HOLTEC INTERNATIONAL

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September 10, 2010

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Reference: 1. USNRC Docket No. 72-1014 (HI-STORM 100)
2. Holtec Project 5014

Subject: License Amendment Request #9 (LAR 1014-9) to HI-STORM 100 Certificate of Compliance 72-1014

Dear Sir or Madam:

Holtec International herein submits a request to amend Certificate of Compliance (CoC) 72-1014 for the Company's HI-STORM 100 Dry Cask Storage System. This license amendment request (LAR) seeks to: 1) broaden the subgrade requirements for the 100U ISFSI, and (2) update the thermal model/methodology for the HI-TRAC transfer cask from a two dimensional thermal-hydraulic model to an inherently more accurate three dimensional model.

This license amendment request focuses on expanding the licensing design basis for the HI-STORM 100U ISFSI such that it may be installed at any U.S. nuclear plant site ranging from deep soil to hard clay and rocky substrates. To align the analysis with the NRC's previously enunciated position on ISFSI structures, the design of the reinforced concrete structures has been specified in this submittal, qualifying analysis have been explicitly performed, and safety margins have been reported. The ISFSI design, sought to be certified under the provisions of 10CFR72.244, has been qualified using a generic site Design Basis Earthquake (DBE) that is expected to bound all site specific DBEs at the candidate nuclear plant sites with substantial margin thus eliminating the need for a site specific safety evaluation pursuant to 10CFR72.212 for most candidate locations.

The other objective of this LAR is to simplify the requirements for short term operations for the HI-STORM 100 System using the HI-TRAC transfer cask so that the occupational dose, loading times, and crew safety are further improved. This is done by utilizing a three dimensional thermal-hydraulic model of the HI-TRAC transfer cask.

A summary of the proposed changes, with detailed references to the CoC and Technical Specifications (TS) is provided in Attachment 1. A copy of the pages of the CoC and TS with the proposed changes is provided in Attachment 2. Attachment 3 provides the FSAR Sections and Supplements which contain the results of the detailed analysis and evaluations in support of

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the LAR as specified in Attachment 1. The licensing drawing for the 100U is provided in Attachment 4. Upon approval of the amendment the FSAR will be appropriately revised.

We respectfully request that the technical review and the approval process for this amendment be completed by mid-2011 to support an effective amendment date in late 2011. We believe that the above schedule is attainable, given the Staff's intimate knowledge of the underground storage technology, the extensive discussions on the appropriate non-linear SSI analysis method that have occurred over the past three years, and the limited number of technical discipline personnel required for the review. Adherence to the above schedule will permit the ground breaking for the first 100U installation to begin by the year end 2011.

Please contact me at 856-797-0900 x 687 if you have any questions.

Sincerely,

Tammy S. Morin
Licensing Manager
Holtec International

cc: Mr. John Goshen, USNRC (letter w/Attachments)
Mr. Doug Weaver, USNRC (letter only)
Mr. Ray Lorson, USNRC (letter only)
Mr. Eric Benner, USNRC (letter only)
Holtec Group 1 (letter only)
HUG distribution (letter only)

Attachment 1: Summary of Proposed Changes (2 pages)
Attachment 2: Proposed Revised CoC/TS - Changed pages only in mark-up format (27 pages)
Attachment 3: Proposed FSAR Changes (196 pages)
Attachment 4: 100U Licensing Drawing 4501R5 (7 pages)

Summary of Proposed Changes for LAR 1014-9

The proposed changes requested in this LAR can be categorized into two major changes; (1) broaden the subgrade requirements of the 100U ISFSI, and (2) update the thermal model for the HI-TRAC transfer cask from two dimensional thermal hydraulic model to a three dimensional thermal hydraulic model.

Changes associated with Proposed Change #1 are as follows:

1. Removal of the restriction which requires the ISFSI support foundation pad to rest on a subgrade material with a shear wave velocity of 3500 ft/s or bedrock.
2. Removal of the restriction which requires any excavation, near an operating 100U ISFSI, to be a distance of ten times the depth of the excavation away from the ISFSI.
3. Removal of the requirement to account for amplification in the seismic analysis.

The above results in modifications to the Certificate of Compliance (CoC) and Technical Specifications (TS), specifically the following:

1. CoC; Condition #12 is deleted and the subsequent Conditions are renumbered.
2. TS Appendix B-100U; Section 3.4 is revised.

The justification for these changes is supported by the modifications made in FSAR Supplements 1.I, 2.I, 3.I, 5.I, 10.I, and 11.I. These are provided with the LAR to assist in the review.

In summary, the essential design details of the VVM and the reinforced concrete structures have been fully articulated along with the maximum magnitude of acceptable Design Basis Earthquake. The reinforced concrete structures within the ISFSI are required to meet the factored load combinations of ACI-318 (2005). Towards this end, the following changes to the system design approach to the safety analyses have been made:

1. The structural embodiment of the VVM including its associated subgrade and reinforced concrete structures are defined with appropriate limits of properties such as the shear wave velocity limits and densities on the various subgrades, minimum compressive strength of reinforced concrete, and rebar strength.
2. The means to strengthen the subgrade underlying the Support Foundation Pad (SFP) by use of conventional measures, such as pilings, is permitted. The effect of settlement is required to be incorporated in the strength analysis of the reinforced concrete pads pursuant to ACI-318 (2005) that are subject to significant loadings, namely the SFP and the Top Surface Pad (TSP)
3. The minimum thickness and section strength requirements of all reinforced concrete structures, namely the SFP, the TSP, the VVM Interface Pad (VIP), and the retaining wall, if used, have been specified. At an ISFSI site, the section strength of every load bearing reinforced concrete structure in the ISFSI must equal or exceed what is specified.

4. A retaining wall (keyed to the SFP at its bottom and the TSP at its top) is recommended if an excavation activity is planned at a later date when the ISFSI is operating. The retaining wall must be located at or beyond the Radiation Protection Space (RPS) and be sufficiently strong to prevent lateral shift of the subgrade beyond the RPS during the site's DBE. If a retaining wall is not used and an excavation is planned an excavation exclusion zone (EEZ) must be determined for that site.
5. New tubular MPC Guides have been used to reduce the local impact strain level in the MPC due to rattling of the MPC during the DBE event.
6. The layout pitch of the VVMs has been increased from 12 to 14 feet.

Changes associated with Proposed Change #2 are as follows:

1. Re-analysis of short-term operations involving the HI-TRAC transfer cask. These include vacuum drying of the MPC, on-site transport of the dry MPC, and time to boil calculations. Results of this change in methodology are (1) there is no longer a need for a supplemental cooling system to maintain peak cladding temperatures below the ISG-11 Rev. 3 limits, (2) decay heat thresholds for vacuum drying increased for both unlimited and time restricted vacuum drying, and (3) time-to-boil limits for various decay heat loads and initial spent fuel pool temperatures have been added.
2. Re-analysis of the accident scenarios involving the HI-TRAC transfer cask, i.e. fire and loss of water in the water jacket.

The above results in modifications to the CoC and TS, specifically the following:

1. CoC; Condition #10, step g. is deleted and the subsequent steps are renumbered.
2. CoC; Condition #11 is deleted and the subsequent Conditions are renumbered.
3. TS Appendix A; LCO 3.1.4 is deleted and LCO 3.1.1 and Table 3-1 are modified.
4. TS Appendix A-100U; LCO 3.1.4 is deleted and LCO 3.1.1 and Table 3-1 are modified.
5. TS Appendix B; Section 3.7 is deleted.
6. TS Appendix B-100U; Section 3.7 is deleted.

The justification for these changes is supported by the modifications made in FSAR Sections 4.5 and 4.6. These are provided with the LAR to assist in the review. Note that editorial corrections will need to be made throughout the FSAR due to the elimination of the requirement for supplemental cooling. These will be incorporated in the FSAR after approval of this amendment.

CERTIFICATE OF COMPLIANCE FOR SPENT FUEL STORAGE CASKS

The U.S. Nuclear Regulatory Commission is issuing this Certificate of Compliance pursuant to Title 10 of the Code of Federal Regulations, Part 72, "Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste" (10 CFR Part 72). This certificate is issued in accordance with 10 CFR 72.238, certifying that the storage design and contents described below meet the applicable safety standards set forth in 10 CFR Part 72, Subpart L, and on the basis of the Final Safety Analysis Report (FSAR) of the cask design. This certificate is conditional upon fulfilling the requirements of 10 CFR Part 72, as applicable, and the conditions specified below.

Certificate No.	Effective Date	Expiration Date	Docket No.	Amendment No.	Amendment Effective Date	Package Identification No.
1014	05/31/00	05/31/20	72-1014	~~7~~ *TBD*	TBD	USA/72-1014

Issued To: (Name/Address)

Holtec International
Holtec Center
555 Lincoln Drive West
Marlton, NJ 08053

Safety Analysis Report Title

Holtec International Inc.,
Final Safety Analysis Report for the
HI-STORM 100 Cask System

CONDITIONS

This certificate is conditioned upon fulfilling the requirements of 10 CFR Part 72, as applicable, the attached Appendix A (Technical Specifications) and Appendix B (Approved Contents and Design Features) for aboveground systems or the attached Appendix A-100U (Technical Specifications) and Appendix B-100U (Approved Contents and Design Features) for underground systems, and the conditions specified below:

1. CASK

   a. Model No.: HI-STORM 100 Cask System

   The HI-STORM 100 Cask System (the cask) consists of the following components: (1) interchangeable multi-purpose canisters (MPCs), which contain the fuel; (2) a storage overpack (HI-STORM), which contains the MPC during storage; and (3) a transfer cask (HI-TRAC), which contains the MPC during loading, unloading and transfer operations. The cask stores up to 32 pressurized water reactor fuel assemblies or 68 boiling water reactor fuel assemblies.

   b. Description

   The HI-STORM 100 Cask System is certified as described in the Final Safety Analysis Report (FSAR) and in the U. S. Nuclear Regulatory Commission's (NRC) Safety Evaluation Report (SER) accompanying the Certificate of Compliance. The cask comprises three discrete components: the MPC, the HI-TRAC transfer cask, and the HI-STORM storage overpack.

   The MPC is the confinement system for the stored fuel. It is a welded, cylindrical canister with a honeycombed fuel basket, a baseplate, a lid, a closure ring, and the canister shell. All MPC components that may come into contact with spent fuel pool water or the ambient environment are made entirely of stainless steel or passivated aluminum/aluminum alloys such as the neutron absorbers. The canister shell, baseplate, lid, vent and drain port cover plates, and closure ring are the main confinement boundary components. All confinement boundary components are made entirely of stainless steel. The honeycombed basket, which is equipped with neutron absorbers, provides criticality control.

1. b. Description (continued)

There are eight types of MPCs: the MPC-24, MPC-24E, MPC-24EF, MPC-32, MPC-32F, MPC-68, MPC-68F, and MPC-68FF. The number suffix indicates the maximum number of fuel assemblies permitted to be loaded in the MPC. All eight MPC models have the same external diameter.

The HI-TRAC transfer cask provides shielding and structural protection of the MPC during loading, unloading, and movement of the MPC from the spent fuel pool to the storage overpack. The transfer cask is a multi-walled (carbon steel/lead/carbon steel) cylindrical vessel with a neutron shield jacket attached to the exterior. Two sizes of HI-TRAC transfer casks are available: the 125 ton HI-TRAC and the 100 ton HI-TRAC. The weight designation indicates ~~is~~ the approximate weight of a loaded transfer cask during any loading, unloading, or transfer operation. Both transfer cask sizes have identical cavity diameters. The 125 ton HI-TRAC transfer cask has thicker shielding and larger outer dimensions than the 100 ton HI-TRAC transfer cask.

Above Ground Systems

The HI-STORM 100 or 100S storage overpack provides shielding and structural protection of the MPC during storage. The HI-STORM 100S is a variation of the HI-STORM 100 overpack design that includes a modified lid which incorporates the air outlet ducts into the lid, allowing the overpack body to be shortened. The overpack is a heavy-walled steel and concrete, cylindrical vessel. Its side wall consists of plain (un-reinforced) concrete that is enclosed between inner and outer carbon steel shells. The overpack has four air inlets at the bottom and four air outlets at the top to allow air to circulate naturally through the cavity to cool the MPC inside. The inner shell has supports attached to its interior surface to guide the MPC during insertion and removal, provide a medium to absorb impact loads, and allow cooling air to circulate through the overpack. A loaded MPC is stored within the HI-STORM 100 or 100S storage overpack in a vertical orientation. The HI-STORM 100A and 100SA are variants of the HI-STORM 100 family and are outfitted with an extended baseplate and gussets to enable the overpack to be anchored to the concrete storage pad in high seismic applications.

Underground Systems

The HI-STORM 100U System is an underground storage system identified with the HI-STORM 100 Cask System. The HI-STORM 100U storage Vertical Ventilated Module (VVM) utilizes a storage design identified as an air-cooled vault or caisson. The HI-STORM 100U storage VVM relies on vertical ventilation instead of conduction through the soil, as it is essentially a below-grade storage cavity. Air inlets and outlets allow air to circulate naturally through the cavity to cool the MPC inside. The subterranean steel structure is seal welded to prevent ingress of any groundwater from the surrounding subgrade, and it is mounted on a stiff foundation. The surrounding subgrade and a top surface pad provide significant radiation shielding. A loaded MPC is stored within the HI-STORM 100U storage VVM in the vertical orientation.

2. OPERATING PROCEDURES

Written operating procedures shall be prepared for cask handling, loading, movement, surveillance, and maintenance. The user's site-specific written operating procedures shall be consistent with the technical basis described in Chapter 8 of the FSAR.

3. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Written cask acceptance tests and maintenance program shall be prepared consistent with the technical basis described in Chapter 9 of the FSAR. At completion of welding the MPC shell to baseplate, an MPC confinement weld helium leak test shall be performed using a helium mass spectrometer. The confinement boundary welds leakage rate test shall be performed in accordance with ANSI N14.5 to "leak-tight" criteria. If a leakage rate exceeding the acceptance criteria is detected, then the area of leakage shall be determined and the area repaired per ASME Code Section III, Subsection NB. Article NB-4450 requirements. Re-testing shall be performed until the leakage rate acceptance criterion is met.

4. QUALITY ASSURANCE

Activities in the areas of design, purchase, fabrication, assembly, inspection, testing, operation, maintenance, repair, modification of structures, systems and components, and decommissioning that are important to safety shall be conducted in accordance with a Commission-approved quality assurance program which satisfies the applicable requirements of 10 CFR Part 72, Subpart G, and which is established, maintained, and executed with regard to the cask system

5. HEAVY LOADS REQUIREMENTS

Each lift of an MPC, a HI-TRAC transfer cask, or any HI-STORM overpack must be made in accordance to the existing heavy loads requirements and procedures of the licensed facility at which the lift is made. A plant-specific review (under 10 CFR 50.59 or 10 CFR 72.48, if applicable) is required to show operational compliance with existing plant specific heavy loads requirements. Lifting operations outside of structures governed by 10 CFR Part 50 must be in accordance with Section 5.5 of Appendix A and Sections 3.4.6 and 3.5 of Appendix B, for above ground systems, section 5.5 of Appendix A-100U for the underground systems.

6. APPROVED CONTENTS

Contents of the HI-STORM 100 Cask System must meet the fuel specifications given in Appendices B for aboveground systems or B-100U for underground systems to this certificate.

7. DESIGN FEATURES

Features or characteristics for the site, cask or ancillary equipment must be in accordance with Appendices B for aboveground systems or B-100U for underground systems to this certificate.

8. CHANGES TO THE CERTIFICATE OF COMPLIANCE

The holder of this certificate who desires to make changes to the certificate, which includes Appendices A and A-100U (Technical Specifications) and Appendices B and B-100U (Approved Contents and Design Features), shall submit an application for amendment of the certificate.

9. SPECIAL REQUIREMENTS FOR FIRST SYSTEMS IN PLACE

The air mass flow rate through the cask system will be determined by direct measurements of air velocity in the overpack cooling passages for the first HI-STORM Cask Systems placed into service by any user with a heat load equal to or greater than 20 kW. In the aboveground HI-STORM Models (HI-STORM 100, 100S, etc.), the velocity will be measured in the annulus formed between the MPC shell and the overpack inner shell. In the underground HI-STORM Model (HI-STORM 100U), the velocity will be measured in the vertical downcomer air passage. An analysis shall be performed that demonstrates the measurements validate the analytic methods and thermal performance predicted by the licensing-basis thermal models in Chapter 4 of the FSAR.

~~Each first time user of a cask supplemental cooling system (SCS) which has not been previously tested and documented with the NRC shall measure and record coolant temperatures for the inlet and outlet of cooling provided to the annulus between the HI-TRAC and MPC and the coolant flow rate. The user shall also record the MPC operating pressure and decay heat. An analysis shall be performed, using this information that validates the thermal methods described in the FSAR which were used to determine the type and amount of supplemental cooling necessary.~~

Letter reports summarizing the results of ~~each~~ thermal validation tests ~~and SCS validation test~~ and analysis shall be submitted to the NRC in accordance with 10 CFR 72.4. Cask users may satisfy these requirements by referencing validation test reports submitted to the NRC by other cask users.

10. PRE-OPERATIONAL TESTING AND TRAINING EXERCISE

A dry run training exercise of the loading, closure, handling, unloading, and transfer of the HI-STORM 100 Cask System shall be conducted by the licensee prior to the first use of the system to load spent fuel assemblies. The training exercise shall not be conducted with spent fuel in the MPC. The dry run may be performed in an alternate step sequence from the actual procedures, but all steps must be performed. The dry run shall include, but is not limited to the following:

a. Moving the MPC and the transfer cask into the spent fuel pool or cask loading pool.

b. Preparation of the HI-STORM 100 Cask System for fuel loading.

c. Selection and verification of specific fuel assemblies to ensure type conformance.

d. Loading specific assemblies and placing assemblies into the MPC (using a dummy fuel assembly), including appropriate independent verification.

e. Remote installation of the MPC lid and removal of the MPC and transfer cask from the spent fuel pool or cask loading pool.

~~f.~~ MPC welding, NDE inspections, pressure testing, draining, moisture removal (by vacuum drying or forced helium dehydration, as applicable), and helium backfilling. (A mockup may be used for this dry-run exercise.)
~~g.~~*f.*
~~g. Operation of the HI-STORM 100 SCS or equivalent system, if applicable.~~

~~h.~~*g.* Transfer cask upending/downending on the horizontal transfer trailer or other transfer device, as applicable to the site's cask handling arrangement.

~~i.~~*h.* Transfer of the MPC from the transfer cask to the overpack/VVM.

~~j.~~*i.* Placement of the HI-STORM 100 Cask System at the ISFSI, for aboveground systems only.

~~k.~~*j.* HI-STORM 100 Cask System unloading, including flooding MPC cavity, removing MPC lid welds. (A mockup may be used for this dry-run exercise.)

~~11. The NRC has approved an exemption request by the CoC applicant from the requirements of 10 CFR 72.236(f), to allow a Supplemental Cooling System to provide for decay heat removal in accordance with Section 3.1.4 of Appendices A and A-100U.~~

~~12. The bounding seismic parameters for net horizontal acceleration at a specific site must account for amplification by either reducing the unamplified pad net horizontal acceleration by the amplification factor that would occur for an SSI analysis had the loaded transporter been present in the analysis, or revising the TSP design to incorporate the effect of the amplification.~~

12~~13.~~ AUTHORIZATION

The HI-STORM 100 Cask System, which is authorized by this certificate, is hereby approved for general use by holders of 10 CFR Part 50 licenses for nuclear reactors at reactor sites under the general license issued pursuant to 10 CFR 72.210, subject to the conditions specified by 10 CFR 72.212, this certificate, and the attached Appendices A, B, A-100U, and B-100U, as applicable. The HI-STORM 100 Cask System may be fabricated and used in accordance with any approved amendment to CoC No. 1014 listed in 10 CFR 72.214. Each of the licensed HI-STORM 100 System components (i.e., the MPC, overpack, and transfer cask), if fabricated in accordance with any of the approved CoC Amendments, may be used with one another provided an assessment is performed by the CoC holder that demonstrates design compatibility.

FOR THE U. S. NUCLEAR REGULATORY COMMISSION

TBD, Chief
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards
Washington, DC 20555

Dated TBD

Attachments:
1. Appendix A
2. Appendix B
3. Appendix A-100U
4. Appendix B-100U

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3.1 SFSC INTEGRITY

3.1.1 Multi-Purpose Canister (MPC)

LCO 3.1.1 The MPC shall be dry and helium filled.

Table 3-1 provides decay heat and burnup limits for forced helium dehydration (FHD) and vacuum drying. FHD is not subject to time limits. Vacuum drying, is subject to the following time limits, from the end of bulk water removal until the start of helium backfill:

MPC Total Decay Heat (Q)	Vacuum Drying Time Limit
Q ≤ ~~23~~ *26* kW	None
~~23~~ *26* kW < Q ≤ ~~28.74~~*30* kW	40 hours
Q > ~~28.74~~*30* kW	Not Permitted (see Table 3-1)

APPLICABILITY: During TRANSPORT OPERATIONS and STORAGE OPERATIONS.

ACTIONS

---NOTES---

Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. MPC cavity vacuum drying pressure or demoisturizer exit gas temperature limit not met.	A.1 Perform an engineering evaluation to determine the quantity of moisture left in the MPC.	7 days
	<u>AND</u>	
	A.2 Develop and initiate corrective actions necessary to return the MPC to compliance with Table 3-1.	30 days

ACTIONS (continued)

B. MPC cavity vacuum drying acceptance criteria not met during allowable time.	B.1 Backfill the MPC cavity with helium to a pressure of at least 0.5 atm.	6 hours
C. MPC helium backfill limit not met.	C.1 Perform an engineering evaluation to determine the impact of helium differential.	72 hours
	AND	
	C.2.1 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition by adding helium to or removing helium from the MPC.	14 days
	OR	
	C.2.2 Develop and initiate corrective actions necessary to demonstrate through analysis, using the models and methods from the HI-STORM FSAR, that all limits for cask components and contents will be met.	
D. MPC helium leak rate limit for vent and drain port cover plate welds not met.	D.1 Perform an engineering evaluation to determine the impact of increased helium leak rate on heat removal capability and offsite dose.	24 hours
	AND	
	D.2 Develop and initiate corrective actions necessary to return the MPC to compliance with SR 3.1.1.3.	7 days

E. Required Actions and associated Completion Times not met.	E.1 Remove all fuel assemblies from the SFSC.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1.1	Verify that the MPC cavity has been dried in accordance with the applicable limits in Table 3-1, within the specified vacuum drying time limits as applicable.	Once, prior to TRANSPORT OPERATIONS
SR 3.1.1.2	Verify MPC helium backfill quantity is within the limit specified in Table 3-2 for the applicable MPC model. Re-performance of this surveillance is not required upon successful completion of Action C.2.2.	Once, prior to TRANSPORT OPERATIONS
SR 3.1.1.3	Verify that the helium leak rate through the MPC vent and drain port confinement welds meets the leaktight criteria of ANSI N14.5-1997.	Once, prior to TRANSPORT OPERATIONS

3.1 SFSC INTEGRITY

3.1.4 *Deleted*

~~Supplemental Cooling System~~

LCO 3.1.4 *Deleted*~~A supplemental cooling system (SCS) shall be operable~~

~~NOTE~~

~~Upon reaching steady state operation, the SCS may be temporarily disabled for a short duration (≤ 7 hours) to facilitate necessary operational evolutions, such as movement of the TRANSFER CASK through a door way, or other similar operation.~~

~~APPLICABILITY: This LCO is applicable when the loaded MPC is in the TRANSFER CASK and:~~

~~A. Within 4 hours of the completion of MPC drying operations in accordance with LCO 3.1.1 or within 4 hours of transferring the MPC into the TRANSFER CASK if the MPC is to be unloaded~~

~~AND~~

~~b1. The MPC contains one or more fuel assemblies with an average burnup > 45,000 MWD/MTU~~

~~OR~~

~~b2. The MPC decay heat load exceeds 28.74 kW.~~

~~ACTIONS~~

~~CONDITION~~	~~REQUIRED ACTION~~	~~COMPLETION TIME~~
~~A. SFSC Supplemental Cooling System inoperable.~~	~~A.1 Restore SFSC Supplemental Cooling System to operable status.~~	~~7 days~~
~~B. Required Action A.1 and associated Completion Time not met.~~	~~B.1 Remove all fuel assemblies from the SFSC.~~	~~30 days~~

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.1.4.1 Verify SCS is operable.	2 hours

Table 3-1
MPC Cavity Drying Limits *for All MPC Types*

Fuel Burnup (MWD/MTU)	MPC Heat Load Q (kW)	Method of Moisture Removal (Notes 1 and 2)
All Assemblies ≤ 45,000	~~≤ 29 (MPC-24/24E/24EF)~~ ~~≤ 26 (MPC-32/32F)~~ ~~≤ 26 (MPC-68/68F/68FF)~~ *≤ 30*	VDS or FHD
All Assemblies ≤ 45,000	~~> 29 (MPC-24/24E/24EF)~~ ~~> 26 (MPC-32/32F)~~ ~~> 26 (MPC-68/68F/68FF)~~ *> 30*	FHD
One or more assemblies > 45,000	≤ 36.9	FHD

Notes:

1. VDS means a vacuum drying system. The acceptance criterion when using a VDS is MPC cavity pressure shall be ≤ 3 torr for ≥ 30 minutes.

2. FHD means a forced helium dehydration system. The acceptance criterion when using an FHD system is the gas temperature exiting the demoisturizer shall be ≤ 21°F for ≥ 30 minutes or the gas dew point exiting the MPC shall be ≤ 22.9°F for ≥ 30 minutes.

3. ~~For total decay heat loads up to and including 20.88 kW for the MPC-24 and 21.52 kW for the MPC-68, v~~*V*acuum drying of the MPC must be performed with the annular gap between the MPC and the HI-TRAC filled with water~~. For higher total decay heat loads in the MPC-24 and MPC-68 or for any decay heat load in an MPC-24E or MPC-32, the annular gap must be continuously flushed with water with sufficient flow to keep the exit water temperature below 125°F~~.

