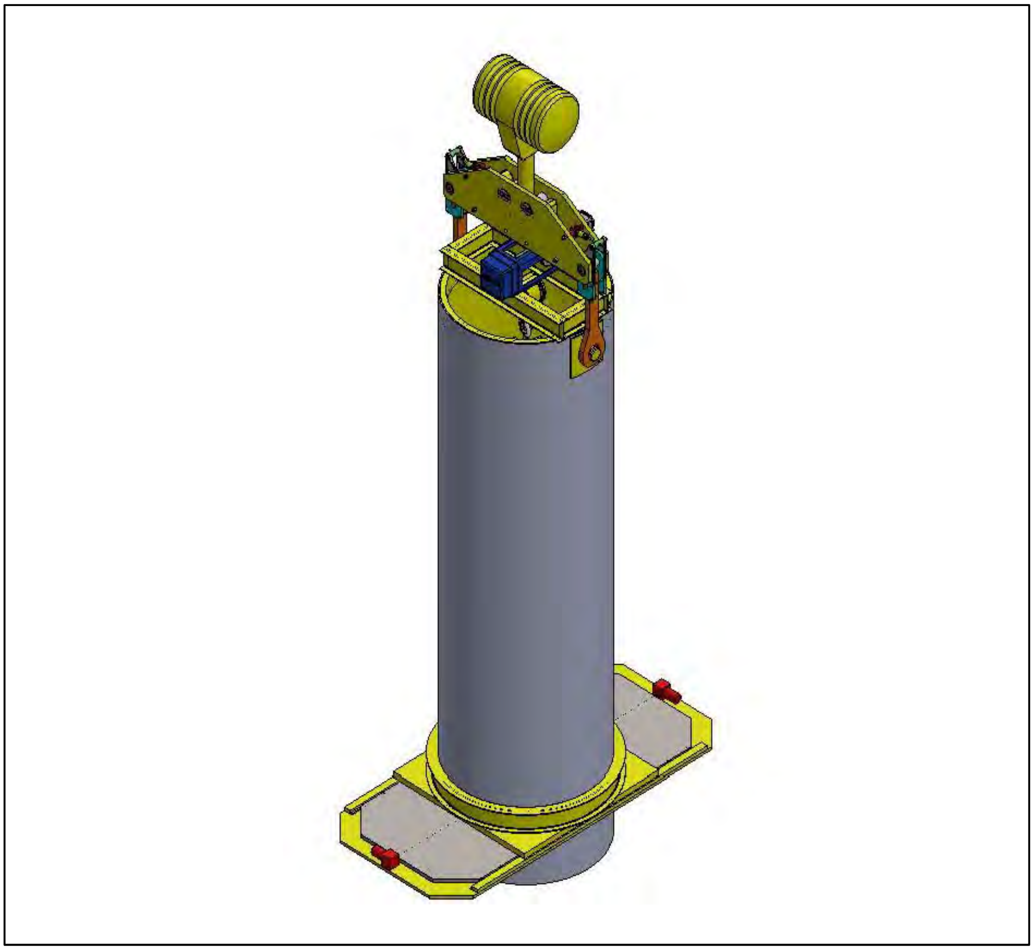
Process Functions: The vertical transfer docking collar provides the alignment interface and mechanical coupling for stability for DPC transfers between the transfer casks which bring the DPCs out to the storage area and the underground storage vault silos.

Description: The vertical transfer docking collar is a two-piece removable mating assembly used to couple vertical transfer casks to individual underground storage vaults installations during DPC transfer operations. The base piece bolts directly to the top head of the silo. The lid removal section bolts to the base piece. The lower flange on the transfer cask then clamps to the lid removal section using a combination of bolts and bar-type clamps. The mechanical connections provide axial alignment between the transfer cask and silo, and lateral stability to mitigate load excursions while the DPC is being lowered into the underground vault.

Operations: The sequence of operations required to place DPCs into underground storage vaults starts with the preparation of the designated storage location. The underground vaults are each capped by a heavy concrete lid that must be removed in order to install the vertical docking collar. The base piece is installed and bolted into place on top of the silo. Then, the lid removal section is placed on top of the base and bolted into position. Next, the VCT aligns the transfer cask with the collar and lowers it down on top of the docking collar. The cask is bolted to the collar and the DPC is rigged to the lift beam and slightly raised. The bolts holding the bottom lid of the transfer cask are removed and the lid drops onto a tray. Hydraulic actuators slide the tray with the lid out of from underneath the cask clearing the path to lower the DPC into the silo. Once the DPC is placed, the rigging is removed from the DPC and retracted. The tray with the lid is slid back into position at the bottom of the cask and air pillows are inflated to force the lid up against the cask so it can be bolted back into place. The transfer cask is unbolted from the docking collar and removed by the VCT. The docking collar is then unbolted and removed, one piece at a time.

Design Codes: Structural Framing and Welds - AISC N690

6.5.2.14
Shielded Transfer Sleeve



Storage Alternatives: CAGVa, CAGVb, CAGVc, CAGVd, CBGVa, CBGVb, CBGVc, CBGVd

Design Specs:			
	Hoist Capacity:	60T	
	Maximum Hook Height:	23’– 3”	
	Hoist Velocity:	design load – 3 fpm	no load – 11 fpm
	Housing inner diameter:	7’– 0”	
	Shielding material:	1” steel + 12” concrete	
	Total weight:	design load – 152,325 lbs.	no load - 32,325 lbs.

Process Functions: The shielded transfer sleeve located in the vault is used to hoist vertical DPCs out of transport or transfer casks and lower them into storage locations on the vault floor. Bare DPCs emit extremely high levels of radiation from the sides; therefore the sleeve must provide required shielding when the DPC is outside of a transfer cell. In order to keep occupational exposures low, the sleeve is designed to perform the DPC transfer operation from grappling to decoupling remotely. The sleeve is also used to lift and set aside the shield plugs over the vault storage locations prior to storing the DPCs and replace them after the DPCs have been stored.

Safety Functions: The primary safety function for the shielded transfer sleeve is to retain the DPC throughout the hoisting, transfer, and lowering process in order to maintain the integrity of the SNF confinement boundary provided by the DPC. Event scenarios for which the transfer sleeve must be qualified include operational accidents including load drops, machine malfunctions, loss of power, and earthquakes. Load drops are mitigated by designing the hoist on the transfer sleeve to be single-failure proof. Single-failure proof design requirements for hoists are identified in ASME NOG-1, for Type I units, including dual load paths for reeving and drive trains, redundant holding brakes, hoist overtravel protection, and overspeed limit devices for the motor. Remote lifting devices are also equipped with sensors to ensure proper engagement of lifting lugs and load sensing.

The transfer sleeve must also provide shielding for the DPCs during transfer operations to reduce occupational exposures to the limits specified in 10CFR20.

Description: The shielded transfer sleeve is a steel and concrete cylinder which hangs from the hook of a bridge crane, with a hoist mounted on top which is capable of remotely grappling, hoisting, transferring, lowering and releasing DPCs weighing up to 110,000 lbs. The bridge crane which supports the sleeve runs on a set of crane rails which provide overhead access to every storage location in the vault, as well as a row of concrete transfer cells where inbound transport or transfer casks are staged for DPC removal. The sleeve is designed to be lowered into recesses in the vault operating floor above each storage location and in the transfer cell ceilings above each cask transfer location, which both align the sleeve with the port through which the DPC is transferred and ensure an overlap in shielding for any gap between the bottom of the sleeve and the concrete slabs which support it. The recesses in the vault operating floor are normally covered with concrete shield plugs. The sleeve is equipped with external lifting lugs near the bottom which are used to rig, lift, and remove the shield plugs from over storage locations to allow DPCs to be loaded into the vault.

The shielded transfer sleeve is used exclusively to store vertical DPCs and horizontal DPCs in lift frames in a vertical orientation in the vault. Remote grappling of vertical DPCs is accomplished by the use of a self-centering lifting device which actuates to engage a centrally located cylindrical lifting lug bolted to the top of the DPC. Horizontal DPC lift frames, which require lifting lugs which are distributed around the periphery of the top of the frame, are grappled remotely using a lifting device where pins rotate in opposite directions to engage the lifting lugs. The different lifting devices may be exchanged to match the type of DPC – vertical or horizontal – being processed.

The transfer sleeve provides shielding in the radial direction by the 1” thick steel cylindrical housing that the DPC is raised into, augmented by an additional 12” layer of concrete placed externally. The bottom of the sleeve is shielded by a pair of sliding doors which close whenever a DPC is drawn up into the sleeve.

DPC hoisting and grappling activities in the transfer cells are monitored by cameras in the cells and onboard the lifting devices to detect abnormal operations. DPC storage activities in the vault are monitored by cameras and load cells onboard the lifting devices to ensure complete disengagement of the lifting device.

Operations: During DPC vertical vault storage operations, inbound transport or transfer casks with vertical DPCs are brought into the vertical cask unloading cell on a motorized cart and centered directly underneath the port in the cell ceiling. Horizontal DPCs in transport casks are downended on transfer carts, horizontally transferred into a lift frame, and upended underneath the port in the cell ceiling. In either case, the cell is then evacuated and the shield doors to the cell are closed.

In the meantime, the shielded transfer sleeve is set down on the shield plug in operating floor above the vault storage location to be loaded. The shield plug is rigged to the transfer sleeve, hoisted, and removed to a temporary storage location. After the shield plug is decoupled, the shielded transfer sleeve is moved into position over the transfer cell in which the inbound DPC is staged.

The sliding doors at the bottom of the shield sleeve are opened and the hoist lowers the lifting device into position, guided by visual observations from the cameras. The lifting device is aligned with the lifting lug(s) on the DPC or lift frame by small movements of the motorized cart on the rails in one direction and the top of the cart in the other. When alignment is achieved, the cart is locked into position, and the lifting device is lowered and actuated to grapple the lifting lug(s) on the DPC or lift frame. The success of the grappling operation is verified visually and by sensors on the lifting device. The DPC or lift frame is then raised up through the port and into the transfer sleeve. During the hoisting operation, the exposed surface of the DPC is visually inspected for condition and damage using the cameras. Once the DPC is verified to be fully raised by sensors and by visual observation, the sliding doors at the bottom of the transfer sleeve are closed and the sleeve is hoisted by the bridge crane, moved into position above the storage location in the vault, and set down in the recess in the operating floor. The sliding doors at the bottom of the sleeve are opened and DPC is lowered into the vault. Concentric internal guides around the bottom of the sleeve ensure that the DPC clears the lip of the hole in the vault operating floor. When the DPC is in position, resting on the floor of the vault, and verified to be by load sensor, the lifting device is released and the hoist retracted.

The transfer sleeve is then moved to the shield plug temporary storage location, the shield plug is rigged to the lugs near the bottom of the sleeve, and the shield plug is transferred to and placed in the hole in the operating floor above the storage location.

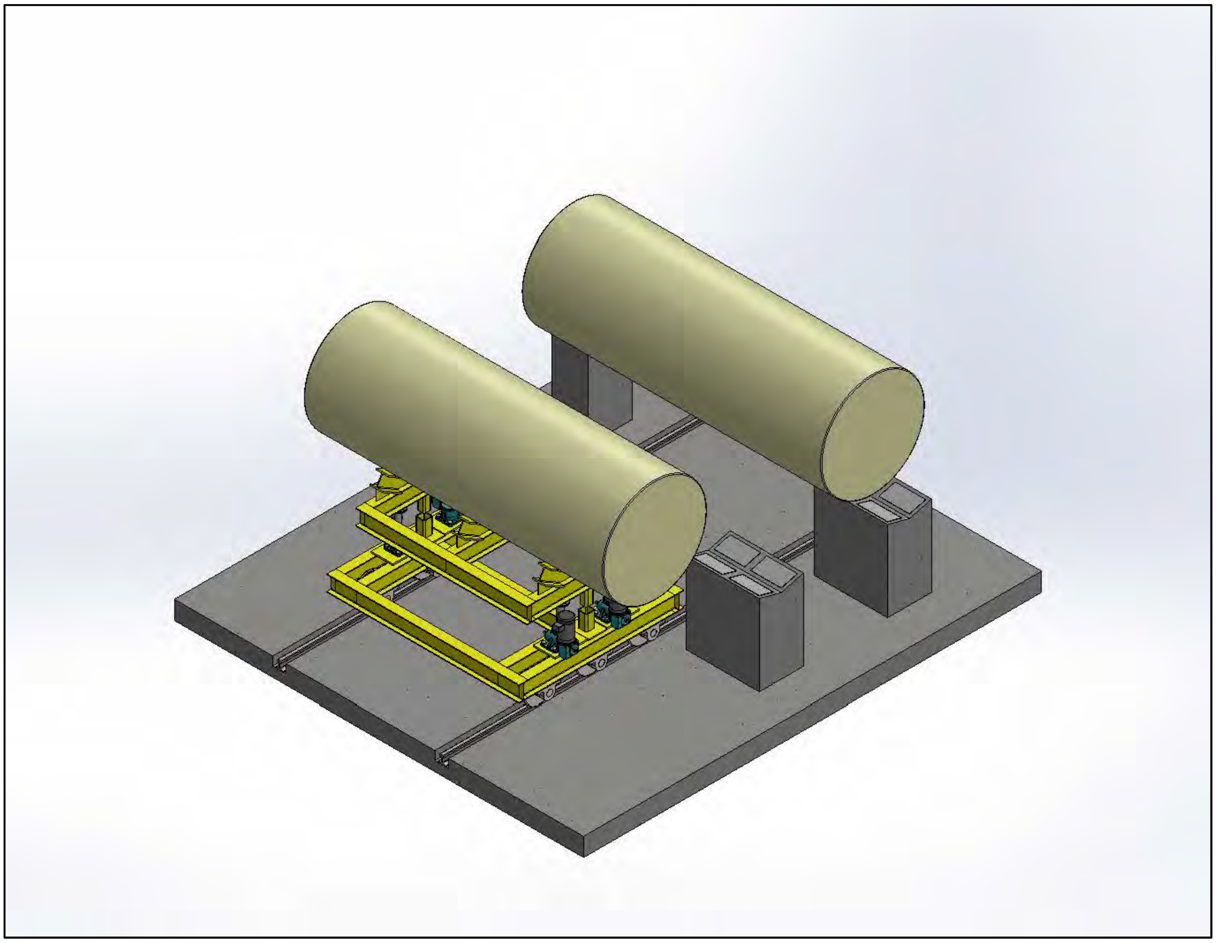
Maintenance: Preventive maintenance activities for the sleeve hoist include inspecting the wire rope and replacing it as required, lubricating mechanical drive components, and overhauling electric motors and brakes. Preventive maintenance activities for other sleeve components include lubricating drive mechanisms and overhauling motors for the shield doors on the bottom of the sleeve and replacing cameras, as required.

Testing: The ASME NOG-1 design code requires a prescribed set of functional tests which are applicable to hoisting equipment, including a no-load test in the shop and a no-load test, full load test, and 125% rated load test in the field. ANSI N14.6 requires a 150% Maximum Credible Load test to be performed prior to use, and annually thereafter. Rated load testing shall also be performed after major corrective maintenance.

Design Codes:

Hoisting Equipment – ASME NOG-1, Type I
Shield Sleeve and Rigging Design – ASME BTH-1
Shield Plug Rigging – ASME B30.9
Shield Door Drive Components - CMAA-70
Operations – ASME B30.16, B30.20
Testing – ASME B30.20, ANSI N14.6

6.5.2.15
Horizontal Vault DPC Transfer Cart



Storage Alternatives: CAGVb, CAGVd, CBGVb, CBGVd

Design Specs:	Cart Lift Capacity:	60T	
	Cart Velocity:	design load – 3 fpm	no load – 11 fpm
	Cart Dimensions:	width - 10'– 6"	length – 9' – 0"
	Cart Table Height:	lowered - 5' – 0"	raised – 6' – 0"
	Total weight:	design load – 130,125 lbs.	no load - 10,125 lbs.
	Wheel Load:	32,600 lbs.	

Process Functions: The horizontal DPC transfer cart is used to remotely place DPCs into horizontal storage in the above and below grade vaults. The DPCs are placed into storage vertically by lowering the DPCs onto elevated concrete pedestals. The horizontal vault is loaded from the far end; sequentially back to the end nearest the loading portal (e.g. first in / last out).

Safety Functions: The primary safety function for the transfer cart is to support the DPC during the transfer and placement process to maintain the integrity of the SNF confinement boundary. Event scenarios for which the transfer cart must be qualified include operational accidents, machine malfunctions, loss of power, and earthquakes. Safety features incorporated in the design to mitigate the consequences of these events include over-travel stops, fail-safe drives on the screw jacks which raise and lower the carriage and fail-safe electric brakes for the cart.

Description: The horizontal DPC transfer cart is a steel-framed, rail-based, motorized cart which is capable of placing and retrieving horizontal DPCs in underground vault storage. The carts run on rails which run longitudinally down the vault from a loading station near the center of the vault building to the far wall. There are four sets of rails, side-by-side, separated by concrete walls which support the ceiling overhead. The loading stations are separated from the main vault storage area by a rollup shield door, and from the personnel access area by a concrete shield wall. DPCs are loaded onto the carts by sliding them out of transport casks through portals in the concrete shield wall, similar to the way that horizontal DPCs are transferred into Horizontal Storage Modules on a pad. Rollers on the cart carriage reduce the friction associated with the sliding transfer. Fixed end of travel stops at the cart loading station ensure the axial positioning of the DPC on the cart carriage. Once the DPCs are loaded on the cart, the shield door to the portal must be closed before the rollup shield door opens, allowing the cart to enter the vault.

The DPCs are stored on v-shaped, concrete pedestals which radially center the DPCs and provide lateral restraint due to the inclined angle of the bearing reaction against the DPC surface. The cart transfers the DPCs down the vault with the carriage elevated such that the DPC clears the concrete storage pedestals. The cart stops when it reaches the last empty storage location, and the carriage is lowered by electric screw jacks until the DPC engages the concrete support pedestals on both sides. The carriage is fully lowered to ensure that it clears the bottom surface of the DPC, and then returns to the loading station.

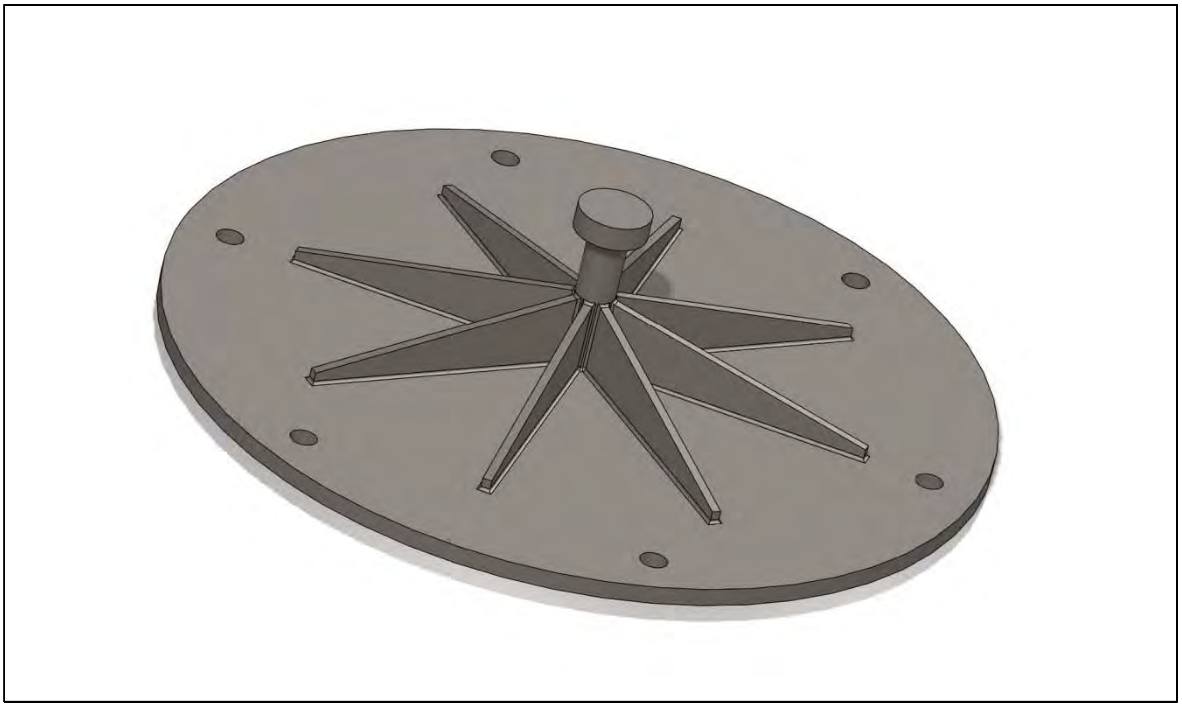
The horizontal DPC transfer cart has all electrically powered actuators, motors brakes, and controls. Power is supplied to each cart by a cable-trac system which runs beneath the cart and is recessed into the vault floor. The cart is controlled remotely by an operator who continuously monitors operations.

Maintenance: Preventive maintenance activities include periodic lubrication of cart bearings, overhauling the motors and brakes on the drives, replacing hydraulic cylinder seals, and changing filters and rebuilding pumps and motors on the hydraulic skid. Consumables in the transfer cart design include local filters and seal kits for the hydraulic cylinders. Maintenance is performed in the loading station with the rollup shield doors closed and additional shielding installed as required to reduce doses to a manageable level.

Testing: After construction, transfer cart power systems are subject to individual system continuity tests, as required by the applicable design codes. The entire transfer cart system will undergo integrated no-load and load testing during initial functional acceptance testing. Load testing should also be performed after corrective maintenance. There are no code-related periodic test requirements after the initial acceptance tests are complete.

Design Codes: Structural Framing and Welds - AISC N690
Mechanical Drive Components – CMAA-70

6.5.3.1
Vertical DPC Lifting Lug



Storage Alternatives: CPAD, CSTDa-c, CUGS, CAGVa-d, CBGVa-d

Design Specs:	Capacity:	55T
	Diameter:	5’– 7”
	Overall Height:	1’– 3½”
	Plate Thickness:	1.5”
	Weight:	1,675 lbs.

Process Functions: The vertical DPC lifting lug bolts to the top of vertical DPCs to allow them to be remotely hoisted out of transport or transfer casks by the shielded transfer cart and shielded transfer sleeve, and transferred to storage or transfer casks or placed directly onto the floor of the vault. For DPCs transferred to storage casks, the vertical DPC lifting lugs will be unbolted and removed after the transfer is complete. For DPCs placed in the vault, the lugs will remain in place throughout the storage period.

Safety Functions: The primary safety function for the vertical DPC lifting lug is to retain DPCs during hoisting operations in order to prevent load drops which could threaten the integrity of the SNF confinement boundary provided by the DPC. Event scenarios for which the lift lugs must be qualified include operational accidents, load excursions, and earthquakes.

Description: The vertical DPC lift lug is a below-the-hook lifting device which bolts to the top of vertical DPCs to allow hoisting by the grapple on shielded transfer carts and sleeves. Since bolt hole patterns vary among the different types of vertical DPCs to be hoisted, the lug must have multiple hole patterns and/or use slotted holes to be able to accommodate every DPC.

The lug is equipped with a cylindrical "button" on top of the lug which is grappled by a mating lifting device on the shielded transfer cart or sleeve hoists. The round design of the lug renders the grapple self-centering, and independent of directional orientation. The bottom of the button slopes up slightly toward the shaft to provide a positive locking action between the grapple and lug during lifting.

Operations: The lug is positioned on the top of the DPC using a jib crane which hoists it from the ground to the top of the DPC, swings it over the DPC, and lowers it into place. The lug is manually aligned with the bolt holes in the lid. Shield plugs in the top of the DPCs limit occupational exposures to the operators during the bolting and unbolting of the lug.

During hoisting operations, the DPC inside the cask is centered beneath the shielded transfer cart or sleeve. The grapple is lowered to a position just above the lug, and the cask is aligned with the lug to within an acceptable tolerance by moving the carts. The grapple is then fully lowered and actuated to grip the lug.