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DESIGN FEATURES (continued)

3.7 ~~Supplemental Cooling System~~*Deleted*

~~3.7.1 System Description~~

~~A supplemental cooling system (SCS) is an external system for cooling the MPC inside the HI-TRAC transfer cask during on-site transport. Use of an SCS is required for post-backfill HI-TRAC operations of an MPC containing one or more high burnup (> 45,000 MWD/MTU) fuel assemblies or MPC heat loads in excess of 28.74kW. The SCS shall be designed for normal operation (i.e., excluding startup and shutdown ramps) in accordance with the criteria in Section 3.7.2.~~

~~3.7.2 Design Criteria~~

~~3.7.2.1 Not Used.~~

~~3.7.2.2 If water is used as the coolant, the system shall be sized to limit the coolant temperature to below 180ºF under steady-state conditions for the design basis heat load at an ambient air temperature of 100ºF. Any electric motors shall have a backup power supply for uninterrupted operation.~~

~~3.7.2.3 The system shall utilize a contamination-free fluid medium in contact with the external surfaces of the MPC and inside surfaces of the HI -TRAC transfer cask to minimize corrosion.~~

~~3.7.2.4 All passive components such as tubular heat exchangers, manually operated valves and fittings shall be designed to applicable standards (TEMA, ANSI).~~

~~3.7.2.5 The heat dissipation capacity of the SCS shall be equal to or greater than the minimum necessary to ensure that the peak cladding temperature is below 400ºC (752ºF). All heat transfer surfaces in heat exchangers shall be assumed to be fouled to the maximum limits specified in a widely used heat exchange equipment standard such as the Standards of Tubular Exchanger Manufacturers Association.~~

~~3.7.2.6 The coolant utilized to extract heat from the MPC shall be high purity water or air. Antifreeze may be used to prevent water from freezing if warranted by operating conditions.~~

~~(continued)~~

DESIGN FEATURES (continued)

3.7 Supplemental Cooling System (continued)

3.7.2.7 All pressure boundaries (as defined in the ASME Boiler and Pressure Vessel Code, Section VIII Division 1) shall have pressure ratings that are greater than the maximum system operating pressure by at least 15 psi.

3.7.2.8 All ASME Code components shall comply with Section VIII Division 1 of the ASME Boiler and Pressure Vessel Code.

3.7.2.9 All gasketed and packed joints shall have a minimum design pressure rating of the pump shut-off pressure plus 15 psi.

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3.1 SFSC INTEGRITY

3.1.1 Multi-Purpose Canister (MPC)

LCO 3.1.1 The MPC shall be dry and helium filled.

Table 3-1 provides decay heat and burnup limits for forced helium dehydration (FHD) and vacuum drying. FHD is not subject to time limits. Vacuum drying is subject to the following time limits, from the end of bulk water removal until the start of helium backfill:

MPC Total Decay Heat (Q)	Vacuum Drying Time Limit
Q ≤ ~~23~~ *26* kW	None
~~23~~ *26* kW < Q ≤ ~~28.74~~ *30* kW	40 hours
Q > ~~28.74~~ *30* kW	Not Permitted (see Table 3-1)

APPLICABILITY: During TRANSPORT OPERATIONS and STORAGE OPERATIONS.

ACTIONS

---NOTES---

Separate Condition entry is allowed for each MPC.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. MPC cavity vacuum drying pressure or demoisturizer exit gas temperature limit not met.	A.1 Perform an engineering evaluation to determine the quantity of moisture left in the MPC.	7 days
	<u>AND</u>	
	A.2 Develop and initiate corrective actions necessary to return the MPC to compliance with Table 3-1.	30 days
B. MPC cavity vacuum drying acceptance criteria not met during allowable time.	B.1 Backfill the MPC cavity with helium to a pressure of at least 0.5 atm.	6 hours

CONDITION	REQUIRED ACTION	COMPLETION TIME
C. MPC helium backfill limit not met.	C.1 Perform an engineering evaluation to determine the impact of helium differential.	72 hours
	<u>AND</u>	
	C.2.1 Develop and initiate corrective actions necessary to return the MPC to an analyzed condition by adding helium to or removing helium from the MPC. <u>OR</u> C.2.2 Develop and initiate corrective actions necessary to demonstrate through analysis, using the models and methods from the HI-STORM FSAR, that all limits for cask components and contents will be met.	14 days
D. MPC helium leak rate limit for vent and drain port cover plate welds not met.	D.1 Perform an engineering evaluation to determine the impact of increased helium leak rate on heat removal capability and offsite dose.	24 hours
	<u>AND</u>	
	D.2 Develop and initiate corrective actions necessary to return the MPC to compliance with SR 3.1.1.3.	7 days

CONDITION	REQUIRED ACTION	COMPLETION TIME
E. Required Actions and associated Completion Times not met.	E.1 Remove all fuel assemblies from the SFSC.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1.1	Verify that the MPC cavity has been dried in accordance with the applicable limits in Table 3-1, within the specified vacuum drying time limits as applicable.	Once, prior to TRANSPORT OPERATIONS
SR 3.1.1.2	Verify MPC helium backfill quantity is within the limit specified in Table 3-2 for the applicable MPC model. Re-performance of this surveillance is not required upon successful completion of Action C.2.2.	Once, prior to TRANSPORT OPERATIONS
SR 3.1.1.3	Verify that the helium leak rate through the MPC vent and drain port confinement welds meets the leaktight criteria of ANSI N14.5-1997.	Once, prior to TRANSPORT OPERATIONS

3.1 SFSC INTEGRITY

3.1.4 Supplemental Cooling System*Deleted*

LCO 3.1.4 A supplemental cooling system (SCS) shall be operable*Deleted*

NOTE

Upon reaching steady state operation, the SCS may be temporarily disabled for a short duration (≤ 7 hours) to facilitate necessary operational evolutions, such as movement of the TRANSFER CASK through a door way, or other similar operation.

APPLICABILITY: This LCO is applicable when the loaded MPC is in the TRANSFER CASK and:

a. Within 4 hours of the completion of MPC drying operations in accordance with LCO 3.1.1 or within 4 hours of transferring the MPC into the TRANSFER CASK if the MPC is to be unloaded

AND

b1. The MPC contains one or more fuel assemblies with an average burnup > 45,000 MWD/MTU

OR

b2. The MPC decay heat load exceeds 28.74 kW.

ACTIONS:

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. SFSC Supplemental Cooling System inoperable.	A.1 Restore SFSC Supplemental Cooling System to operable status.	7 days
B. Required Action A.1 and associated Completion Time not met.	B.1 Remove all fuel assemblies from the SFSC.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.1.4.1 Verify Supplemental Cooling System is operable.	2 hours

Table 3-1
MPC Cavity Drying Limits *for All MPC Types*

Fuel Burnup (MWD/MTU)	MPC Heat Load *Q* (kW)	Method of Moisture Removal (Notes 1 and 2)
All Assemblies ≤ 45,000	≤ ~~29 (MPC-24/24E)~~ ~~≤ 26 (MPC-32)~~ ~~≤ 26 (MPC-68)~~*30*	VDS or FHD
All Assemblies ≤ 45,000	> ~~29 (MPC-24/24E)~~ ~~> 26 (MPC-32)~~ ~~> 26 (MPC-68)~~*30*	FHD
One or more assemblies > 45,000	≤ 36.9	FHD

Notes:

1. VDS means a vacuum drying system. The acceptance criterion when using a VDS is the MPC cavity pressure shall be ≤ 3 torr for ≥ 30 minutes.
2. FHD means a forced helium dehydration system. The acceptance criterion when using an FHD System is the gas temperature exiting the demoisturizer shall be ≤ 21°F for ≥ 30 minutes or the gas dew point exiting the MPC shall be ≤ 22.9°F for ≥ 30 minutes.
3. ~~For total decay heat loads up to and including 20.88 kW for the MPC-24 and 21.52 kW for the MPC-68, v~~*V*acuum drying of the MPC must be performed with the annular gap between the MPC and the HI-TRAC filled with water~~. For higher total decay heat loads in the MPC-24 and MPC-68 or for any decay heat load in an MPC-24E or MPC-32, the annular gap must be continuously flushed with water with sufficient flow to keep the exit water temperature below 125°F~~.

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DESIGN FEATURES (continued)

3.4 Site-Specific Parameters and Analyses

Site-specific parameters and analyses that will require verification by the system user are, as a minimum, as follows:

1. The temperature of 80° F is the maximum average yearly temperature.

2. The allowed temperature extremes, averaged over a 3-day period, shall be greater than -40° F and less than 125° F.

3. The analyzed flood condition of 15 fps water velocity and a height of 125 feet of water (full submergence of the loaded cask) are not exceeded.

4. The potential for fire and explosion shall be addressed, based on site-specific considerations. The user shall demonstrate that the site-specific potential for fire is bounded by the fire conditions analyzed by the Certificate Holder, or an analysis of the site-specific fire considerations shall be performed.

5. The *resultant zero period accelearation* at the *top of the grade and at the elevation of the Support Foundation Pad (SFP) at the host* -site *(computed by the Newmark's rule as the sum of- A+0.4*B+0.4*C, where A, B, C denote the free field ZPA's in the three orthogonal directions in decreasing magnitude-, i.e., A ≥ B ≥ C)* shall *be less than or equal to 1.3 and 1.228, respectively.*

~~5.~~*6.* a. *The criteria used to qualify the protection of the reactor building base mat foundation at the nuclear plant shall also be used to insure that sub-grade supporting the SFP shall not violate the plant's acceptance criteria for the potential of liquefaction.* ~~The shear wave velocity of the substrate on which the SUPPORT FOUNDATION rests shall be greater than or equal to 3500~~ ~~*800*~~ ~~ft/s or the SUPPORT FOUNDATION shall rest directly on bedrock.~~

b. *The depth averaged densities and strain compatible shear wave velocities in the different regions of the subgrade shall meet the minimum requirements of Table 3-4.* ~~The substrate surrounding the VVM, out to a distance equal to five (5) times the diameter of the VVM cavity, shall have a minimum density of 106 lb/ft³ and a depth weighted average density of 120 lb/ft³.~~

7. *The moment and shear capacities of the ISFSI Structures shall meet the structural requirements under the load combinations in Table 3-3.*

~~7.~~*8.* Radiation Protection Space (RPS) as defined in Subsection 5.7.9 of

Appendix A-100U, is intended to ensure that the sub~~*strate*~~*grade* material ~~*(such as natural subgrade, and engineered fill)*~~ *in and around the lateral space occupied by the VVMs* remains essentially intact under all service conditions including during an excavation activity adjacent to the RPS.

~~6.~~*9.* The Support Foundation Pad (mat) for a VVM array established in ~~a~~ *any one* construction campaign shall be of monolithic construction, *to the extent practicable,* to maximize the physical stability of the underground installation.

(continued)

TABLE 3-3 LOAD COMBINATIONS FOR THE TOP SURFACE PAD, VVM INTERFACE PADS, SUPPORT FOUNDATION PAD, AND THE RETAINING WALL PER ACI-318 (2005)	
Load Combination	
LC-1	*1.4D*
LC-2	*1.2D + 1.6L*
LC-3	*1.2D + E + L*

where:
D: Dead Load including long-term settlement effects.
L: Live Load
E: DBE for the Site

Table 3-43
Values of Principal Design Parameters for the Underground ISFSI

Thickness of the *Support* Foundation Pad, inch *(nominal)*	≥330
Thickness of the VVM Interface Pad, inch *(nominal)*	≥28*34*
Thickness of the Top Surface Pad, inch *(nominal)* *Thickness of Retaining Wall, inch (nominal)*	≥24*30* *≥24*
Rebar Size* (min.) and Layout* (max)	#1*1*0 @ 9" each face, each direction
Rebar Concrete Cover (top and bottom)*, inch	per 7.7.1 of ACI 318 (2005)
Compressive Strength of Concrete*, psi	≥40500
Shear Wave Velocity in the ~~Substrate~~ *Subgrade* lateral to the VVM, fps *(nominal)*	≥800500
Shear Wave Velocity in the ~~Substrate~~ *Subgrade* Below the *Support* Foundation Pad, fps (nominal)	≥3500*485*
* Applies to *Support* Foundation *Pad*, VVM Interface *Pad*, ~~and~~ Top Surface Pads *and Retaining Wall*	

(continued)

DESIGN FEATURES (continued)

3.4 Site-Specific Parameters and Analyses (continued)

~~8~~*10.* Prior to an excavation activity contiguous to an RPS, a seismic qualification of the ISFSI in the structurally most vulnerable configuration (i.e., maximum amount of earth removed) shall be performed to verify that the stability of the ~~Support Foundation~~*SFP*, the ~~ISFSI *Top Surface* pad~~*TSP* and the shielding material within the RPS, *with or without the Retaining Wall,* is maintained. ~~Excavation can only occur at a distance from the RPS greater than 10 times the depth of the planned excavation.~~ *If a Retaining Wall is not installed in any side of the ISFSI then* ~~A~~*an Excavation Exclusion Zone shall be established inside which excavation is prohibited by performing an appropriate SSI analysis.*

~~9~~*11.* In cases where engineered features (i.e., berms and shield walls) are used to ensure that the requirements of 10 CFR 72.104(a) are met, such features are to be considered important to safety and must be evaluated to determine the applicable quality assurance category.

~~10~~*12.* LOADING OPERATIONS, TRANSPORT OPERATIONS, and UNLOADING OPERATIONS shall only be conducted with working area ambient temperatures ≥ 0° F.

~~11~~*13.* For those users whose site-specific design basis includes an event or events (e.g., flood) that result in the blockage of any VVM inlet or outlet air ducts for an extended period of time (i.e, longer than the total Completion Time of LCO 3.1.2), an analysis or evaluation may be performed to demonstrate adequate heat removal is available for the duration of the event. Adequate heat removal is defined as fuel cladding temperatures remaining below the short term temperature limit. If the analysis or evaluation is not performed, or if fuel cladding temperature limits are unable to be demonstrated by analysis or evaluation to remain below the short term temperature limit for the duration of the event, provisions shall be established to provide alternate means of cooling to accomplish this objective.

~~12.~~*14.* Users shall establish procedural and/or mechanical barriers to ensure that during LOADING OPERATIONS and UNLOADING OPERATIONS, either the fuel cladding is covered by water, or the MPC is filled with an inert gas.