After hoisting is completed, the hoist is lowered to take the load off the lug and the grapple arms are fully opened. The hoist can then be retracted.

Maintenance: There are no preventive maintenance activities which must be performed for the vertical DPC lifting lug, other than periodic inspections and tests.

Testing: The vertical DPC lifting lug is subject to an initial 125% rated load test before service and after corrective maintenance. ANSI N14.6 requires a 150% Maximum Credible Load test prior to service, and annually thereafter.

Design Codes: Structural Framing and Welds – ASME BTH-1
Testing and Operations – ASME B30.20, ANSI N14.6

6.5.3.2
Horizontal DPC Lift Frame

Storage Alternatives: CUGS, CAGVa, CAGVc, CBGVa, CBGVc

Design Specs:			
	Capacity:	55T	
	Diameter:	inner - 5’– 8”	outer - 6’– 8.5”
	Overall Height:	16’– 6”	
	Tare weight:	4,800 lbs.	

Process Functions: The horizontal DPC lift frame is used to hoist horizontal DPCs which have been upended into a vertical position. The tops of horizontal DPCs are not designed to support the entire weight of the DPC and contents during hoisting like the tops of vertical DPCs are. Therefore, in order to transfer and store horizontal DPCs in a vertical orientation, external provisions for handling them vertically must be provided.

Safety Functions: The primary safety function for the horizontal DPC lift frame to retain DPCs during hoisting operations in order to prevent load drops which could threaten the integrity of the SNF confinement boundary provided by the DPC. Event scenarios for which the transfer casks must be qualified include operational accidents, load excursions, load drops, and earthquakes.

Description: The lift frame is a below-the-hook lifting device into which horizontal DPCs are inserted to enable them to be handled vertically. The frame consists of structural steel columns which span between top and bottom plates. The DPC is stored upside-down in the frame, therefore the bottom plate of the frame is designed to capture the top of the DPC around it's periphery to ensure it will remain in place. The upper plate is equipped with four lifting lugs located 90° apart, where the openings on adjacent lugs face each other. Three sets of v-rollers are built into the sides of the frame, to reduce friction during the DPC insertion process.

Operations: The lug is positioned on the top of the DPC using a jib crane which hoists it from the ground to the top of the DPC, swings it over the DPC, and lowers it into place. The lug is manually aligned with the bolt holes in the lid. Shield plugs in the top of the DPCs limit occupational exposures to the operators during the bolting and unbolting of the lug.

During hoisting operations, the DPC inside the cask is centered beneath the shielded transfer cart or sleeve. The grapple is lowered to a position just above the lug, and the cask is aligned with the lug to within an acceptable tolerance by moving the carts. The grapple is then fully lowered and actuated to grip the lug.

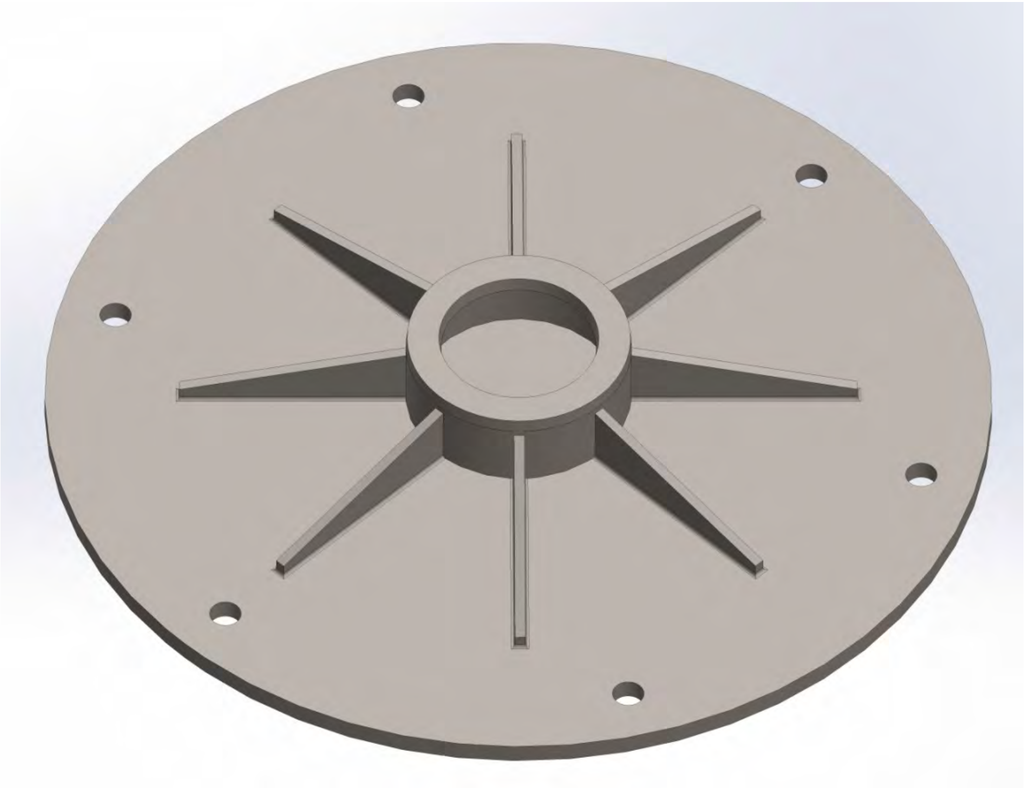
After hoisting is completed, the hoist is lowered to take the load off the lug and the grapple arms are fully opened. The hoist can then be retracted.

Maintenance: There are no preventive maintenance activities which must be performed for the horizontal DPC lift frame, other than periodic inspections and tests.

Testing: The horizontal DPC lift frame lug is subject to an initial 125% rated load test before service and after corrective maintenance. ANSI N14.6 requires a 150% Maximum Credible Load test prior to service, and annually thereafter.

Design Codes:
Structural Framing and Welds – ASME BTH-1
Testing and Operations – ASME B30.20, ANSI N14.6

6.5.3.3
Vertical DPC Pulling Lug



Storage Alternatives: CSTDc

Design Specs:	Capacity:	40T
	Diameter:	5'– 7"
	Overall Height:	1'– 3½"
	Plate Thickness:	1.5"
	Weight:	1,700 lbs.

Process Functions: The vertical DPC pulling lug bolts to the top of vertical DPCs to allow them to be remotely pulled into and out of transfer casks and horizontal storage modules for the storage alternative where vertical DPCs are stored horizontally. The lug has a grapple ring connection which engages the end of the rod on the hydraulic ram used to perform the transfers. The pulling lug remains in place on the vertical DPC throughout the storage period.

Safety

Functions: Since the vertical DPCs are completely supported by external means during transfers, the pulling lug is not credited with any safety functions.

Description: The vertical DPC pulling lug is a device which bolts to the top of vertical DPCs to provide a means to transmit forces to the DPC during horizontal transfers. The lug has a grapple ring connection on it which is identical to the grapple ring connection found on the bottom of horizontal DPCs. The connection is designed to transmit enough tension or compression force to overcome the frictional resistance of DPCs laying on their side, in order to push or pull DPCs from one cask into another. Pulling loads induce tension in the bolts attaching the lug to the DPC lid. Since it takes less force to slide the DPC than to lift it, the bolt pattern used on the vertical DPC lifting lug will be more than adequate to develop the tension required to overcome friction. For compression loading, the gusset plates on the top of the lug will distribute the concentrated compression load applied by the rod on the hydraulic ram.

Operations: The lug is positioned on the top of the DPC using a jib crane which hoists it from the ground to the top of the DPC, swings it over the DPC, and lowers it into place. The lug is manually aligned with the bolt holes in the lid. Shield plugs in the top of the DPCs limit occupational exposures to the operators during the bolting and unbolting of the lug.

During transfer operations, the DPC inside the cask is aligned and docked with the shielded sleeve on the transfer cart using a bolted docking collar. The rod on the hydraulic cylinder is extended through a port in the base of the shielded sleeve and engages the grapple ring connection on the lug. The rod is then retracted, pulling the DPC into the shield sleeve. Pushing the DPC out of the shield sleeve into a transfer cask is accomplished by performed the transfer operation in reverse.

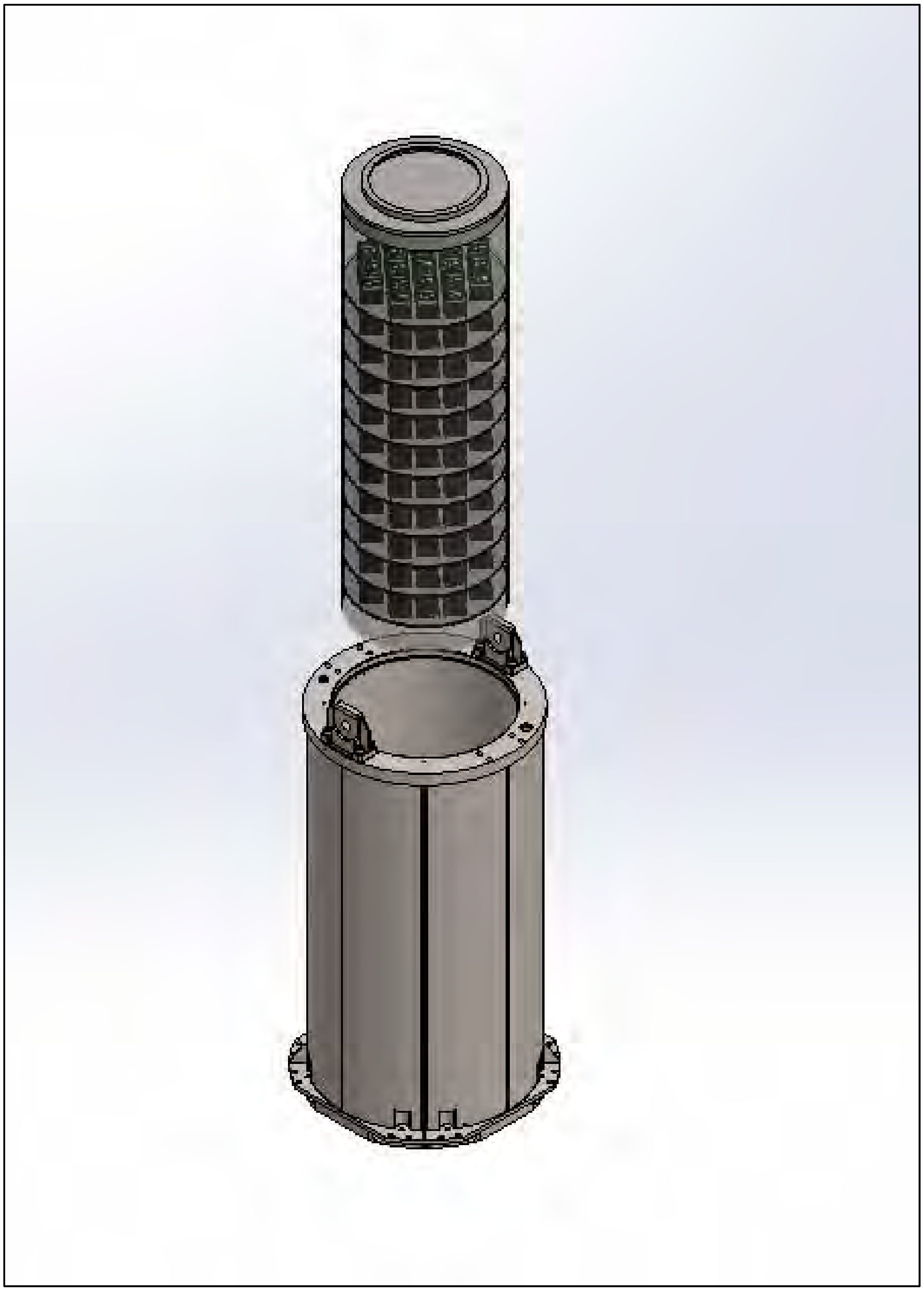
Maintenance: There are no preventive maintenance activities which must be performed for the vertical DPC pulling lug, other than periodic inspections and tests.

Testing: The vertical DPC pulling lug is not subject to any design code load testing, but an operability test at the rated load is recommended to verify structural capacity prior to service.

Design Codes:
Structural Framing and Welds – AISC Manual of Steel Construction
Testing and Operations – None

6.5.3.4

Vertical Transfer Cask



Storage Alternatives: CUGS, CAGVc, CAGVd, CBGVc, CBGVd

Design

Specs:	Diameter:	inner - 6’– 4.25”	outer - 8’– 4”
	Overall Height:	15’– 8”	

Weight: 120,725 lbs.

Process Functions: The vertical transfer cask is used to provide a safe, shielded means of transferring vertical DPCs from the Cask Handling Building to storage in individual underground vaults or above and below grade main vaults.

Safety Functions: The primary safety function for the vertical transfer cask is to retain DPCs during hoisting and transfer operations in order to prevent load drops which could threaten the integrity of the SNF confinement boundary provided by the DPC. Event scenarios which the transfer casks must be qualified for include operational accidents, load excursions, load drops, and earthquakes. The transfer cask must also provide shielding to prevent radiation from the SNF inside the DPC from over-exposing personnel in the vicinity of the cask.

Description: The vertical transfer cask is a container into which vertical DPCs are inserted to enable them to be hoisted and transferred in a vertical orientation. The cask is equipped with a bolted upper lid and a bottom lid which is removable, so DPCs can be transferred vertically into storage casks or individual underground storage vaults. The cask is equipped with lifting lugs to facilitate rigging for lifting operations. Shielding in the radial direction is provided by water volumes and by the steel in the cask walls.

Maintenance: There are no preventive maintenance activities which must be performed for the bottom lid and lifting lugs, other than periodic inspections and tests.

Testing: The bolted bottom lid and lifting lugs are subject to an initial 125% rated load test before service and after corrective maintenance. ANSI N14.6 requires a 150% Maximum Credible Load test prior to service, and annually thereafter.

Design Codes:
Structural Framing and Welds – ASME BTH-1
Testing and Operations – ASME B30.20, ANSI N14.6

6.5.3.5
Horizontal Transfer Cask

Storage Alternatives: CUGS, CAGVc, CBGVc

Design Specs:	Diameter:	inner - 7’– 4”	outer - 9’– 4”
	Overall Height:	18’– 8”	
	Weight:	160,000 lbs.	

Process Functions: The horizontal transfer cask is used to provide a safe, shielded means of transferring horizontal DPCs stored in a vertical orientation inside of a lift frame from the Cask Handling Building to storage in individual underground vaults or above and below grade main vaults.

Safety Functions: The primary safety function for the horizontal transfer cask is to retain DPCs during hoisting and transfer operations in order to prevent load drops which could threaten the integrity of the SNF confinement boundary provided by the DPC. Event scenarios for which the lift frames must be qualified include operational accidents, load excursions, load drops, and earthquakes. The transfer cask must also provide shielding to prevent radiation from the SNF inside the DPC from over-exposing personnel in the vicinity of the cask.

Description: The horizontal transfer cask is a container into which horizontal DPCs are inserted inside of lift frames to enable them to be hoisted and transferred in a vertical orientation. The cask is equipped with a bolted upper lid and a bottom lid which is removable, so DPCs can be transferred vertically into storage casks or individual underground storage vaults. The cask is equipped with lifting lugs to facilitate rigging for lifting operations. Shielding in the radial direction is provided by water volumes and by the steel in the cask walls.

Maintenance: There are no preventive maintenance activities which must be performed for the bottom lid and lifting lugs, other than periodic inspections and tests.

Testing: The bolted bottom lid and lifting lugs are subject to an initial 125% rated load test before service and after corrective maintenance. ANSI N14.6 requires a 150% Maximum Credible Load test prior to service, and annually thereafter.

Design Codes: Structural Framing and Welds – ASME BTH-1

Testing and Operations – ASME B30.20, ANSI N14.6

7.0 COSTS AND CONCLUSIONS

This section addresses comparisons among alternatives and various insights from the three studies, with focus on cost and schedule. Issues of throughput, manning requirements, and dose impacts to workers for various alternatives or combinations of alternatives are also addressed.

7.1 Cost Analysis

7.1.1 General Discussion of Costs

Task Order 16 required numerous capital, operational, decontamination and decommissioning (D&D) and life cycle cost analyses. The cost analyses have been approached from a top down perspective starting with the five separate storage alternatives including:

1. C-PAD Storage on ISFSI type pads either in a horizontal or vertical configuration. This is really three sub options including Vertical, Horizontal, and a mixture of the horizontal and vertical configurations.
2. C-STD storage on ISFSI type pads either in a vertical, horizontal or blended configuration. This option uses standardized overpacks as opposed to individualized overpack designs for each distinct manufacturer and canister configuration.
3. C-UGS is an underground storage system utilizing design similar or identical to the HOLTEC UMAX silo type storage system.
4. C-AGV is an above ground vault storage system, with the single building holding the module size of 450 canisters or approximately 5,000 MTHM.
5. C-BGV is essentially the same design as the Above Ground Vault storage design with the distinction that the operating floor is at ground level as opposed to 25 feet above the ground level.

Each of the main alternatives precipitates numerous sub-alternatives and differing design options. As an example, the vault storage systems may include either a steel superstructure or a concrete superstructure. Within each of the sub-alternatives, there can be design options for storage and handling capabilities.

Given the large number of alternatives, sub-options and design options (nearly 300 separate cases) this cost study focused on those that have distinct differences in capital and operational costs. If options do not show any cost differential, they are not presented.

Cost information is presented in two distinct views:

1. Modular costs for receipt and storage of 5,000 MTHM of SNF and GTCC waste in each of the five main alternatives. Costs for a First Module were distinguished from a Subsequent module. First module requires site development and cask handling capabilities, while a subsequent module only requires the additional storage capacity.

2. Total Pilot ISF and Expanded Pilot ISF costs. These costs include additional capital and operating costs that are not included in the modular costs developed in 1 above.

For each of the above noted approaches for the five main alternatives, sub-alternatives or design options, information was also developed related to a low seismic (0.25 g) implementation, as well as a high seismic implementation (0.75 g).

Cost information in this report is straightforward and uncomplicated to the extent practical. Substantial details on the supporting cost data are contained in the Appendices and original source files are available for DOE review.

Separate cost discussions for Study #1, Study #2 and Study #3 are provided.

7.1.2 Estimating Approach

Throughout the cost engineering process, cost information has been generated at the greatest level of detail for the given designs. As an example, the vault superstructure was estimated using concrete sections and costs per square foot for a steel superstructure. As later designs were developed, a more detailed estimate was produced using engineered sections and re-bar callouts and the detailed member sizing of the steel superstructure. This detailed analysis indicated that the earlier analyses were bounding and conservative compared to the more detailed take-offs and pricing.

As the work progressed, relevant cost references were identified for many of the cost elements (e.g., cubic yards of concrete materials, pounds of reinforcing steel, cost per linear foot of each structural steel member, labor costs for placement of concrete, forming, shoring, etc.). These cost references were adjusted for criteria applicable to a DOE site with a remote location and greater than commercial requirements. In many cases a factor a three was used for conversion of typical commercial construction costs to DOE and nuclear industry construction costs, which would be more applicable at the ISF.

A detailed explanation of how costs were developed and the assumptions included in the estimate are presented in the Basis of Estimates (BOE) for each Study in the sections below. Separate BOEs are provided for the modularized cost analysis, Pilot ISF cost estimates and Expanded Pilot ISF cost estimates.

While the point estimates are of most interest for comparison of options, certain options (AGV, BGV) will have greater uncertainties related to design, licensing and construction. As such, a range of costs were developed surrounding the point estimates which reflect many of these uncertainties. The range of costs is far greater for the vault options.

When assessing Management Reserve (MR) and Contingencies, values that are a percentage of the direct and indirect cost are applied. Typically a detailed risk analysis and an associated cost will be developed at a later date, starting at CD-1, and then managed in accordance with the Risk Management Plan throughout the remainder of the project. A formalized risk analysis is not included in the cost estimates presented in this report.

7.1.3 Reference for Cost Data

Cost references were developed using several sources as appropriate. This includes:

1. RS Means cost data factored up for DOE requirements and site location.
2. DOE Construction cost data from current projects was used where available.
3. Subject Matter Expert opinion was used where needed.

7.1.4 Basis of Estimate

The Basis of Estimate (BOE) contains the basic assumptions for each of the five main alternatives in Study #1 and four related alternatives in Study #3.

The project required modularized cost estimates for each option, sub option and variation of storage systems. To address these modular issues, the meaning of “module” needed to be defined. In defining what a module should consist of, the team assumed that the entire site development is handled separately by some prior or subsequent project. The storage module itself would include only work necessary to design, develop, license, and construct the storage system, along with a cask handling capability. The Cask Handling Building (CHB) could be either integral to the storage module, or separate from the storage module. In Study #2 alternative operational schemes are investigated which concentrate on differing methods of cask handling from no CHB through a fully remote cask handling operation.

For the purposes of this report, it was assumed that a “Module” would include the storage system for 5,000 MTHM or approximately 450 DPCs, as currently deployed throughout the fleet of commercial reactor sites. Additionally, the module would include the CHB, whether integral with the storage module or separated from the storage module. Site work to provide either rail access or transporter access to the storage unit would be part of the module cost. Along with these cost elements, limited site development for the module would include site utilities and security systems required for the storage module itself.

For each potential option, sub-option or variation, we have also considered the impacts of a First Module (FM) versus a subsequent module (SM) construction.

In addition to the direct capital costs of a module and its support systems, we have included the indirect costs associated with designing, licensing, start up, testing, and commissioning of a module. For the FM, the module bears the costs of design, licensing, public review, siting and numerous other first development costs. These costs are not amortized over subsequent modules, but are shown specifically assigned to the FM costs.

7.1.4.1 BOE for First or Subsequent Module Construction

For each of the basic five options we assumed that the CHB was located separate from the storage unit itself. The variation wherein the CHB is integral with the storage module was a sub-option or variation to the base case cost model.

Each module estimate is based upon conceptual sketches provided by the design team. The module costs take into consideration the initial analysis for seismic loading, thermal performance, and licensing ability. Many of the cost elements that differentiate one option from another are based upon subject matter expert (SME) expertise and opinion. Cost references where available, have been taken from numerous sources including RS Means and various DOE construction projects. In all cases we have attempted to normalize the unit costs for performance of work on a DOE site (usually a factor from 1.25 to 3 times a commercial rate to obtain an appropriate DOE site unit rate).

In the case of the AGV versus the BGV, it was determined that the AGV will be subject to higher seismic loading than the BGV fault. Therefore, simple basic assumptions have been made such as placing reinforcing within the concrete structure at 6 inches on the BGV which was assumed to be only 90% of what is used in the AGV. While this is a subtle difference between the two vault concepts, it does indicate a significant difference in the cost between the AGB and BGV. Estimates have been prepared for a large earthquake (0.75G) and the NRC required smaller earthquake (0.25G). The initial design assumptions for the smaller earthquake were bounding when compared against a detailed reinforcing steel details and specific structural steel design details. To estimate the larger earthquake, the structural costs for the vaults were increased by a factor of 1.5 times the bounding assumptions for the smaller earthquake.

Similarly the differences between an FM module and an SM module are substantial and are related to pre-construction costs such as design, siting, licensing, and analysis. Each case is presented as if it were a standalone project; and the total module costs includes the general costs of construction such as project management, construction management, field engineering, quality, safety, testing and project controls.

Each of the alternatives considered contain the same cost elements, including the following:

- Design Costs (First Module only)
- Licensing (First Module Only)
- Site Selection
- Public information and involvement
- Host Site management costs
- DOE, NRC and legal project related costs
- Construction and permit Costs
- Land Costs for 640 acres
- Site development costs for 250 Acres
- Offsite development for 20 miles
- Escalation for the 10 year Design/Construction Period
- Contractor held management reserve

Specifically excluded from module cost estimates are the following cost elements for the total project:

- Off-site roads or access
- Off-site utilities
- Rail access to site
- Site development
- Site utilities
- Support facilities other than the cask handling building
- Perimeter protection
- Roads and access on site
- Administration building
- Visitor center
- Security building
- All other facilities other than the cask handling building

All of these excluded costs are assumed to be part of a prior or subsequent project, so that a pure cost for each module (first or subsequent) is provided to DOE for analysis. Most of this development is required to operate any single module; however these costs are being collected and tabulated outside the costs of each module.