DESIGN FEATURES (continued)

3.7 ~~Supplemental Cooling System~~*Deleted*

~~3.7.1 System Description~~

~~A supplemental cooling system (SCS) is a water circulation system for cooling the MPC inside the HI-TRAC transfer cask during on-site transport. Use of an SCS is required for post-backfill HI-TRAC operations of an MPC containing one or more high burnup (> 45,000 MWD/MTU) fuel assemblies or MPC heat loads in excess of 28.74 kW. The SCS shall be designed for normal operation (i.e., excluding startup and shutdown ramps) in accordance with the criteria in Section 3.7.2.~~

~~3.7.2 Design Criteria~~

~~3.7.2.1 Not Used.~~

~~3.7.2.2 If water is used as the coolant, the system shall be sized to limit the coolant temperature to below 180ºF under steady-state conditions for the design basis heat load at an ambient air temperature of 100ºF. Any electric motors shall have a backup power supply for uninterrupted operation.~~

~~3.7.2.3 The system shall utilize a contamination-free fluid medium in contact with the external surfaces of the MPC and inside surfaces of the HI -TRAC transfer cask to minimize corrosion.~~

~~3.7.2.4 All passive components such as tubular heat exchangers, manually operated valves and fittings shall be designed to applicable standards (TEMA, ANSI).~~

~~3.7.2.5 The heat dissipation capacity of the SCS shall be equal to or greater than the minimum necessary to ensure that the peak cladding temperature is below 400ºC (752ºF). All heat transfer surfaces in heat exchangers shall be assumed to be fouled to the maximum limits specified in a widely used heat exchange equipment standard such as the Standards of Tubular Exchanger Manufacturers Association.~~

~~3.7.2.6 The coolant utilized to extract heat from the MPC shall be high purity water or air. Antifreeze may be used to prevent water from freezing if warranted by operating conditions.~~

~~(continued)~~

~~DESIGN FEATURES (continued)~~

~~3.7 Supplemental Cooling System (continued)~~

~~3.7.2.7 All pressure boundaries (as defined in the ASME Boiler and Pressure Vessel Code, Section VIII Division 1) shall have pressure ratings that are greater than the maximum system operating pressure by at least 15 psi.~~

~~3.7.2.8 All ASME Code components shall comply with Section VIII Division 1 of the ASME Boiler and Pressure Vessel Code.~~

~~3.7.2.9 All gasketed and packed joints shall have a minimum design pressure rating of the pump shut-off pressure plus 15 psi.~~

SUPPLEMENT 1.I

GENERAL DESCRIPTION OF HI-STORM 100U SYSTEM

1.I.0 GENERAL INFORMATION

The HI-STORM 100U System is an alternative Vertical Ventilated Module (VVM) design to be used with the Holtec International Multi-purpose Canisters (MPCs) for dry storage of spent nuclear fuel at an Independent Spent Fuel Storage Installation (ISFSI). Information pertaining to the HI-STORM 100U System is generally contained in the "I" supplements to each chapter of this FSAR. Certain sections of the main FSAR are also affected and are appropriately modified for continuity with the "I" supplements. Unless superseded or specifically modified by information in the "I" supplements, the information in the main FSAR is applicable to the HI-STORM 100U System. Drawings specific to the HI-STORM 100U VVM are in Subsection 1.I.5. The Glossary has been appropriately augmented to include the terms particular to the HI-STORM 100U VVM.

1.I.1 INTRODUCTION

HI-STORM 100U, like HI-STORM 100[1] and HI-STORM 100S[2], is a vertical, ventilated dry spent fuel storage system engineered to be fully compatible with the presently certified HI-TRAC transfer casks and MPCs. HI-STORM 100U is an underground vertical ventilated module (VVM) designed to accept all MPC models for storage at an ISFSI (see Figure 1.I.1). ISFSIs employing the VVM may be designed for any number of MPCs and expanded to add additional storage modules as the need arises. Each VVM stores one MPC.

The design and operational attributes of the HI-STORM 100U VVM, described in the following paragraphs pursuant to the provisions of 10CFR72.24(b), are subject to intellectual property rights in the U.S. and abroad under the patent laws governing the respective jurisdictions.

1.I.2 GENERAL DESCRIPTION OF HI-STORM 100U SYSTEM

1.I.2.1 HI-STORM 100U Vertical Ventilated Module

The VVM provides for storage of MPCs in a vertical configuration inside a subterranean cylindrical cavity entirely below the top-of-the-grade (TOG) of the ISFSI (Figure 1.I.2 provides identification of the TOG). The MPC Storage Cavity is defined by the Cavity Enclosure Container (CEC), consisting of the Container Shell integrally welded to the Bottom Plate. The top of the Container Shell is stiffened by the Container Flange (a ring shaped flange), which is also integrally welded. As shown in licensing basis drawings provided in Section 1.I.5, all of the constituent parts of the CEC are made of thick low carbon steel plate (See Table 2.I.8 for component materials). In its installed configuration, the CEC is interfaced with the surrounding subgrade for most of its height except for

[1] U.S. Patent No. 6,064,710 dated May 16, 2000.

[2] U.S. Patent No. 6,718,000 dated April 6, 2004.

the top region where it is girdled by the ISFSI pad. The ISFSI pad serves several purposes in the HI-STORM 100U storage system, such as:

- It provides an essentially impervious barrier of reinforced concrete against seepage of water from rain/snow into the subgrade.

- It provides the interface surface for the CEC flange.

- It helps maintain a clean, debris-free region around the VVMs.

- It provides the necessary riding surface for the cask transporter (see Figure 1.I.7).

The ISFSI pad is actually composed of two distinct regions separated by suitably engineered expansion joints. These are referred to as (see Figure 1.I.3):

i. the VVM Interface Pad (VIP) and
ii. the Top Surface Pad (TSP).

As its name implies, the VIP is in close contact with the Container Flange and the upper part of the Container Shell for sealing and shielding purposes. In Figures 1.I.1 and 1.I.2, the elevated portion of the ISFSI pad is the VIP.

The balance of the ISFSI pad, lower in elevation than the VIP, is the top surface pad (TSP). The TSP carries no significant loads except during the movement of the cask transporter over portions of its surface. The substantial difference in the dead load patterns on the two regions of the ISFSI pad warrants that the two regions be physically disconnected so that differential settlement between the two do not produce (undesirable) flexural and shear loadings. Governing codes for the ISFSI pad design and construction are described (see Supplement 2.I) to ensure a high integrity design. Expansion joints are placed between the two pads where necessary to ensure that vertical movements are independent. As discussed in Supplement 3.I, an optional concrete encasement around the coated external surface of the CEC may be added to control the pH at the CEC-to-subgrade interface.

Corrosion mitigation measures commensurate with site-specific conditions are implemented on below-grade external surfaces of the CEC. A corrosion allowance (metal wastage) equal to 1/8" on the external surfaces of the VVM in contact with the subgrade is nevertheless assumed in the structural evaluation in Supplement 3.I. All external and internal surfaces of the VVM are coated with an appropriate surface preservative. The top surfaces of the MPC Bearing Pads are equipped with stainless steel liners so that the MPC is not resting directly on carbon steel components. Details of corrosion mitigation measures are described in Section 3.I.4.

With the Closure Lid removed, the CEC is a closed bottom, open top, thick walled cylindrical vessel that has no penetrations or openings. Thus, groundwater has no path for intrusion into the interior space of the MPC storage cavity. Likewise, any water that may be introduced into the MPC storage cavity through the air passages in the top lid will not drain out on its own. The Bottom Plate of the CEC is round and slightly larger in diameter than the Container Shell to accommodate an all around weld between the plate and the shell.

The Support Foundation has circular VVM Lateral Support Recessed Regions to locate and contain lateral motion of each VVM with respect to the Support Foundation. The VVM Support Foundation and the underlying substrate must be sufficiently strong to prevent significant long-term settlement under the weight of the loaded storage cavities. The appropriate requirements on the Support Foundation's structural strength and the applicable industry code are specified in Supplement 2.I of this FSAR. Like the ISFSI pad above, the Support Foundation is classified as an "interfacing structure" in this FSAR.

The MPC Bearing Pads and the Divider Shell, two parts internal to the CEC, are important to the VVM's thermal performance. The Divider Shell, as its name implies, is a vertical cylindrical shell concentrically situated in the CEC. The Divider Shell creates an outer annular coolant air or intake plenum and an inner annular coolant air space around the MPC. The bottom end of the Divider Shell has cutouts to enable incoming air streaming down the intake plenum to enter the inner coolant air space from around the circumference of the Divider Shell in a symmetric manner (Figures 1.I.2 and 1.I.4). The sectors of the Divider Shell that rest on the CEC Bottom Plate are also the locations where MPC Bearing Pads provide for a Bottom Plenum underneath the MPC for access of coolant air. The cutouts in the Divider Shell are sufficiently tall to ensure that if the cavity were to be filled with water, the bottom region of the MPC would be submerged for several inches before the water level reaches the top edge of the cutouts. This design feature is important to ensure uncompromised thermal performance of the system under any conceivable accidental flooding of the cavity by any means whatsoever. The Divider Shell is laterally restrained in the horizontal plane at its bottom end by the Divider Shell Restraints and rotationally restrained in the horizontal plane by the MPC Bearing Pads. The Divider Shell is not attached to the CEC; this allows convenient removal for decommissioning, for unplanned in-service maintenance, or for any other unforeseeable reason. The Divider Shell's interface with the Closure Lid features a small gap to permit the Divider Shell to expand freely from heating by ventilation air.

In addition to the lateral restraints at the bottom, the Divider Shell is also restrained against lateral movement at the top by the cylindrical protrusion in the Closure Lid. In addition, the Divider Shell is equipped with Upper and Lower MPC Guides. The Upper MPC Guides are radially symmetric and located at the elevation of the MPC's top lid. The Upper MPC Guides serve to guide the MPC down to the Lower MPC Guides and MPC Bearing Pads during the MPC's lowering operation, as well as to limit the MPC's lateral movement relative to the CEC, during an earthquake event, to a fraction of an inch.

The cylindrical surface of the Divider Shell is equipped with insulation to ensure that the heated air streaming up around the MPC in the inner coolant air space causes minimal preheating of the air streaming down the intake plenum. As discussed in Supplement 3.I.4, the insulation material is selected to be water and radiation resistant and non-degradable under accidental wetting.

Finally, the Closure Lid shown in Figure 1.I.6 completes the physical embodiment to the VVM. The Closure Lid is a steel structure filled with shielding concrete. The design of the top lid fulfills the following principal performance objectives:

i. Both the inlet and outlet air passages are located in the Closure Lid, so there are no lateral radiation leakage paths during the MPC lowering or raising operation. The need for shield blocks (necessary to close off vents in some aboveground HI-STORM 100 overpacks) is eliminated.

ii. Both inlet and outlet passages are radially symmetric so that the air cooling action in the system is not affected by the change in the horizontal direction of the wind.

iii. By locating the air inlet at the periphery of the Closure Lid and the air outlet at its top central axis, mixing of entering and exiting air streams is essentially eliminated.

iv. The inlet and outlet air passages are made of "formed and flued" heads (i.e., surfaces of revolution) that serve three major design objectives as noted below.

  a. The curved passages eliminate any direct line of sight to the MPC storage space and serve as an effective means to scatter the photons streaming from the stored fuel.

  b. The curved steel plates significantly increase the load bearing capacity of the Closure Lid much in the manner as a curved beam exhibits considerably greater lateral load bearing capacity in comparison to its straight counterpart. This design feature is a valuable attribute if a "beyond-the-design basis" impact scenario involving a large and energetic missile needs to be evaluated for a particular ISFSI site.

  c. The curved passages, as is well known in classical hydraulics, provide for minimum loss of pressure in the coolant air stream, resulting in a more vigorous ventilation action.

v. The Closure Lid rests on the Container Flange and is gasketed to minimize foreign material intrusion.

vi. The top surface of the Closure Lid is also curved and extended beyond the air inlet perimeter to efficiently drain off rainwater.

vii. The Container Flange restrains the Closure Lid against horizontal movement, during a Design Basis Earthquake event or a tornado missile strike.

viii. The radially symmetric air inlet passage in the lid is geometrically aligned with the annular opening formed between by the Divider Shell and the CEC Shell.

ix. Because the inlet opening extends around the circumference of the Closure Lid, the hydraulic resistance to the incoming airflow, a common limitation in ventilated modules, is minimized. A similar airflow resistance minimization facility is built into the pathway for the exiting air. A circumferentially circumscribing vent opening is also quite obviously less apt to be completely blocked under even most extreme environmental phenomena involving substantial quantities of debris.

x. To minimize the VVM's height, a portion of the Closure Lid extends into the cylindrical space above the MPC. This cylindrical below-surface extension of the Closure Lid is also made of steel filled with shielding concrete to maximize the blockage of skyward radiation issuing from the MPC.

xi. All inlet and outlet air passages are equipped with screens, as in the aboveground HI-STORM overpacks, to prevent debris, insects, and small animals from entering the VVM. Although the screen is a non-structural member, it is designed for long-term durability and easy maintainability to ensure that its installation, removal, and maintenance are ALARA.

Finally, particular attention is paid to the design of the exit vent assembly (at the top of the outlet air passages in Figure 1.I.2) to ensure that wind-driven rain at up to 45° inclination from the vertical will not have a direct line of sight to the vertically oriented portion of the air passage in the Closure Lid.

xii. As can be seen from the drawings in Section 1.I.5, the Closure Lid is substantially larger in diameter than the Divider Shell in the CEC and the MPC is positioned to be at a significant vertical depth below the top of the Container Flange. These geometric provisions ensure that the Closure Lid will not fall into the MPC storage cavity space and strike the MPC if it were accidentally dropped during its handling. An accidental drop of the MPC, however, can lead to a collision with the top of the Divider Shell. The Divider Shell, if damaged due to a handling accident, can be readily removed and repaired or replaced without affecting any other parts of the VVM. Because the Closure Lid is the only removable heavy load, the carefully engineered design features to facilitate recovery from its accidental drop provide added assurance that a handling accident at the ISFSI will not lead to radiological release. This additional measure against accidental Closure Lid drop does not replace the drop prevention features mandated in this FSAR on heavy load lifting devices such as the cask transporter (illustrated in Figure 1.I.7) that have been a standard and established requirement in the HI-STORM 100 docket.

From a jurisdictional standpoint, the CEC, the Container Flange, and the Closure Lid, constitute the body of the VVM. The Support Foundation on which the VVM rests, however, must be designed to meet certain structural criteria to minimize long-term settlement and physical degradation from aggressive attack of the materials in the surrounding subgrade. Likewise, the Top Surface Pad serves to augment shielding, but is mainly needed to provide a sufficiently stiff roadway for the transporter. Similarly, the VVM Interface Pad (Figure 1.I.2) serves to augment shielding, as a barrier against gravity induced seepage of rain or floodwater around the VVM body, and as a barrier against a missile directed towards the underground portion of the CEC structure. The essential structural requirements applicable to the design of the Support Foundation, the VVM Interface Pad, and the Top Surface Pad for proper functioning of the VVM are provided in Supplement 2.I (Principal Design Criteria). Similarly, typical physical characteristics of the surrounding substrate are provided in Supplement 2.I. This data is intended to provide guidelines for the design of SSCs proximate to the VVM to ensure that the VVM, regardless of the wide variations in the properties at an ISFSI site, will render its intended function for the duration of its Design Life.

The foregoing description of the VVM clearly indicates that the principal function of the VVM structure is to provide the biological shield and cooling facility. However, for conservatism, stress limits of the "Level A" service condition in Subsection NF of the ASME Code are applied to establish the embedded structural margins of safety in the primary load bearing parts of the VVM under normal conditions of storage. For short term and accident conditions (i.e., earthquakes, missile strike, etc.), the continued functional adequacy of the system is the appropriate criterion. For the VVM, continued functional adequacy under accident or extreme environmental events demands absence of a complete blockage of the ventilation passages and a non-significant amount of loss of shielding. Supplement 2.I provides complete details on the applicable design criteria.

All MPC types certified for storage in the aboveground overpacks can be stored in the below ground VVM. The chief distinguishing features of the VVM are its low profile and subterranean configuration. The Container Shell is buried below the ISFSI Pad for virtually its entire height, resulting in a near complete blockage of laterally emanating radiation from the stored fuel.

In summary, the notable design and operational features of the HI-STORM 100U System are:

i. The MPC is supported on MPC Bearing Pads to provide an inlet air plenum at the bottom of the storage cavity (Figure 1.I.2). The bottom of the MPC, however, will be in contact with water if the cutouts at the bottom of the Divider Shell were to be filled with water cutting off feed air. As long as the MPC is wetted with water, the peak cladding temperature of the stored spent fuel will not exceed the regulatory off-normal condition temperature limit. Thus, the VVM configuration provides a built-in protection against flood events.

ii. Like the HI-STORM 100A and 100SA models, tipover of the canister in storage is not possible.

iii. Although the modules may be closely spaced, as illustrated in Figure 1.I.5, the design permits any MPC located in any cavity to be independently accessed and retrieved using a HI-TRAC transfer cask.

iv. A cask transporter typical of those used in numerous Holtec ISFSI projects for on-site transport of loaded HI-TRACs and HI-STORMs can provide the means to deliver the loaded HI-TRAC to the HI-STORM 100U VVM and to carry out the MPC lowering operation (Figure 1.I.7). The same cask transporter can also be used to remove an MPC from storage and place it in a recipient HI-TRAC transfer cask.

v. To exploit the biological shielding provided by the surrounding soil subgrade, the MPC is entirely situated well below the top-of-grade level. The open plenum above the MPC also acts to boost the ventilation action of the coolant air.

vi. Because the VVM is rendered into an integral part of the subgrade, it cannot be translocated to another ISFSI site. It also cannot be lifted and, therefore, is not subject to the potential for a handling accident.

vii. Removal of water from the bottom of the storage cavity can be carried out by the simple expedient use of a flexible hose inserted through either the inlet or the outlet passageway.

viii. As discussed in Supplement 3.I.4, all exposed surfaces of the VVM are coated with proven surface preservatives that meet the toxicological and extraction test requirements of ANSI/NSF Standard 61.

ix. The VVM is a formed metallic welded structure with a removable Closure Lid. The Closure Lid is also a formed metallic welded structure but filled with shielding concrete. The requirements on the shielding concrete are specified in Appendix 1.D.

As can be readily deduced from the above description of the VVM, the MPC storage cavity (consisting of the Container Shell and Bottom Plate) is at or near ambient temperature during normal operations. The only portions of the VVM in contact with heated ventilation air are the Divider Shell and the domed annular outlet in the Closure Lid, neither of which is in contact with the subgrade soil.

It should be recognized that the depth of the MPC Storage cavity determines the height of the hot air column in the annular region during the system's operation. Therefore, deepening the cavity has the beneficial effect of increasing the quantity of the ventilation air and, thus, enhancing the rate of heat rejection from the stored MPC. Further, lowering the MPC in the MPC Storage cavity will increase the subterranean depth of the radiation source, making the site boundary dose even more miniscule. To ensure that the thermal and shielding performance is the bounding minimum, the top of the MPC is assumed to be at its maximum permissible elevation with respect to the Top-of-the-Grade and the MPC Storage Cavity depth is assumed to be accordingly at its permitted minimum in all thermal and shielding analyses reported in Supplements 4.I and 5.I, respectively, and in the drawings provided in Section 1.I.5. At a specific ISFSI site, the user has the latitude to deepen the VVM cavity and situate the MPC at a deeper depth using the §72.48 process.

The VVM implements seals or gaskets at the Closure Lid. The outer seal is a weather seal (between the Closure Lid and the top of the Divider Shell), which facilitates maintenance by minimizing foreign material intrusion into the MPC storage cavity. The inner seal (between the Closure Lid skirt and the Divider Shell (not shown on the licensing drawing 4501)) provides an enhanced barrier against mixing of inlet and outlet air in the annular space between the Divider Shell and the cylindrical protrusion in the Closure Lid (even though the pressure differential between the two sides is extremely low – less than a few inches of water). The outer seal relies on the weight of the Closure Lid to insure sealing. A polymeric gasket made from EPDM[3] is preferred for this purpose. The inner seal is made of a durable radiation and heat resistant material and designed to have no credible mechanism for significant degradation or detachment from its sealing location. The seals do not

[3] Radiation resistant polymeric gasket materials are available from the Presray and Pawling Corporations, for example.

provide a safety function because their loss during operation would not have an effect on safe operation of the system.

Finally, the physical hardening of the VVM against impulsive and impactive loadings is a major consideration in the embodiment of the HI-STORM 100U System. Quite obviously, the low physical profile of the VVM reduces the probability of impact from a missile or a projectile. In addition, to impute maximum margin against extreme environmental phenomena loads, the Closure Lid is a METCON® (metal/concrete) structure engineered to possess considerably greater strength reserve than that required to prevent design basis missiles from penetrating into the MPC storage cavity, as demonstrated by analysis in Supplement 3.I. Another design consideration is protection against intrusion of rainwater and other liquid matter into the MPC storage cavity. In contrast to typical ventilated modules, the VVM air passages are elevated above the Top-of-the-Grade, providing a physical barrier against the intrusion of any accumulating pool of fluid (including combustibles) on the ISFSI surfaces into the module cavity. A significantly enhanced level of protection against incident missiles and an improved barrier against ingress of rainwater or spilled fluids into the module cavity space, and a design that is ideally configured for a flood event, are among the many distinguishing features of the HI-STORM 100U System.

1.I.2.2 HI-STORM 100U System Sequence of Operations

Fuel loading operations and MPC preparation are identical for the VVM as they are with the other HI-STORM overpack designs. The HI-TRAC transfer cask is used for on-site transport of the loaded MPC from the MPC preparation area to the VVM at the ISFSI. The Closure Lid will have been previously removed from the VVM. The cask transporter carrying the transfer cask and the MPC moves over the top of the open VVM where the HI-STORM mating device (shown beneath the HI-TRAC in Figure 1.I.7) is in place. The MPC inside the transfer cask is lifted slightly by the cask transporter (or an equivalent heavy load handling device) to allow the transfer cask pool lid to be removed. Once the pool lid is removed, the heavy load handling device is used to lower the MPC into the VVM. The transfer cask and mating device are removed from the top of the VVM, the MPC lift connectors are removed, and the VVM Closure Lid is installed. Supplement 8.I provides a more detailed discussion of operations involving the HI-STORM 100U System. (The "mating device" aided MPC transfer operation is an exclusive intellectual property of Holtec International under U.S. Patent No. 6,853,797 B2 dated February 8, 2005.)

1.I.3 IDENTIFICATION OF AGENTS AND CONTRACTORS

Same as in Section 1.3.

1.I.4 GENERIC CASK ARRAYS

An ISFSI deploying the HI-STORM 100U System may use an unlimited number of VVMs. The preferred embodiment of the VVM array is a rectangular grid as illustrated in Figure 1.I.5. The minimum pitch between the VVM cavities is shown on the licensing drawing in Subsection 1.I.5. In either or both directions, the spacing can be increased by the site to ensure that any of the commercially available cask transporters can traverse the VVM arrays to provide autonomous access to each stored MPC. This minimum spacing also serves to provide adequate shielding around each storage cavity.

No limit is placed on the maximum spacing. Multiple VVMs in an ISFSI shall be founded on a continuous support foundation to prevent an unacceptable level of differential settlement between adjacent VVMs and to enhance the seismic response characteristics of the ISFSI.

The design of the expansion joints between the VVM Interface Pad and the Top Surface Pad regions of the ISFSI Pad is guided by the need to physically decouple the settlement of the two regions due to long term creep effects.

Additional VVMs may be built adjacent to existing VVMs without imparting excessive dose to the construction crew, if a sufficient distance to loaded VVMs is kept. To ensure that this distance is kept, a "Radiation Protection Space" (RPS) boundary is specified in the drawing package in Section 1.I.5. This boundary shall not be encroached upon during any site construction effort. Subsection 2.I.6(xii) contains additional requirements on the design and qualification of the RPS to insure that the earthen shielding in the RPS shall be protected against a significant loss due to human error or natural events such as earthquakes and tornado borne missiles.

1.I.5 FIGURES AND DRAWINGS

Figures associated with Supplement 1.I and the licensing drawing package of the HI-STORM 100U VVM, pursuant to the requirements of 10CFR72.24(c)(3), are provided in this subsection. The material in the licensing drawing package in this section contains sufficient information to articulate major design features and general operational characteristics of the HI-STORM 100U VVM. Further, it is intended to serve as the control information to guide the preparation of the documents required to manufacture the components under the company's quality assurance system. Some key document types needed for manufacturing in the factory under the company's fail-safe configuration control protocol are:

- Purchasing Specifications (PSs)
- Manufacturing Drawing Package
- Holtec Standard Procedures (HSPs)
- Holtec Project Procedures (HPPs)
- Bill-of-Materials
- Fabrication and NDE Procedures
- Shop Travelers

Holtec's Quality Assurance Program requires that the entire array of manufacturing documents must remain in complete consonance with the Licensing Drawing Package (and other provisions in this FSAR) at all times.

Drawing Number/Sheet	Description	Rev.
4501	HI-STORM 100U Vertical Ventilated Module	4

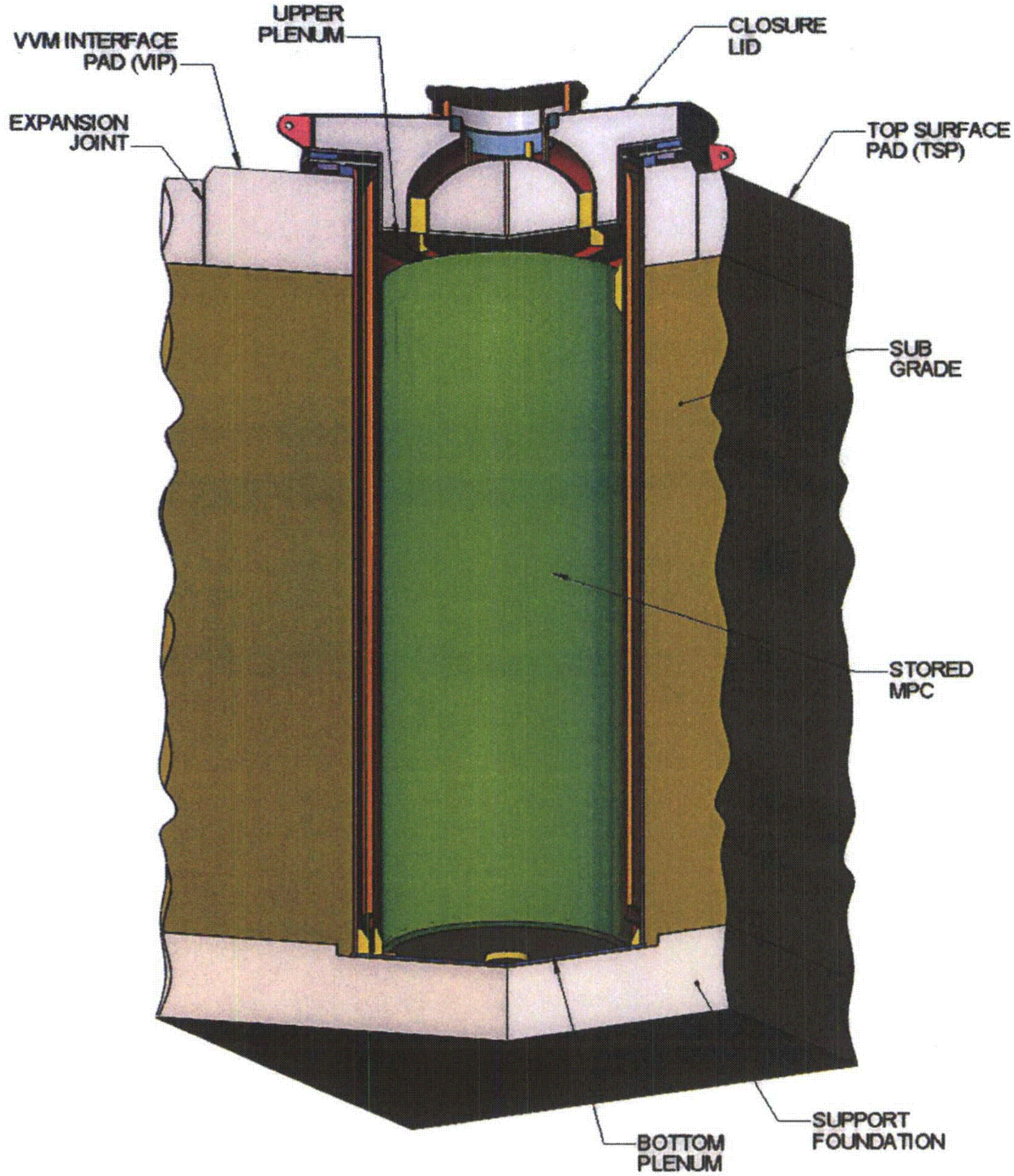


FIGURE 1.I.1: CUT-AWAY VIEW OF HI-STORM 100U SYSTEM)