During the construction of a facility there will be significant indirect costs, which include the following:

- Project Management
- Construction Management
- Procurement and contracting
- Field Engineering
- Temporary facilities
- Construction Waste Management
- Quality Assurance
- Quality Control
- Integrated Safety management
- Document Control
- Site Access control
- Site security
- Construction Testing
- Insurance: General Liability, Workers Compensation, Builders Risk, Other
- Title III Engineering
- Engineering support to construction
- Utilities coordination
- Project Controls and reporting
- Temporary utilities
- Consumables & Office supplies
- Computers, printers, scanners, faxes, copiers and other office equipment

These costs will be encountered for both the FM and the SM modules.

7.1.4.2 BOE for PAD Storage (C-PAD, C-STD and S-PAD)

C-PAD storage was the basic design for the consolidated storage facility (CSF) design concept developed as part of Task Order 11. This design scheme has been used commercially at numerous nuclear reactors. The existing canisters and overpacks are placed on a 3 foot thick pad, which has been seismically designed and licensed. Each pad is wide enough to hold two canisters and overpacks, thus allowing access to each canister without having to relocate any, as might be required if we employed a “deep stack” arrangement. Gravel pathways are provided to allow movement of vertical cask transporter around each of the storage pads.

For the pilot plant, it was envisioned that approximately 450 storage locations are required whether they be vertical, horizontal, or a combination of the two. Each concrete pad supports storage of 50 DPCs and associated overpacks. Costs were developed for all horizontal or all vertical storage in the C-PAD option, but the Pilot and Expanded Pilot costs estimates are based on a 60% vertical and 40% horizontal development.

The C-PAD design consists of a number of pads each containing 50 vertical storage positions for the canister and over pack. Surrounding this module will be a radiation area boundary fence, which would then also be enclosed in a PIDAS (perimeter intrusion detection and security system). Each of these storage locations will be surrounded by a gravel pathway also known as the vertical task transporter haul path. The intent of the gravel is to provide a structurally sound base for the vertical cask transporter to place or remove a canister/over pack.

Each storage pad is three feet thick and has four layers of reinforcing mats with #11 Rebar at 12” on center each way (OCEW). Concrete is assumed to be of strength consistent with design specifications, which will likely have lower and upper limits on ultimate strength.

Separate from the C-PAD storage location will be the CHB. This is designed as a stand-alone facility. The offsite/on-site rail system will lead directly into the CHB for placement of rail car and loaded transport cask at the start point of the cask handling process.

In addition to the C-PADs and the CHB, other cost elements will be required to operate any C-PAD module. These cost elements include lighting around the perimeter of the storage area, electrical distribution within the CHB and storage area, security cameras and detection systems for the module itself, and other miscellaneous items directly related to the module operation. No operation or transportation costs are included in the module costs.

In the case of the horizontal storage design concept, the pads are larger than the pads for the vertical storage. Additionally, a 30-foot concrete apron is required for the transporter to load canisters into each horizontal storage unit. The net results are that there is substantially more concrete pad with the horizontal storage system than there is with the vertical storage system. Additionally, the overpack storage for horizontal systems is more costly than the vertical storage overpacks ($400K verses $300K for vertical).

Since both shutdown reactors and operating have both vertical and horizontal storage systems functioning today, accommodations will need to be made to store the fuel in both configurations to accommodate the fuel that is already in storage canisters at these reactor sites. As such, when the Pilot and Expanded Pilot Facility costs are presented for the C-PAD and C-STD options, it was assumed to have a 60/40% split of the vertical to horizontal canisters.

The facility with a combination of 60% vertical and 40% horizontal storage capabilities was developed as a sub-option for the pad storage concept. The single mixed module contains 450 storage units, which equates to approximately 250 vertical storage and 200 horizontal storage units in the combination module.

In addition to storing currently used commercial canister applications, PAD storage options with a standardized overpack design (C-STD) (both horizontal and vertical) were examined. This would require modifications in the facility including potentially larger pads for all storage locations.

Starting from these basic Design Study #1 PAD storage options (vertical, horizontal, 60/40% split, standardized vertical overpacks, or standardized horizontal overpacks), multiple variations related to task number three using smaller standardized canisters were developed for S-PAD in Design Study #3. TO 16 requested that three separate standardized canisters, small (4P/9B), medium (12P/32B) and large (21P/44B) canister sizes be assessed. Each of these storage configurations has significant impact on the design and cost for the S-PAD storage concept.

For each of the options/sub-options/variations, a FM cost as well as an SM cost estimate were generated. For each of these options, the common elements were the CHB, radiation area boundary, PIDAS, and site lighting/security costs. Some of these standard costs may vary depending on the area required for the specific PAD storage option/sub-option/variation.

7.1.4.3 BOE for Underground Storage (C-UGS and S-UGS)

The underground storage system (UGS) is based upon a proprietary system design by Holtec. This is effectively an underground silo installation using a proprietary piece of equipment known as a CEC. The proprietary system is also known as UMAX.

The system essentially consists of a 30 foot deep excavation, placement of a 7 foot thick foundation slab, installation of the 450 CEC (Cavity Enclosure Container) units, select backfill (concrete slurry) around the units and the placement of a 5 foot thick cap slab as the operating deck which completes the installation.

The C-UGS installation would have the same types of site development costs as the C-PAD storage systems including radiation area boundary fence, PIDAS, access routes from the cask handling building, and the CHB itself.

Operation of the UGS is achieved without a superstructure over the storage units. Canisters are transferred from the transport cask to a transfer cask in the CHB. Canisters are then placed into a vertical task transporter, which moves the canister to any one of the 450 storage locations. The costs of the Vertical Cask Transporter (VCT), and transfer casks are included in the module costs.

Advantages of the UGS System are lower seismic loads, enhanced radiation protection, and enhanced protection from naturally generated missiles (Hurricane, tornado) as well as man-made missiles including airplane collision.

While the system is designed specifically for vertical storage of canisters, horizontal canisters, currently stored at existing shutdown and operating nuclear plants could be stored in this system with the use of a lifting frame, which effectively converts the horizontal canister into a vertically stored canister. Since the basic scenario for the Pilot or Expanded Pilot includes 60%/40% vertical to horizontal systems, the estimate included the cost of 200 lifting frames for the Pilot Facility to store horizontal canisters in a vertical position. Each subsequent C-UGS module also included the cost for 200 lifting frames.

In addition to the basic unit using the commercially available vertical and horizontal canisters, TO 16 scope requires, as part of Design Study #3, that standardized canisters be investigated, in the small, medium, and large configurations discussed above, for the S-UGS concept.

When assessed as a “module” as opposed to a full Pilot or Expanded Pilot ISF, the costs associated with the engineering, licensing, CM, PM and field engineering are only included in the modular costs for those elements included in the cost for each module.

7.1.4.4 BOE for Above Grade Vault (C-AGV and S-AGV)

The above grade storage vault (C-AGV) system is essentially a large concrete box with dividers, intended to store 450 spent fuel canisters. The C-AGV system is approximately 25 feet tall from the mat foundation to the operating floor. While the design is still in the pre-conceptual stage, it was assumed that the foundation slab is seven feet thick, the operating floor is five feet thick, the walls are four feet thick, and divider fins between each storage vault are three feet thick. In the case of a concrete superstructure it was assumed that the roof is three feet thick. After assessment of numerous module options, a more detailed analysis was performed for the Pilot and Expanded Pilot Facility using an above grade vault with a steel superstructure. Modularized costs are provided for both the concrete superstructure and a steel superstructure.

While seismic, thermal, and licensing analyses are all pre-conceptual, it is assumed that the vault will be convectively cooled and active cooling and will not be required. The report design included heat shields where indicated by the thermal analysis in each of the storage cells. Essentially the vault system is subject to the same functional design criteria as the C-PAD system, which stores the canisters/overpacks in the open air subject to wind, rain, sleet, hail, and other natural phenomenon. The concrete vault replaces the overpacks for shielding and protection of the canisters from the elements and natural or manmade hazards such as hurricane driven missiles.

Above the operating deck is a superstructure. The superstructure can be either a poured in place concrete structure or a steel structure. Both options have been evaluated. Final numbers for the Pilot and the Expanded Pilot ISF have utilized a steel superstructure design.

Thermal modeling was conducted to determine if the bare canister concept within the vault is thermally feasible. The thermal evaluation concluded that heat shields would be required at specific locations to protect the structure from the thermal heat of the installed canisters. These shields are made of plate aluminum and are placed on the walls and the underside of the floor plugs.

The C-AGV is the template for all of all vault options being considered. The current conceptual design is identical for both the C-AGV and the C-BGV, with the only difference being that the operating floor is for the AGV is 25 feet above that the finished grade, while for the C-BGV the operating floor is at grade level.

The C-AGV would be subject to higher seismic loading than the below ground vault since it is higher. As such, it was assumed that additional levels of reinforcing in the concrete would be required to withstand more severe seismic loads. The report assumed that each horizontal and vertical concrete section has four mats of #11 bar placed at 6 inches OCEW. For the underground vault, with lower seismic loads, the same number of mats were used but it was assumed that only 90% of the rebar that is included in the AGV alternative would be required.

Seismic analysis was performed for a greater magnitude earthquake with a 0.75g design horizontal motion. The added rebar increased the structural costs by 50% to accommodate the larger earthquake. Detailed designs were not generated for the higher earthquake systems; however, the method of factoring up the structural costs is deemed appropriate from a cost perspective.

As with the C-PAD, C-STD storage and C-UGS options, the CHB is a part of the module cost for the C-AGV modular cost estimate.

7.1.4.5 BOE for Below Grade Vault (C-BGV and S-BGV)

The below grade vault (C-BGV) is very similar to the C-AGV with the distinction that the operating floor is at grade instead of 25 feet above grade. This simple distinction should lead to savings in structural costs for seismic requirements. For the purpose of this pre-conceptual effort, it was assumed that the reinforcing, while still substantial, is 90% of that used in the C-AGV systems. The C-AGV uses four mats of #11 reinforcing at 6” OCEW in every concrete section. The concrete sections assumed for the C-BGV are the same as for the C-AGV, with the mat foundation being 7ft., the walls 4 ft., the operating deck 5 ft. and the roof 3 feet thick concrete.

The C-BGV should have some advantages over the AGV in radiation shielding, protection from missiles both natural (hurricane, tornado) and man-made (airplanes crashes), since the storage area is below grade elevation.

The C-AGV and the C-BGV have a superstructure that can be either concrete or steel, and the operational methods can be either bridge crane or vertical cask transporter or both. For the final estimate of the Pilot and Expanded Pilot facilities, it was assumed that the vault utilized a steel superstructure design for the C-BGV.

As with the C-PAD, C-STD and C-UGS options, the report also assessed the capital cost differences between various vault options for storing standardized canisters for small, medium and large standard canisters in Design Study #3, S-BGV. The structural differences among the various standardized canister options are significant and show substantial capital cost differential.

7.1.4.6 BOE for Pilot ISF – Scope for Cost Analysis

The Pilot ISF was developed with the minimum capital costs required to effectively and efficiently handle and store 5,000 MTHM of SNF. As such, a number of cost elements that might be considered in a full implementation of an ISF are not included in the Pilot facility. The Pilot costs were developed in two general categories.