Note: The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

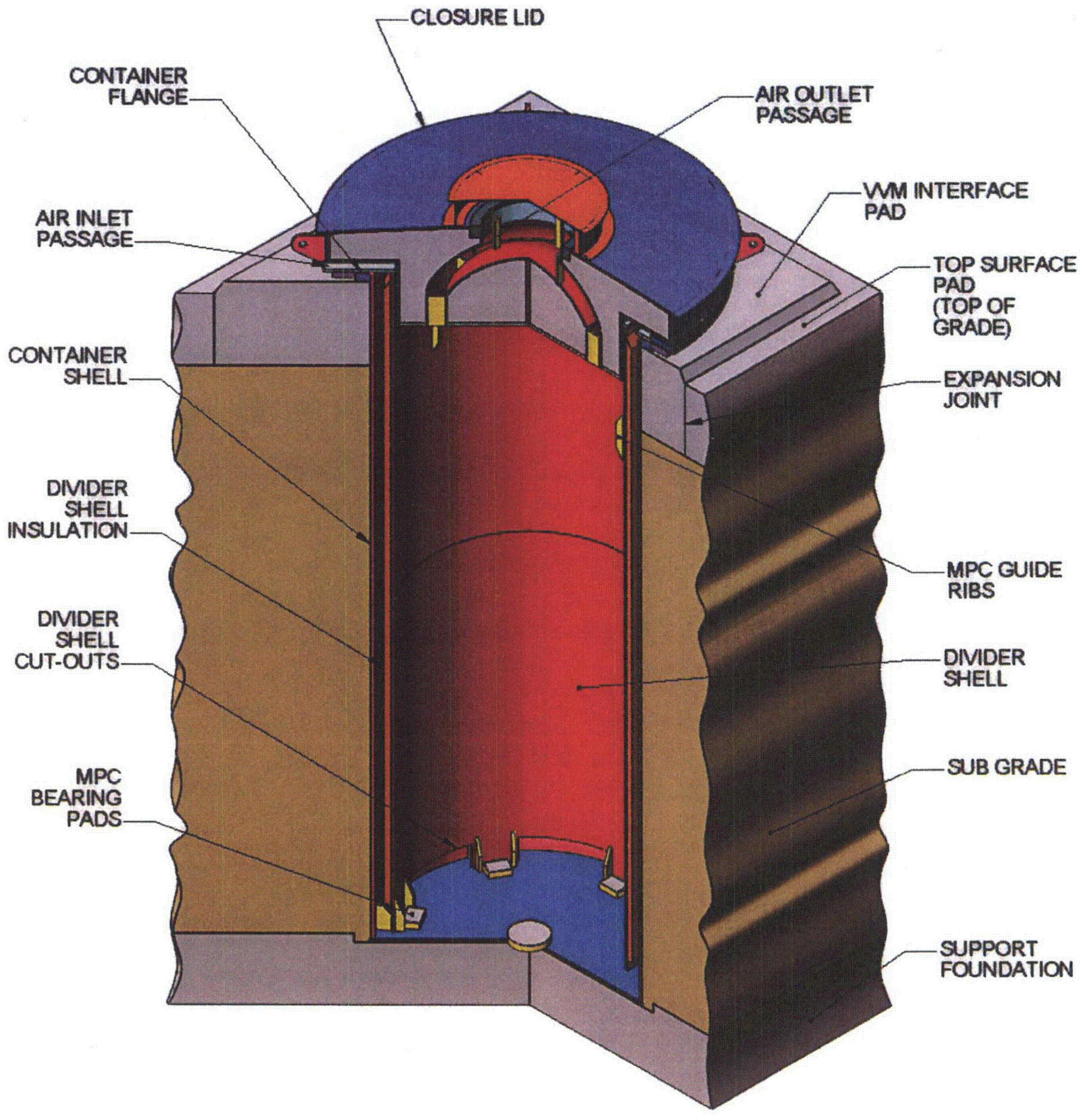


FIGURE 1.I.2: CUT-AWAY VIEW OF THE HI-STORM 100U VVM

Note: The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

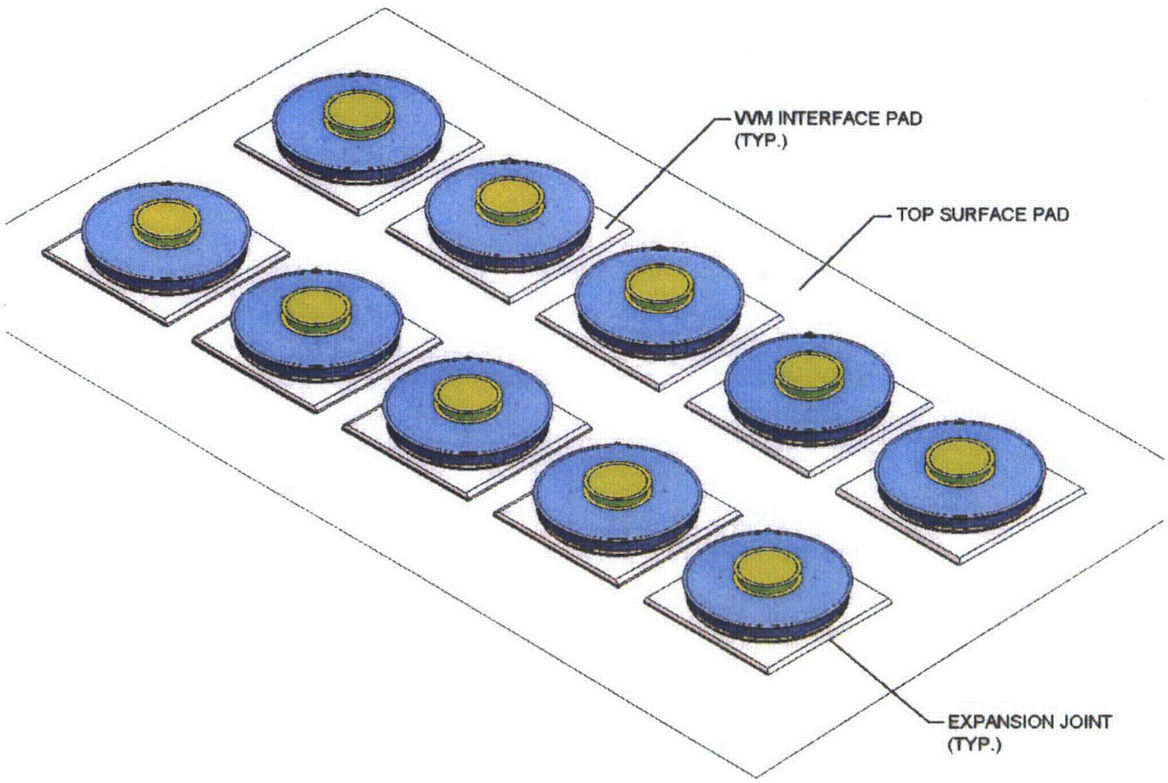


FIGURE 1.I.3: TYPICAL HI-STORM 100U SYSTEM ISFSI 2 x 5 ARRAY

Note: The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

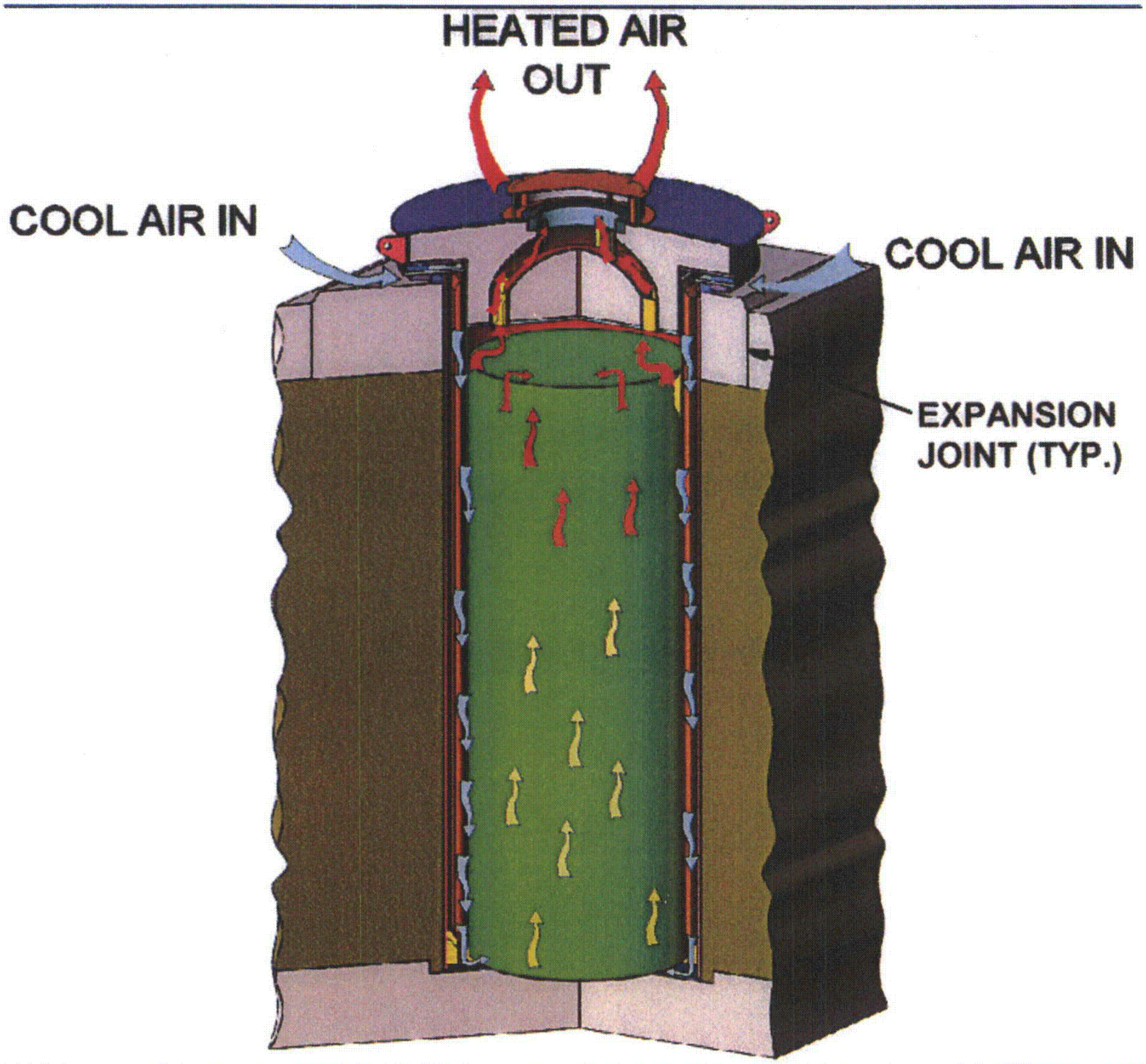


FIGURE 1.I.4: HI-STORM 100U SYSTEM AIR FLOW PATTERN

Note: The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

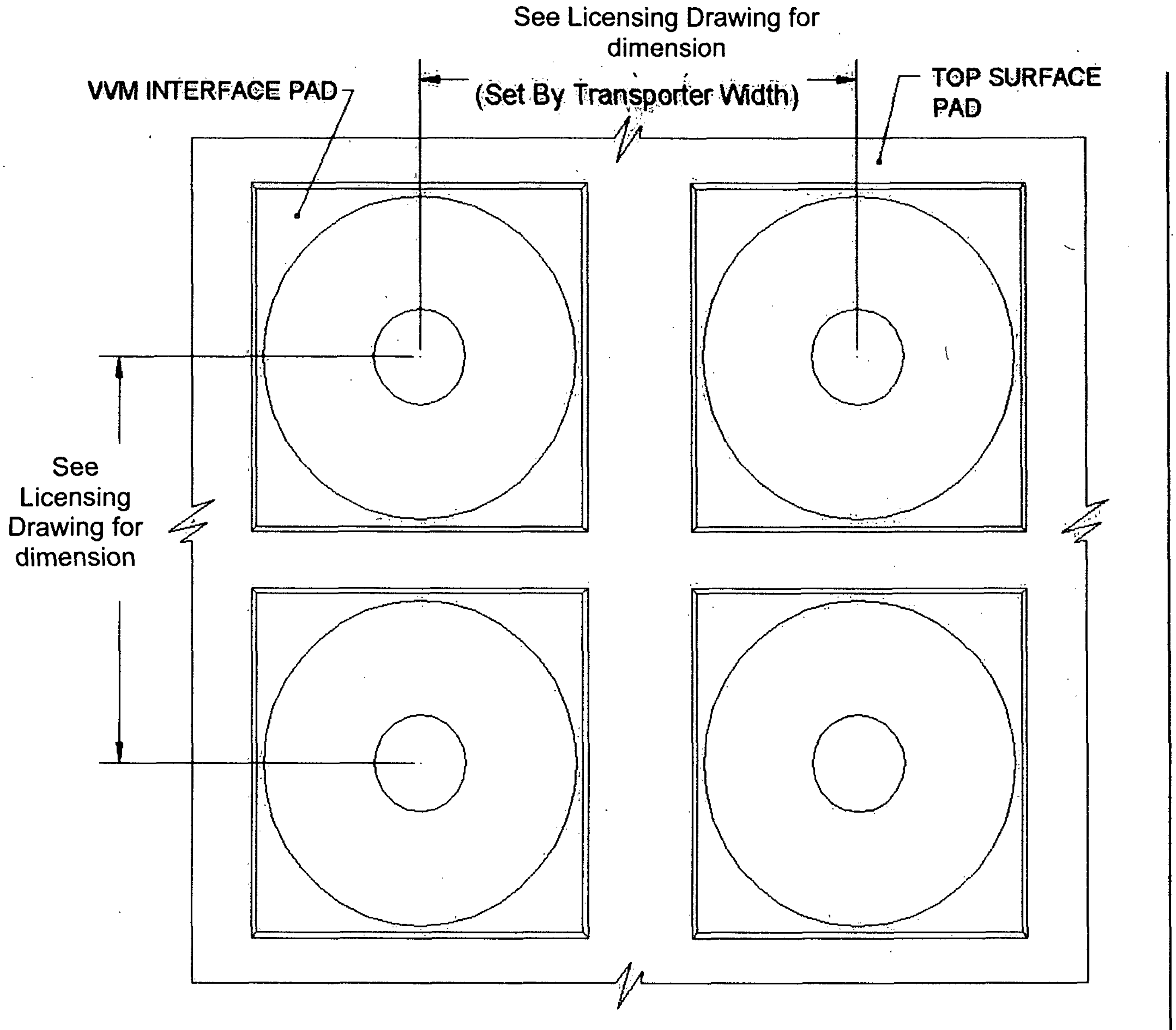


FIGURE 1.I.5: PLAN VIEW OF A 2X2 HI-STORM 100U SYSTEM STORAGE ARRAY

Note: The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

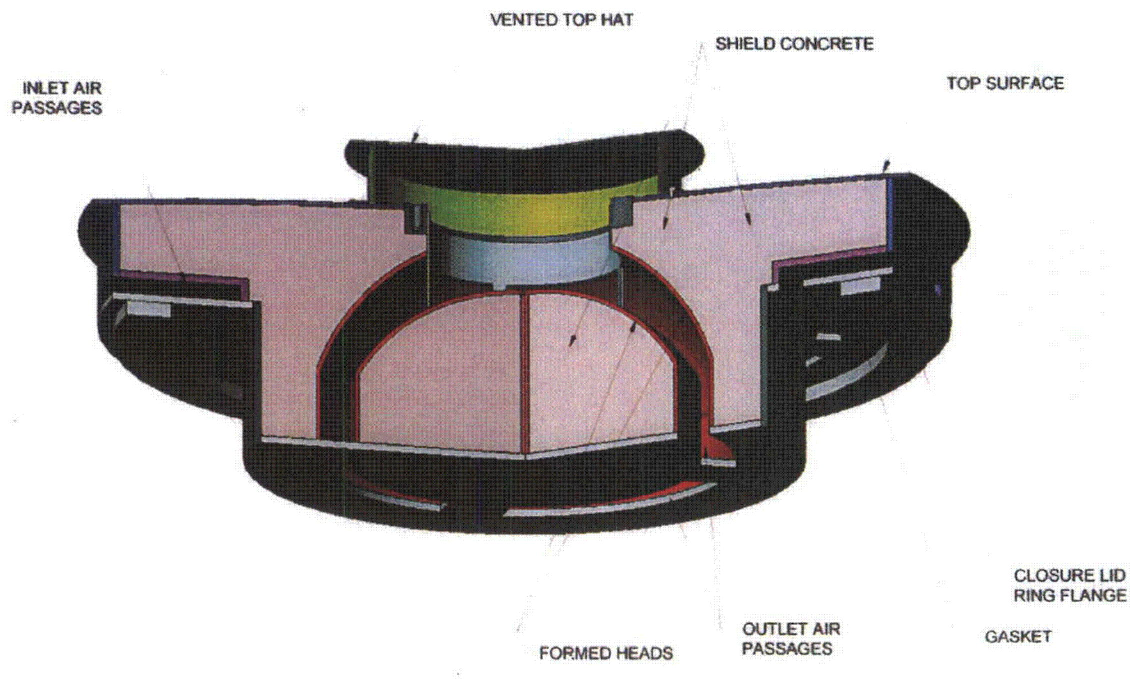


FIGURE 1.I.6; HI-STORM 100U VVM CLOSURE LID GENERAL ARRANGEMENT (SHOWN IN CUT-AWAY VIEW)

Note: The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

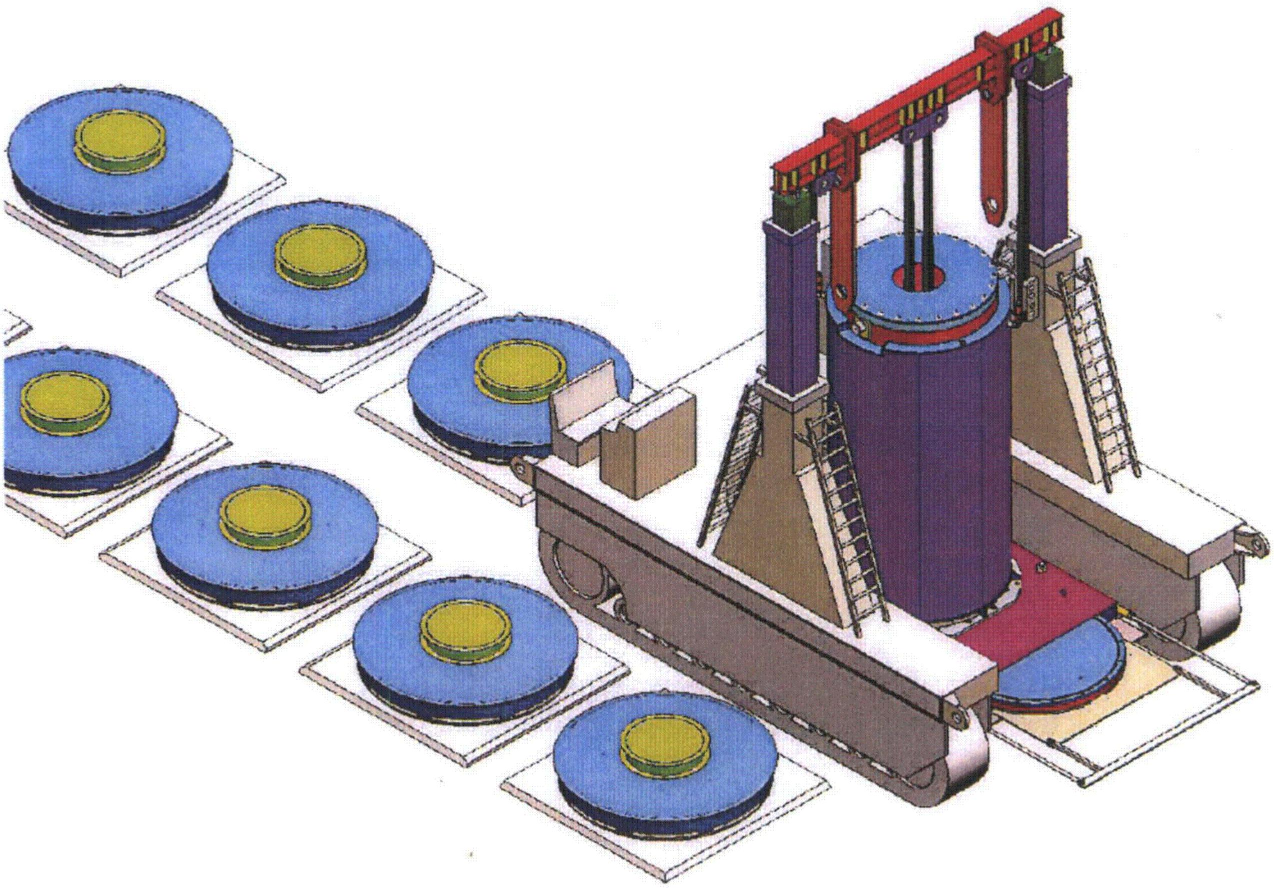


FIGURE 1.I.7; MPC TRANSFER IN A HI-STORM 100U VVM USING A VERTICAL CASK TRANSPORTER

Note: The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM 100U depicted here may vary slightly from the licensing drawings in Subsection 1.I.5.

SUPPLEMENT 2.I
PRINCIPAL DESIGN CRITERIA FOR THE HI-STORM 100U SYSTEM

2.I.0 OVERVIEW OF THE PRINCIPAL DESIGN CRITERIA

General

A description of the HI-STORM 100U VVM is provided in Supplement 1.I. Because the HI-STORM 100U System uses the same MPCs, transfer cask, and ancillary equipment as the aboveground systems, the design criteria presented in Table 2.0.1 for the MPC, and Table 2.0.3 for the HI-TRAC transfer cask provide the basis for setting down the applicable criteria in this supplement with due recognition of the advances in the analysis methodologies over the past decade. The applicable loads, the affected parts under each loading condition, and the applicable structural acceptance criteria are compiled in this supplement to provide a complete framework for the required qualifying analyses in Supplement 3.I. Information consistent with the regulatory requirements related to shielding, thermal performance, confinement, radiological, and operational considerations is also provided. The licensing drawing of the HI-STORM 100 System 100U VVM, provided in Section 1.I.5, along with Table 2.I.2 herein provide information on all necessary critical characteristics to define the "100U" storage system. The constituents of the HI-STORM 100U ISFSI fall into two broad categories, namely:

i. VVM components
ii. ISFSI structures

The safety analyses documented in Supplement 3.I address both the VVM components and the ISFSI Structures. The ISFSI Structures consist of:

i. The Support Foundation Pad (SFP)
ii. The Top Surface Pad (TSP),
iii. The VVM Interface Pad (VIP), and
iv. The Retaining Wall, if used at the site.

Figure 2.I.5 depicts the subgrade and undergrade nomenclature for the ISFSI. The density and shear wave velocities of these are given in Table 2.I.2. The following are a description of the areas shown in Figure 2.I.5 which contribute to the analysis of the ISFSI.