- <u>Initial Infrastructure Costs - Items common to all Alternatives and required prior to the first SNF receipt at the ISF</u>
    - Site Selection, Public Involvement
    - Land, roads, utilities, site PA security barriers and boundary
    - Railroad (20 mi) to ISF from mainline, rail yard
    - 20 miles of road and utilities to the site
    - Site design, licensing, construction indirect costs
    - Administrative, security and maintenance buildings, warehouse

- <u>Module Costs – Facilities required for the Pilot ISF operation:</u>
    - Storage Area for 450 canisters (1 module)
    - Cask Handling Building (CHB) and utilities
    - Security local to module, radiation area barrier
    - Overpack Fabrication area (C-PAD & C-STD overpacks only)
    - Concrete Batch Plant
    - Storage systems for 450 canisters (PADs, AGV, BGV, UGS)

- <u>Excluded Scope - Capital costs for all Pilot ISF options:</u>

    - Rail rolling stock
    - Transport Casks
    - Rail and Cask Maintenance Facilities
    - Repackaging costs

  - Transportation Costs
  - Bare fuel handling capabilities and pool facilities
  - Hot cell facilities
  - Consent-based siting process, community support
  - Any other cost prior to "decision to proceed"

7.1.4.7 BOE for Expanded Pilot ISF – Scope for Cost Analysis

The Expanded Pilot ISF is comprised of all the scope within the Pilot facility plus one additional storage module and a few additional site buildings and utilities expansion. A detailed BOE is contained in Appendix A6 "Cost Details." The following summary details demonstrate what is included and excluded from the Expanded Pilot ISF.

- <u>Initial Infrastructure Costs (items common to all Alternatives)</u>
  - Site Selection, Public Involvement
  - Land, roads, utilities, site PA security barriers and boundary
  - Railroad (20 mi) to ISF from mainline, rail yard
  - 20 miles of road and utilities to the site
  - Site design, licensing, construction indirect costs
  - Administrative, security and maintenance buildings, warehouse visitor center

- <u>Module Costs – Facilities required for the Expanded Pilot ISF operation:</u>
  - Storage Area for 900 canisters (2 modules)
  - Security local to module, radiation area barrier
  - Overpack Fabrication area (C-PAD & C-STD overpacks only)
  - Two Concrete Batch Plants
  - Storage systems for 900 canisters (PADs, AGV, BGV, UGS)

- <u>Excluded Scope - Capital costs for all Pilot ISF options:</u>
  - Rail rolling stock
  - Transport Casks
  - Rail and Cask Maintenance Facilities
  - Repackaging costs
  - Transportation Costs
  - Bare fuel handling capabilities and pool facilities
  - Hot cell facilities
  - Consent-based siting process, community support
  - Any other cost prior to "decision to proceed"

7.1.5 Annual Operating and Maintenance (O&M) Costs

The annual operating costs are prepared based on the resources needed to staff the facility and conduct all operations and maintenance activities. O&M cost details are presented in Appendix A6 for each of the Study #1 Alternatives, Appendix B5 for each of the Study #2 Alternatives and C5 for each of the Study #3 Alternatives.

Operational costs are initiated in the final year of construction for purposes of training, and support of the construction completion activities. During the startup and commissioning year a full operational staff is present and assisting in the startup and commissioning of the facility.

Following the startup additional personnel are brought on board for the loading of SNF into the facility storage locations. This staff is assessed separately as it is a short-term manpower loading and is eliminated after completion of the load in phase. In the case of a Pilot facility (5,000 MTHM) we have assumed a three-year load-in, while for an Expanded Pilot Facility (10,000 MTHM) we have assumed a six-year load-in program.

Following completion of the load in activities, the operational staff is reduced to a minimum staffing level to maintain a secure facility. While the facility may be further expanded, necessitating more construction, engineering, cask handling, and other activities not included in the Pilot or Expanded Pilot Facility (Labs, Hot Cells, Pool transfer, etc.), we have included only the minimal staff required to monitor and secure the storage facility assuming no other activities on the site, following load-in.

7.1.6 Total Estimated Costs (TEC)

The Total Estimated Cost (TEC) includes all design, licensing, construction, and turnover/startup. The TEC also includes any contractor held Management Reserve (MR) and contractor fees.

TEC details are presented in Appendix A6 for each of the Study #1 Alternatives, Appendix B5 for each of the Study #2 Alternatives and C5 for each of the Study #3 Alternatives.

7.1.7 Total Project Costs (TPC)

The Total Project Cost (TPC) includes all the costs in the TEC plus the DOE operations, DOE held contingency and the DOE Other Project Costs (OPC). The TPC is the cost number carried forward as the total capital costs when considering the Life Cycle Cost Analysis.

TPC details are presented in Appendix A6 for each of the Study #1 Alternatives, Appendix B5 for each of the Study #2 Alternatives and C5 for each of the Study #3 Alternatives.

7.1.8 Total Life Cycle Costs

A life cycle cost analysis was produced for each of the alternatives for an operating life of 40 years and 80 years. These Life Cycle costs were developed and are presented herein.

In all cases, whether Pilot or Expanded Pilot, Low or High Seismic, it was assumed that the design and construction is competed in 10 years, the facility operates for the designated operating life and then a D&D effort is undertaken to return the site to a brown field condition. Therefore, for a 40 year operating life, the total life cycle cost analysis will include costs for 55 years of the facility life including 10 years in design and construction and 5 years in D&D.

The most significant cost in the Life Cycle Cost is the dollar amount associated with inflation. It was assumed there is a 2% year over year escalation of costs from the beginning of the design/construction phase until the completion of the D&D phase.

7.2 Design Study #1 Costs

Design Study #1 assessed the costs for five basic alternatives as follows:

- C-PAD, Commercial DPCs stored on a Pad
- C-STD, Commercial DPCs stored in Standard Overpacks on a Pad
- C-UGS, Commercial DPCs stored in an underground storage system
- C-BGV, Commercial DPCs stored in a below grade vault
- C-AGV, Commercial DPCs stored in an above grade vault

The initial requirement for the throughput of the CHB was 1,500 MTHM per year. As designed in this report, the CHB can handle almost 3,000 MTHM per year, on a single shift basis. Given these capabilities, the CHB remains unchanged as it was determined that increased number of large STAD canisters (526 canisters in lieu of 450 DPCs) is only 17% greater than the total cask handling operations. Obviously the small STAD canister places the greatest operational load on the CHB at over 6 times the total cask handling operations as the Study #1 Commercial Canisters.

Costs for a modular implementation with just the costs of the storage unit alone, together with a CHB, as the two cost elements of a module were determined. In each case the First Module (FM) and a Subsequent Module (SM) were analyzed. The TEC includes all design, licensing, construction, and turnover/startup. The TEC also includes any Contractor held Management reserve (MR) and contractor fees.

The Total Project Cost (TPC) includes all the costs in the TEC plus the DOE operations, DOE held contingency and the DOE Other Project Costs (OPC). **Table 7-1** presents the costs for the 5,000 MTHM Pilot ISF in a low seismic location. **Table 7-2** presents the costs for the 5,000

MTHM Pilot ISF in a high seismic location. **Table 7-3** presents the costs for the 10,000 MTHM Expanded Pilot ISF in a low seismic location. **Table 7-4** presents the costs for the 10,000 MTHM Expanded Pilot ISF in a high seismic location.

The tables show capital costs, operations and maintenance (O&M) costs, decontamination and decommissioning (D&D) costs, and life cycle costs. All dollars are in present value (PV) **CY2014 dollars** except the annual operating and maintenance costs and the life cycle cost noted as escalated value (EV). See Appendix A6 for details.

Table 7-1
Pilot ISF Comparative Costs ($M) Using Commercial DPCs in a Low Seismic Area

Alternative	Capital Cost	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-PAD	$780- $970	$39	$91	$1,226 $2,177 (EV)	$1,429 $4,252 (EV)
C-STD	$809 - $998	$40	$93	$1,269 $2,254 (EV)	$1,481 $4,411 (EV)
C-UGS	$793 - $990	$39	$118	$1,152 $2,213 (EV)	$1,290 $4,293 (EV)
C-BGV	$784 - $1,252	$39	$187	$1,178 $2,387 (EV)	$1,299 $4,657 (EV)
C-AGV	$838 - $1,383	$39	$181	$1,222 $2,437 (EV)	$1,345 $4,691 (EV)

Table 7-2
Pilot ISF Comparative Costs ($M) Using Commercial DPCs in a High Seismic Area

Alternative	Capital Cost	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-PAD	$863 - $1,076	$39	$104	$1,229 $2,309 (EV)	$1,377 $4,422 (EV)
C-STD	$892 - $1,112	$40	$105	$1,260 $2,373 (EV)	$1,414 $4,567 (EV)
C-UGS	$846 - $1,056	$39	$140	$1,208 $2,338 (EV)	$1,341 $4,487 (EV)
C-BGV	$852 - $1,368	$38	$187	$1,236 $2,469 (EV)	$1,358 $4,740 (EV)
C-AGV	$875 - $1,414	$39	$187	$1,256 $2,497 (EV)	$1,378 $4,740 (EV)

Table 7-3
Expanded ISF Comparative Costs ($M) Using Commercial DPCs in a Low Seismic Area

Alternative	Capital Cost	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-PAD	$1,094 - $1,347	$77	$161	$1,486 $2,796 (EV)	$1,622 $5,085 (EV)
C-STD	$1,153 – 1,418	$77	$164	$1,554 $2,916 (EV)	$1,697 $5,292 (EV)
C-UGS	$1,099- $1,353	$77	$170	$1,472 $2,779 (EV)	$1,599 $5,021 (EV)
C-BGV	$1,055- $1,780	$77	$232	$1,463 $2,888 (EV)	$1,576 $5,298 (EV)
C-AGV	$1,157 – 1,985	$77	$232	$1,552 $3,013 (EV)	$1,664 $5,422 (EV)

Table 7-4
Expanded ISF Comparative Costs ($M) Using Commercial DPCs in a High Seismic Area

Alternative	Capital Cost	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-PAD	$1,170 - $1,445	$77	$179	$1,560 $2,938 (EV)	$1,692 $5,283 (EV)
C-STD	$1,228 - $1,515	$77	$182	$3,058 $3,058 (EV)	$1,767 $5,490 (EV)
C-UGS	$1,136 - $1,359	$77	$179	$1,508 $2,848 (EV)	$1,633 $5,118 (EV)
C-BGV	$1,143 - $1,944	$77	$247	$1,546 $3,035 (EV)	$1,656 $5,490 (EV)
C-AGV	$1,194 - $2,043	$77	$259	$1,596 $3,132 (EV)	$1,703 $5,626 (EV)

Notes:

- C-PAD, C-UGS have been licensed, built and operated. All Engineered Equipment (Overpacks/CECs) is included in Capital Cost. Upper estimate reflects lower risk of licensing, constructability and operability.
- There is greater uncertainty on the Vault estimates, since they have not been licensed, built, or operated.
- Life Cycle costs are based on the Point Estimate for Capital Cost
- O&M costs are measured during load in period and include cask handling costs. Costs following load in are lower.

Appendix A6 contains details of the capital costs, O&M costs, D&D costs and the life cycle cost for each of the Study #1 alternatives.

7.3. Study #2 Cost Impacts

Design Study #2 estimated the costs of the four operation alternatives as follows:

- C-OPS Conventional within a CHB
- A-OPS Automated handling within a CHB
- R-OPS Remote handling within a CHB
- S-OPS Simplified handling operations

When assessing the costs associated with each of the Study #2 alternatives it is important to note that all the cost variance resides within the cask handling operations, costs of the cask handling building (CHB) and associated modifications or enhancements to the CHB.

In S-OPS, the cask handling building is not constructed and the ISF operations is initiated at the lowest costs option using techniques that are currently in use at operating reactor sites. S-OPS represents the lowest cost operational scenario for the Pilot ISF because there is minimal development cost and utilization of mobile lifting equipment to effect the transfer of DPCs from the transport cask into the storage overpack. The lack of a cask handling building in S-OPS eliminates a substantial capital cost and minimizes the time required to implement an operational ISF.

Operational steps are more substantial for C-OPS and S-OPS, which include time for stacking the transport and transfer casks and the placement operations into the storage overpacks. Operations staff is increased somewhat over the alternatives with the cask handling building.

Costs associated with the storage systems, whether PAD, STD, UGS, AGV or BGV, remain unchanged; and the only cost variations occur in the cask handling capabilities and the cask handling operations. As such, the Design Study #2 alternatives are based on the C-PAD storage option, with variations in the cask handling methods.