i. Space A is the lateral subgrade space, in and around the VVMs, which may be excavated and refilled with engineered fill.
ii. Space B is the lateral subgrade that extends by the amount W around the ISFSI where W is the characteristic dimension of the ISFSI.
iii. Space C is the undergrade below the SFP extending 100 feet below the bottom of the SFP.
iv. Space D is the undergrade surrounding Space C extending 100 feet below the bottom of the SFP.

Structural

All required information on the design bases and criteria for the VVM are compiled in this supplement to fulfill the requirements of 10CFR72.24(c)(3) and 72.44(d). Table 2.I.1 contains a detailed listing of the information and its location in this FSAR corresponding to each relevant requirement in 10CFR72 with reference to the VVM. The VVM structure described in Supplement 1.I is designed for all applicable normal, off-normal, extreme environmental phenomena, and accident condition loadings pursuant to 10CFR72.24(c), 72.122(b) and 72.122(c).

The subgrade surrounding the VVM, the SFP on which the VVM is founded, and the VIP are categorized as "interfacing SSCs", while the TSP and the retaining wall (if used) are categorized as "proximate structures". All of these structures are classified as important-to-safety (ITS) (see Table 2.I.8) and are included in the analyses in Supplement 3.I, and in other supplements as applicable. Table 2.I.2 defines the essential design requirements for these structures. ACI-318 (05) [2.I.5] is specified as the governing code for the design qualification of the SFP, VIP, the TSP, and the retaining wall (if used) using the load combinations specified in Table 2.I.11. The seismic qualification of the storage system is performed in Supplement 3.I using the design data of the ISFSI.

In addition to defining the design details of the ISFSI components and structures, the material types used in the VVM are also identified in Table 2.I.8. Material designations used by ASTM and ASME for various product forms are, however, subject to change as these material certifying organizations publish periodic updates of their standards. Material designations adopted by the International Standards Organization (ISO) also affect the type of steels and steel alloys available from suppliers around the world. Therefore, it is necessary to provide for the ability in this FSAR to substitute materials with equivalent materials in the manufacture of the equipment governed by this FSAR.

As defined in this FSAR, the term "Equivalent Material" has a specific meaning: Equivalent materials are those that can be substituted for each other without adversely affecting the safety function of the SSC (system, structure, and component) in which the substitution is made. Substitution by an equivalent material can be made after the equivalence in accordance with the provisions of this FSAR has been established.

The concept of material equivalence explained above has been previously used in this FSAR to qualify four different austenitic stainless steel alloys (ASME SA240 Types 304, 304LN, 316, and 316LN) to serve as candidate MPC basket materials.