For the C-OPS, A-OPS and the R-OPS where a cask handling building is incorporated into the capital costs, there are small variations in the staffing and overall operational costs. The benefits to implementing the A-OPS or the R-OPS reside in lower staffing levels and reduced radiation exposure to the operational staff.

Table 7-5 shows a summary of the Total Project Cost (TPC) for the Design Study #2 alternatives cost estimates, which are based on the Pilot facility capacity of 5,000 MTHM and lower seismic criteria.

Appendix B5 contains details of the capital costs for each of the Study #2 alternative.

Table 7-5
Summary of Total Project Costs for the Study #2 Operation Alternatives

Alternative	Capital Cost	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-OPS	$795 - $1,001	$39	$91	$2.009	$3,205
A-OPS	$801 - $1,008	$39	$91	$2.016	$3,212
R-OPS	$812 - $1,015	$39	$91	$2,025	$3,221
S-OPS	$653 - $820	$51	$73	$1,812	$3,045

7.4 Study #3 Standard Canisters (STADs) Cost Impacts

Design Study #3 estimated the costs of the following four alternatives using Standardized Transport, Aging and Disposal (STAD) canisters in lieu of the commercial canisters currently in use:

- S-PAD, STAD canisters stored on a Pad
- S-UGS, STAD canisters stored in an underground storage system
- S-BGV, STAD canisters stored in a below grade vault
- S-AGV, STAD canisters stored in an above grade vault

There are numerous cost impacts from using STAD canisters. These cost elements include:

1. Original loading of STAD canisters
2. Repackaging of existing canisters
3. Storage costs at reactor sites
4. Transportation costs to ship to ISF
5. Increased Rolling stock and Transportation Casks
6. Increased handling at the ISF
7. Increased costs of the ISF storage systems
8. Shipment from ISF to repository

Only items 6 and 7 are reflected in the cost analyses presented in this report.

The primary cost driver of the use of smaller STAD canisters is in the cost of engineered equipment such as overpacks (pad storage), CECs (underground storage silos) or vaults. The smaller canister capacity is reflected in the increased number of canisters required to storage 5,000 MTHM of SNF as follows:

Approximate number of canisters required to store 5,000 MTHM:

Commercial DPCs	450
Small STAD canister	2,778
Medium STAD canister	926
Large STAD canister	526

The increased number of STAD canisters is reflected directly in the number of pads or underground silos that are constructed, and by the vault length, which grows from 800 ft. to 1500 ft. for the smallest canister. Even when unit costs are reduced by 50%, the total engineered equipment costs increase by a factor of four.

The TEC includes all design, licensing, construction, and turnover/startup. The TEC also includes any contractor held Management Reserve (MR) and contractor fees. All assumptions for Study #3 are similar to those of Study #1, with the exception of the unit costs of the engineered equipment. As smaller canisters are used, the pricing for the overpacks or underground silos is assumed to decrease due to smaller sizes and economy of scale due to the manufacture of greater numbers.

While the size of the storage units increases as smaller STAD canisters are employed, it was assumed that the CHB remains unchanged. The smaller STAD canisters require added time in cask handling operations and thus increase the annual operating and maintenance (O&M) costs.

The initial requirement for the throughput of the CHB is 1,500 MTHM per year. As designed in this report, the CHB can handle almost 3,000 MTHM per year, on a single shift basis. Given these capabilities, the CHB remains unchanged, as it was determined that increased number of large STAD canisters (526 canisters in lieu of 450 DPCs) is only 17% greater than the total cask handling operations. Obviously the small STAD canister places the greatest operational load on the CHB, at over six times the total cask handling operations as compared to the Study #1 Commercial Canisters.

The Total Project Cost (TPC) includes all the costs in the TEC plus the DOE operations, DOE held contingency and the DOE Other Project Costs (OPC). The summary of TPC costs is shown below in **Table 7-6.**

Appendix C5 contains details of the capital costs, O&M costs, D&D costs and the life Cycle cost for each of the Study #3 cases.

Table 7-6
Study #3 – Pilot Facility Costs using STAD canisters, Low Seismic

Alternative	Description	Capital Costs	Annual O&M Cost	D&D Cost	40 Year LCC	80 Year LCC
C-PAD	DPC	$780 - $970	$39	$91	$1,226 $2,177 (EV)	$1,429 $4,252 (EV)
S-PAD	Large STAD	$895 - $ 1,108	$39	$96	$1,333 $2,331 (EV)	$1,534 $4,421 (EV)
S-PAD	Med. STAD	$1,153 - $1,417	$39	$123	$1,580 $2,714 (EV)	$1,776 $4,885 (EV)
S-PAD	Small STAD	$962 - $1,188	$39	$171	$1,435 $2,612 (EV)	$1,622 $4,928 (EV)
C-UGS	DPC	$796 - $990	$39	$118	$1,152 $2,213 (EV)	$1,290 $4.293 (EV)
S-UGS	Large STAD	$890 - $1,106	$39	$110	$1,233 $2,309 (EV)	$1,372 $4,365 (EV)
S-UGS	Med. STAD	$935 - $1,332	$39	$131	$1,281 $2,419 (EV)	$1,416 $4,537 (EV)
S-UGS	Small STAD	$1,726 - $2,108	$39	$215	$2,003 $3,605 (EV)	$2,120 $5,984 (EV)
C-BGV	DPC	$748 - $1,252	$39	$187	$1,178 $2,387 (EV)	$1,299 $4,657 (EV)
S-BGV	Large STAD	$795 - $1,274	$39	$133	$1,163 $2,256 (EV)	$1,295 $4,364 (EV)
S-BGV	Med. STAD	$823 - $1,328	$39	$144	$1,192 $2,318 (EV)	$1,322 $4,459 (EV)
S-BGV	Small STAD	$879 - $1,434	$39	$211	$1,271 $2,567 (EV)	$1,287 $4,911 (EV)
C-AGV	DPC	$838 – 1,383	$39	$181	$1,222 $2,437 (EV)	$1,345 4,691 (EV)
S-AGV	Large STAD	$840 - $1,387	$39	$138	$1,204 $2,324 (EV)	$1,335 $4,448 (EV)
S-AGV	Med. STAD	$844 - $1,392	$39	$149	$1,212 $2,357 (EV)	$1,341 $4,513 (EV)
S-AGV	Small STAD	$906 - $1,515	$39	$191	$1,285 $2,545 (EV)	$1,406 $4,829 (EV)

Notes:

- Small STADs require a 4-pack multi-can container or 8-pack block overpack system.
- O&M costs are measured during load in period and include cask handling costs. O&M costs are lower following load in period.

7.5 Schedule

The time to design, license and construct the Pilot ISF is significantly impacted by the alternative selected. NRC licensing is expected to have significant impacts on schedule. Overall project schedules can become protracted when a Site Specific ISFSI license is reviewed and subject to the Atomic Safety Licensing Board (ASLB) hearings which invite public review and potential contentions. In addition, the schedule is impacted when NRC is asked to review and approve new technology, or to review design or operational approaches that lack a track record or operating experience. STAD options evaluated in Study #3 will require extensive design and licensing work. Other, less onerous issues that could cause additional licensing time include storing fuel contained in horizontal canisters in a vertical configuration and storing vertical canisters in a horizontal configuration.

There are a number of approaches that could impact schedule, including considerations outside the scope of this report (e.g., government project rules vs. commercial projects that can start site preparation and early construction activities “at risk” while licensing efforts are in progress).

Figure 7-1 below shows each storage option from Study #1 + Study #2 and the estimated time frame until Pilot ISF operation can begin.

NOTE - Time zero cannot start until the site is selected, environmentally investigated, approved and given a ‘Decision to Proceed’ recommendation.

Figure 7-1
Study #1 + Study #2 – Estimated Schedule Duration for the Start of the Pilot ISF Operations

ID	Task Name	Duration
1		
2	C-PAD + S-OPS Transfer - No Cask Handling Bldg	2340 days
3	Engineering and Licensing	520 days
4	Construction	780 days
5	Start Operations	0 days
6	Operation - Initial Pilot ISF	1300 days
7		
8	C-PAD + C-OPS Transfer - w/ Cask Handling Bldg	2860 days
9	Engineering and Licensing	780 days
10	Construction	1040 days
11	Start Operations	0 days
12	Operation - Initial Pilot ISF	1300 days
13		
14	C-STD existing cask+ S-OPS Transfer - No Cask Handling Bldg	2600 days
15	Engineering and Licensing	780 days
16	Construction	780 days
17	Start Operations	0 days
18	Operations - Initial Pilot ISF	1300 days
19		
20	C-STD existing cask + C-OPS Transfer - w/ Cask Handling Bldg	2860 days
21	Engineering and Licensing	780 days
22	Construction	1040 days
23	Start Operations	0 days
24	Operation - Initial Pilot ISF	1300 days
25		
26	C-STD new cask + C-OPS Transfer - w/ Cask Handling Bldg	3120 days
27	Engineering and Licensing	1040 days
28	Construction	1040 days
29	Start Operations	0 days
30	Operation - Initial Pilot ISF	1300 days
31		
32	C-UGS + S-OPS Transfer - No Cask Handling Bldg	2600 days
33	Engineering and Licensing	780 days
34	Construction	780 days
35	Start Operations	0 days
36	Operation - Initial Pilot ISF	1300 days
37		
38	C-UGS + C-OPS Transfer - w/ Cask Handling Bldg	2860 days
39	Engineering and Licensing	780 days
40	Construction	1040 days
41	Start Operations	0 days
42	Operation - Initial Pilot ISF	1300 days
43		
44	C-BGV / C-AGV + C-OPS Transfer - w/ Cask Handling Bldg	3640 days
45	Engineering and Licensing	1040 days
46	Construction	1300 days
47	Start Operations	0 days
48	Operation - Initial Pilot ISF	1300 days

Quickest Alternatives to Implement
This is Base Case

Add 1 yr to design and license Cask Handling Bldg
Add 1 yr to construct Cask Handling Bldg

Use HI-STORM or MAGNASTOR cask for STD overpack
Add 1 year to license cask for use with all canisters

Use HI-STORM or MAGNASTOR cask for STD overpack
Add 1 year to license cask for use with all canisters
Add 1 year to construct Cask Handling Bldg

Add 2 years to design and license new STD overpack
Add 1 year to construct Cask Handling Bldg

Add 1 year to license UMAX for all canisters

Add 1 year to license UMAX for all canisters
Add 1 year to construct Cask Handling Bldg

Add 2 years to design and license vault
Add 2 years to construct vault
No early start - vault must be completely constructed for operation

Project: TO16 Pilot ISF Schedule	Task	Progress	Summary	External Tasks	Deadline
	Split	Milestone ◆	Project Summary	External Milestone ◆	

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7.6 Staffing Requirements and Throughput

The ISF operates 24-hour, 7-days a week basis, but cask handling operations were limited to a single 8-hour shift, 40-hour work week. This was done because deliveries of transport casks to the site do not warrant around-the-clock cask handling operations. It also provided the ability to accommodate surges of work that might be necessary by adding additional cask handling crew shifts.

There are two phases to ISF operations: Cask Handling Operations and Storage Facility Surveillance and Maintenance Operations. The Cask Handling Operations are the activities necessary to accept transport casks from nuclear plants and to place the canisters in them into interim storage on site. In addition, there are other supporting activities such as storage overpack fabrication, procurement to support the overpack production, maintenance of equipment, planning and scheduling, engineering, record keeping, physical security of the site and management.

The time and motion study identified all of the steps necessary to be performed in sequence in order to move the canisters from the railbay to the pad. In addition to the sequencing and timing, the staff required for each step was developed from the experience with operating nuclear plant ISFSI operations. In the time and motion study, the number of people and the time required for each step was used to determine the throughput and the total staffing requirement.

The design basis throughput for the Pilot ISF is 1,500 MTHM/yr. Later, the throughput is expected to grow to 3,000 MTHM/yr. or 4,500 MTHM as required. **Table 7-7 through Table 7-9** show a summary of the number of workers that were determined required for each storage and operational alternative. The table also shows the maximum throughput of the alternatives. A minimum throughput of 5 canisters processed a week is required to obtain 3,000 MTHM per year. The table also shows the processing structures or equipment that is required to achieve 3,000 MTHM per year throughput.

Table 7-7
Study #1 – Summary of ISF Staff and Throughput

Alternative	Total ISF Staffing (workers)	Max. Throughput (DPCs/week)	ISF Requirements
C-PAD, Pad Storage w/ DPCs	196	5	CHB w/ 2 RR bays, 2 cranes, 4 HCTs, 3 VCTs
C-STD, Standard Overpack w/ DPCs	201	5	CHB w/ 2 RR bays, 2 cranes, 4 HCTs, 4 VCTs
C-UGS, Underground Storage w/ DPCs	185	5	CHB w/ 2 RR bays, 2 cranes, 4 VCTs
C-BGV, Below Grade Vault w/ DPCs	164 integral CHB 182 external CHB	2.5 integral CHB 5 external CHB	CHB w/ 2 RR bays, 2 cranes, 2 VCTs
C-AGV, Above Grade Vault w/ DPCs	Same as C-BGV		

Table 7-8
Study #2 – Summary of Operations Throughput

Alternative	Max. Throughput (DPCs/week)	ISF Requirements
C-OPS, Current Canister Transfer	5	CHB w/ 2 RR bays, 2 cranes, 4 HCTs, 4 VCTs
A-OPS, Automated Canister Transfer	5	CHB w/ 2 RR bays, 2 cranes, 4 HCTs, 3 VCTs
R-OPS, Remote Canister Transfer	5	CHB w/ 2 RR bays, 2 cranes, 4, HCTs, 4 VCTs
S-OPS, Simplified Canister Transfer	5	2 Gantry Cranes, 2 Outdoor Canister Transfer Facilities, 2 HCTs, 2 VCTs

Table 7-9
Study #3 – Summary of ISF Staff and Throughput

Alternative	Total ISF Staffing (workers)	Max. Throughput (DPCs/week)	ISF Requirements
S-PAD, Pad Storage w/ DPCs	193	5*	CHB w/ 2 RR bays, 2 cranes, 3 VCTs
S-UGS, Underground Storage w/ DPCs	173	5*	CHB w/ 2 RR bays, 2 cranes, 4 VCTs
S-BGV, Below Grade Vault w/ DPCs	151 integral CHB	2.5 integral CHB	CHB w/ 2 RR bays, 2 cranes, 2 VCTs
	181 external CHB	5 external CHB	
S-AGV, Above Grade Vault w/ DPCs	Same as C-BGV		

* Note: Throughput is 1 large STAD, 1 medium STAD or 4-pack small STAD multi-can container.

7.7 Dose Impacts on Workers

The exposures to radiation for the workers at the ISF were based on the time and motion study and the assumed average dose rates from the canisters stored at the site. Once installed in their storage overpack, the doses to workers and to the public are quite small. However, during Cask Handling Operations, workers need to work on top of canisters and near the transport cask and the transfer casks.

The time and motion study determined the number and type of staffing for each activity associated with processing a canister. These values were further decomposed into the individual sub-activities necessary and the location of each member of the staff relative to the canister. The radiation doses from each storage system were obtained from the various Safety Analysis Reports. These doses are based on design basis fuel that could be loaded into a canister from the spent fuel pool. For this report, those doses were evaluated and collectively merged and reduced to create an approximate average design basis fuel for a typical canister that would be received at the ISF. The average design basis dose values were then used to determine the dose emitted from the top, sides, and bottom of a typical canister. A workers location and time spent there determined the dose the worker received. The individual activity duration and doses were summed to determine the total values for processing a canister. These durations and doses were used to provide an accurate comparison between alternatives.

Table 7-10 through Table 7-11 show a summary of the durations required for an alternative to process a canister from receipt to placement into storage and the corresponding total dose received by the entire crew. Note that the storage alternatives using in Study #1 and Study #3, assumed that A-OPS, automated canister transfer was used for transfer operations.

Table 7-10
Study #1 – Summary of DPC Process Duration and Total Worker Dose

Alternative	Storage Configuration	Duration of Transfer (hours)	Dose / Transfer (mrem) (Total Worker Dose)
C-PAD, Pad Storage w/ DPCs	Vertical	21	251
	Horizontal	24	198
C-STD, Standard Overpack w/ DPCs	Vertical	21	251
	Horizontal	24	192
C-UGS, Underground Storage w/ DPCs	Vertical	27	313
	Horizontal	26	350
C-BGV or C-AGV, Below or Above Grade Vault w/ DPCs – integral CHB	Vertical	21	173*
	Horizontal	25	178*
C-BGV or C-AGV, Below or Above Grade Vault w/ DPCs – standalone CHB	Vertical	29	173*
	Horizontal	30	178*

* There are many variations to the vault alternatives. The values shown represent a vault with an integral CHB.

Table 7-11
Study #2 – Summary of DPC Process Duration and Total Worker Dose

Alternative	Storage Configuration	Duration of Transfer (hours)	Dose / Transfer (mrem) (Total Worker Dose)
C-OPS, Current Typical Canister Transfer	Vertical	29	391
	Horizontal	24	203
A-OPS, Automated Canister Transfer	Vertical	21	251
	Horizontal	22	198
R- OPS, Remote Canister Transfer	Vertical	21	248
	Horizontal	Horizontal system cannot be transferred remotely	
S-OPS, Simplified Canister Transfer	Vertical	29	458
	Horizontal	24	203

Table 7-12
Study #3 – Summary of STAD Process Duration and Total Worker Dose*

Alternative	Storage Configuration	Duration of Transfer Operation (hours)	Dose / Transfer (mrem) (Total Worker Staff Dose)
S-PAD, Pad Storage w/ STADs	Vertical	29	251
S-UGS, Underground Storage w/ STADs	Vertical	21	313
S-BGV, Below Grade Vault w/STADs	Vertical	21	173
S-AGV, Above Grade Vault w/ STADs	Vertical	29	173

* Note: STAD canisters have not been designed, so radiation values were assumed to be similar to the doses emitted from commercial canisters.

7.8 Alternative Comparison and Conclusions

Despite the significant variations in design approach among the alternatives in Study #1, bottom line costs do not vary dramatically among the many scenarios evaluated. The same trend was observed in Studies #2 and #3. This observation suggests that other metrics, in addition to cost, could be used in making design decisions. Central to the conclusions that might be drawn from other metrics are issues that impact schedule as discussed in **Section 7.5** above.

Table 7-13summarizes the pros and cons of each design alternative in Study #1.

Table 7-14 summarizes the pros and cons of each design alternative in Study #2.

Table 7-15 summarizes the pros and cons of each design alternative in Study #3.

Table 7-13
Study #1 – Summary of Pros and Cons

Alternative	Pros	Cons
C-PAD	• Quickest and easiest to implement – already licensed • Performance capabilities are known • Can be constructed in phases allowing earlier operations	• Multiple overpack designs to fabricate, maintain and monitor • Canister transfer facility may be required for a high throughput operation • Overpacks may need to be bolted to pad to mitigate a hypothetical tip-over at high seismic sites • Some licensing revisions may be required • Equipment is needed to accommodate 13 storage systems • Multiple systems complicate pad analysis

C-STD	• Simplifies overpack fabrication • One storage overpack to consider for pad design • Can be constructed in phases allowing earlier operations	• Obtaining single storage license difficult with multiple vendor proprietary designs • Canister transfer facility may be required for a high throughput operation • Overpacks may need to be bolted to pad to mitigate a hypothetical tip-over at high seismic sites • Design and licensing time required for overpack • One size fits all requires design and installation of shims • Horizontal canisters require lifting cage • Possible horizontal to vertical DPC fuel orientation concerns
C-UGS	• No tip-over due to an earthquake • Ground provides radiation shielding • Ground shields DPCs from view • Already licensed for a limited number of licensed canisters • Reduces security staffing • Can be constructed in phases allowing earlier operations	• Obtaining single storage license difficult with multiple vendor proprietary designs • Canister transfer facility may be required for high throughput operation • Large sections of storage area construction required up front • One size fits all requires design and installation of shims • Horizontal DPCs require lifting cage to place in vertical position • Possible horizontal to vertical DPC fuel orientation concerns
C-BGV	• Controlled storage environment (indoors) compared to outdoor storage • All operations are maintained within structure • Shields DPCs from view easing security concerns • Provides good radiation shielding using the earth • Removes a seismic tip-over event since DPCs are locked in place • Lower bldg. / crane height	• Storage concept with commercial DPCs unproven • Large nuclear structure increases engineering and initial capital costs • Requires long design and licensing time • Thermal performance capability limited to the design of current transport casks • Obtaining single storage license difficult with multiple vendor proprietary designs • One size fits all requires design and installation of shims • Horizontal DPCs require lifting cage for vertical position • Possible horizontal to vertical DPC fuel orientation concerns • Entire vault needs to be constructed to be operational
C-AGV	• Same Pros as C-BGV except: no underground radiation shielding or lower bldg. / crane height	• Same Cons as C-BGV • Taller vault complicates seismic design • Vault wall requires radiation/explosion pressure design

Table 7-14
Study #2 – Summary of Pros and Cons

Alternative	Pros	Cons
C-OPS	• Proven method of canister transfer • Equipment already licensed and deployed at existing plants	• Multiple systems/steps add time, dose, equipment • Requires Cask Handling Building
A-OPS	• Equipment replaces manual tasks • Standardizes transfer equipment • Reduces time, dose, equipment • Improves safety	• Requires Cask Handling Building • Higher cost than C-OPS • Shielding innovations required
R- OPS	• Eliminates transfer equipment • Reduces time, dose, equipment	• Requires hot cell • Failure Mitigation required • Higher cost than C-OPS
S-OPS	• No CHB - Easy to implement • Proven method of canister transfer • Licensed for use • Lowest cost	• Labor intensive; adds higher dose. Experience shows that dose may be minimized using proper precautions • Low throughput

Table 7-15
Study #3 – Summary of Pros and Cons

Alternative	**Pros**	**Cons**
S-PAD	• Pad storage is proven technology • Easiest to implement	• Overpacks must be designed for seismic stability
S-UGS	• No tip-over due to an earthquake • Ground provides radiation shielding • Ground shields STADs from view	• Large sections of the storage area must be constructed at one time
S-BGV	• Building provides environment control • Ground provides radiation shielding and explosion protection to vault • Lower bldg. and crane height improves seismic resistance • Vault shields STADs from view • No tip-over due to an earthquake	• Large nuclear structure requires more design / construction time • Passive heat removal limited • Vault throughput is limited due to cask handling congestion in the storage hall
S-AGV	• Building provides environment control • Vault shields STADs from view • No tip-over due to an earthquake	• Large nuclear structure requires more design / construction time • Passive heat removal limited • Vault throughput is limited due to cask handling congestion in the storage hall • Vault walls must provide radiation shielding • Higher crane height increases seismic loads

As discussed above, this report is focused on generic design alternatives for storing SNF at a Pilot ISF, with maximum flexibility to accommodate an Expanded Pilot ISF. Conceptual plot plans, CHB layouts and equipment drawings, time and motion studies, cost analyses, seismic analyses, and radiation dose analyses developed in this report provide information that can assist decision makers in selecting options for the Pilot ISF.

This report does not address other key elements of the Strategy that are prerequisites to achieving an operational Pilot ISF, including the consent based siting process, the transportation system needed to move SNF from shutdown plants to the Pilot ISF, and the governance and funding elements of the strategy.

Other approaches that could support more timely initial Pilot ISF operations can be gleaned from the analyses in this report. A prime example is the use of "S-OPS" to begin pad ("C-PAD") storage of DPCs shipped to the Pilot ISF, while the cask handling building is still under construction. "S-OPS" equipment and operational procedures are proven at existing NPPs, so NRC approval should be straightforward. This strategy might lead to an operational Pilot ISF four years or less after a site is identified (under the consent-based siting approach) and DOE achieves a "decision to proceed." Similarly, the use of "S-OPS" in combination with below grade storage of DPCs (C-UGS) might lead to an operational Pilot ISF five years. In contrast, other alternatives would likely require 6-10 years from that decision to completion of the Pilot ISF.