The equivalence of materials is directly tied to the notion of *critical characteristics.* A critical characteristic of a material is a material property whose value must be specified and controlled to ensure an SSC will render its intended function. The numerical value of the critical characteristic invariably enters in the safety evaluation of an SSC and therefore its range must be guaranteed. To ensure that the safety calculation is not adversely affected, material properties such as Yield Strength, Ultimate Strength and Elongation must be specified as *minimum* guaranteed values in

VVM Components. However, there are certain properties where both minimum and maximum acceptable values are required. In this category lie VVM Component properties such as specific gravity and thermal expansion coefficient.

Table 2.I.10 lists the array of material properties typically required in safety evaluation of an SSC in dry storage and transport applications. The required value of each applicable property, guided by the safety evaluation defines the critical characteristics of the material. The subset of applicable properties for a material depends on the role played by the material. The role of a material in the SSC is divided into three categories:

Type	Technical Area of Applicability
S	Those needed to ensure structural compliance
T	Those needed to ensure compliance with thermal (temperature limits)
R	Those needed to ensure radiation (criticality and shielding) compliance

The material properties listed in Table 2.I.10 are the ones that may apply in a dry storage or transport application.

To summarize, the following procedure shall be used to establish acceptable equivalent materials for a particular application.

Criterion i: Functional Adequacy:
Evaluate the guaranteed critical characteristics of the equivalent material against the values required to be used in safety evaluations. The required values of each critical characteristic must be met by the minimum (or maximum) guaranteed values (MGVs of the selected material).

Criterion ii: Chemical and Environmental Compliance:
Perform the necessary evaluations and analyses to ensure the candidate material will not excessively corrode or otherwise degrade in the operating environment.

A material from another designation regime that meets Criteria (i) and (ii) above is deemed to be an acceptable material, and hence, equivalent to the candidate material.

Equivalent materials as an alternative to the U.S. national standards materials (e.g., ASME, ASTM, ANSI) shall not be used for the Confinement Boundary materials. For other ITS materials, recourse to equivalent materials shall be made only in the extenuating circumstances where the designated material in this FSAR is not readily available.

As can be ascertained from its definition in the glossary, the *critical characteristics* of the material used in a subcomponent depend on its function. The Closure Lid, for example, serves as a shielding device and as a physical barrier to protect the MPC against loadings under all service conditions, including the Extreme Environmental phenomena. Therefore, the critical characteristics of steel used in the lid are its strength (yield and ultimate), ductility, and fracture resistance.

The appropriate critical characteristics for structural components of the VVM, therefore, are:

i. Material yield strength, σ_y
ii. Material ultimate strength, σ_u
iii. Elongation, ε
iv. Charpy impact strength at the lowest service temperature for the part, C_i

Thus, the carbon steel specified in the drawing package can be substituted with different steel so long as each of the four above properties in the replacement material is equal to or greater than the minimum values used in the qualifying analyses in this FSAR. The above *critical characteristics* apply to all materials used in the structural parts of the CEC. Table 2.I.9 provides guidance for the critical characteristics associated with the steels used in the VVM.

In the event that one or more of the *critical characteristics* of the replacement material is slightly lower than the original material, then the use of the §72.48 process is necessary to ensure that all regulatory predicates for the material substitution are fully satisfied.

In addition to the design configuration, the maximum magnitude of Design Basis Earthquake for the "100U" ISFSI is also specified in this FSAR. A three-dimensional non-linear time-history solution procedure implemented on LS-DYNA is used in Supplement 3.I to qualify the ISFSI including the storage system. This same three-dimensional non-linear time-history solution procedure may be used to perform safety evaluation under 10CFR72.212 at a host site, as indicated in Paragraph 2.I.6(v). Likewise, the loadings from the extreme environmental phenomena, defined in the main body of Chapter 2, are considered in Supplement 3.I. Site specific loadings that deviate from those analyzed in Supplement 3.I are subject to 72.212 safety evaluations in the manner of all HI-STORM models.

To serve their intended functions, the CEC and Closure Lid shall ensure physical protection, biological shielding, and allow the retrieval of the MPC under all conditions of storage (10 CFR 72.122(l)). Because the VVM is an in-ground structure, drops and tip-over of the VVM are not credible events and, therefore, do not warrant analysis. The load cases germane to establishing the structural adequacy of the VVM pursuant to 10 CFR 72.24(c) are compiled in Table 2.I.5. The physical characteristics of the MPC intended for storage in the VVM are presented in the main body of Chapter 1.

The design bases and criteria provided in this supplement are intended to quantify the safety margins in the VVM design with respect to all applicable loadings that follow from the provisions of 10CFR72.24(c)(3), §72.122(b) and §72.122(c).

Thermal

The engineered thermal performance of the HI-STORM 100U system is essentially equivalent to its aboveground counterparts under quiescent conditions. Ambient air enters from a circumferential opening provided in the Closure Lid. The intake air flows downward through an annular passage or intake plenum formed between the CEC and the Divider Shell. At the bottom of the intake plenum the air turns inwards through openings or cutouts provided in the Divider Shell bottom and rises up through an annular gap formed between the MPC and the Divider Shell. Heat is dissipated from the MPC to this upward rising column of air. The rising air column enters the curved flow passages engineered in the Closure Lid and exhausts from the top through a large central opening (see Figure 1.I.4). To minimize the heating of the downward flowing inlet air and the upward column of heated air, the divider shell is insulated on its outside surface. The *critical characteristic* of the insulation is specified in Table 2.I.1. This thermal insulation material is required to meet the service conditions (temperature and humidity) for the design life of the VVM. Because the thermal performance of the HI-STORM 100U relies on buoyancy-driven convection of air and because of the relative proximity of the inlet and outlet vents to each other, the effect of wind on its thermal performance is also considered.

The allowable long-term and short term section-average temperature limits for concrete (used in the Closure Lid) are established in Appendix 1.D. Section-average temperature limits for structural steel in the VVM are provided in Table 2.I.8.

The VVM is designed for extreme cold conditions, as discussed in Subsection 2.2.2.2. The safety of structural steel material used for the VVM from brittle fracture is discussed in Subsection 3.1.2.3.

The VVM is designed to reject the maximum allowable heat load as defined below in a reliable and testable manner consistent with its important-to-safety designation (10CFR72.128(a)(4)).

The maximum permissible HI-STORM 100U heat load Q(X) is a function of the parameter "X" defined as the ratio of the maximum permissible inner region assembly heat load q_1, and outer region assembly heat load q_2. The inner and outer fuel storage regions are defined in Table 2.1.27. The functional relationship Q(X) is presented below:

$$Q(X) = 2 \cdot \alpha \cdot Q_d / (1 + X^y) \text{ where } y = 0.23/X^{0.1}$$

Q_d is the maximum heat load where X=1 (34kW) and α is a penalty factor for underground storage discussed in Supplement 4.I.

<u>Shielding</u>

The off-site dose for normal operating conditions to any real individual beyond the controlled area boundary is limited by 10CFR72.104(a) to a maximum of 25 mrem/year whole body, 75 mrem/year thyroid, and 25 mrem/year for other critical organs, including contributions from all nuclear fuel cycle operations. Since these limits are dependent on plant operations as well as on site-specific conditions (e.g., the ISFSI design and proximity to the controlled area boundary, and the number and arrangement of loaded storage casks at the ISFSI), the determination and comparison of ISFSI doses to these limits are necessarily site-specific. Dose rates from the HI-STORM 100U System are provided in Supplement 5.I. The determination of site-specific ISFSI dose rates at the site boundary and demonstration of compliance with regulatory limits is to be performed by the licensee for the specific VVM array in accordance with 10CFR72.212.

The VVM is designed to limit the dose rates for all MPCs to ALARA values. The VVM is also designed to maintain occupational exposures ALARA during MPC transfer operations, in accordance with 10CFR20. The underground location of the VVM significantly reduces the radiation from the ISFSI at the site boundary compared to an aboveground cask. The calculated VVM dose rates are discussed in Supplement 5.I, which also discusses dose rates during site construction next to an operating ISFSI.

The dose rate calculations presented in Supplement 5.I conservatively use a lower density for the subgrade than is specified in Table 2.I.2. For dose rate calculation at a particular ISFSI, the spatial average of the actual subgrade density shall be used.

Criticality

The VVM does not perform any criticality control function. The MPCs provide criticality control for all design basis normal, off-normal and postulated accident conditions, as discussed in Chapter 6.

Confinement

The VVM does not perform any confinement function. Confinement during storage is provided by the MPC and is addressed in Chapter 7. The CEC provides physical protection and biological shielding for the MPC confinement boundary during MPC dry storage operations.

Operations

MPC preparation for storage and onsite transport of the MPC in the HI-TRAC transfer cask is the same for the VVM as for the aboveground overpack designs. The cask transporter is used to move the loaded transfer cask to the ISFSI and to transfer the MPC into the VVM. Generic operating instructions for the use of the HI-STORM 100U System that parallel those for the aboveground overpack are provided in Supplement 8.I.

Acceptance Tests and Maintenance

The fabrication acceptance bases and maintenance program to be applied to the VVM are described in Supplement 9.I. Application of these requirements will assure that the VVM is fabricated and maintained in a manner that satisfies the design criteria defined in this FSAR.

Decommissioning

Decommissioning considerations for the HI-STORM 100U System, including the VVM, are addressed in Section 2.I.11.

2.I.1 SPENT FUEL TO BE STORED

There is no difference in the authorized contents of the HI-STORM 100U VVM and the aboveground HI-STORM systems. The information in Section 2.1 is applicable.

2.I.2 HI-STORM 100U VVM COMPONENTS, ISFSI STRUCTURES, AND CORROSION MITIGATION MEASURES

The VVM is engineered for below-grade storage for the duration of its design life, and is designed to withstand normal, off-normal, and extreme environmental phenomena as well as accident conditions of storage with appropriate margins of safety.

As discussed in Supplement 1.I, the VVM Components are (see Figure 1.I.2):

1. The MPC Cavity Enclosure Container (CEC), and
2. The Closure Lid

The CEC is comprised of the following subcomponents:

1. Container Shell (a cylindrical enclosure shell)
2. Bottom Plate
3. Container Flange (a top ring flange)
4. Divider Shell with insulation and MPC Guides
5. MPC bearing pads

The Closure Lid consists of:

1. The integral steel weldment (filled with shielding concrete), and
2. The removable vent screen assemblies (inlet and outlet).

The structural limit criteria imposed on the VVM Components are selected to comply with the provisions of 10CFR72, with an embedded large margin of safety. Table 2.I.1 provides the principal design criteria applicable to the VVM Components. The specifications of the materials of construction for the load bearing and non-load bearing parts are provided in Table 2.I.8 along with their maximum permissible temperature for different conditions of storage.

The interfacing SSCs, the proximate structures, and corrosion mitigation measures germane to the design of a HI-STORM 100U ISFSI are:

i) The SFP that supports the weight of the loaded VVMs.

ii) The ISFSI pad consisting of the VIP which provides a water seepage barrier against rainwater and melting snow and also acts as a missile barrier, and the TSP which serves as a water seepage barrier as well as the riding surface for the transporter.

iii) The lateral subgrade (natural or engineered fill) surrounding the CEC (Space "A" in Figure 2.I.5).

iv) The impressed current cathodic protection system (ICCPS) that may be used as a corrosion mitigation measure for the CEC in accordance with the Technical Specifications.

v) The concrete encasement that may be used as a corrosion mitigation measure for the CEC in accordance with Technical Specifications. Reference is made to Figure 2.I.3 for typical concrete encasement of the CEC.

vi) The retaining wall used to protect the soil column in the Radiation Protection Space from excavation activities adjacent to the ISFSI.

Each of these is discussed below:

i. <u>The Support Foundation Pad (SFP) (Interfacing Structure)</u>

The structural requirements on the SFP are focused on providing a robust support to the CEC structure (for shear and compression), and to limit the long-term settlement of the SFP. The minimum structural design requirements on the SFP are provided in Table 2.I.2 and the licensing drawing in 1.I.5.

ACI-318(2005) is the prescribed Code for SFP design. As specified in ACI-318(2005), the applicable loads on the SFP are:

1. Dead load (from the TSP, the VIP, the loaded VVM, and the mass of soil above the SFP).
2. Live load (from the loaded vertical cask transporter bearing on the TSP).
3. Seismic load (the additional inertia load, in excess of the dead weight, live load transmitted to the SFP from the loaded VVM and the transporter under the ISFSI's DBE event).
4. Long-term settlement.

The load combinations for the structural analysis of the SFP pursuant to ACI-318(2005) are provided in Table 2.I.11.

Of the above loads, the effect of long-term settlement on the SFP is treated together with the Dead load. The standard approach to compute the long-term settlement is provided in [2.I.6]. This methodology, which is based on classical soil mechanics and is utilized in the structural analysis in Supplement 3.I, is summarized below.

1. Compute the total long-term settlement, "d", of the subgrade under the SFP (Space C) over the Design Life assuming that the total load "P" (modeled as a uniform pressure at the top of the subgrade) is equivalent to that produced by the SFP fully populated with loaded VVMs for the entire life using the methodology in [2.I.6].

2. Determine an "effective" elastic spring constant "K" of Space C that emulates the cumulative settlement:

$$K = P/d.$$

3. Using the spring constant computed above, which accounts for the effect of long-term settlement under static loading, an appropriate elastic modulus is defined for the soil column under the SFP. The degraded soil modulus so defined is used in the finite element model of the SFP to evaluate the pad flexure under the factored dead load.

The maximum permitted settlement of the SFP is limited to the value specified in Table 2.I.2. Remedial measures such as pilings must be used if the Table 2.I.2 limit can not be met.

In the structural qualification of the SFP, the loading from the seismic event is computed using the dynamic elastic modulus corresponding to the minimum strain wave velocity of the subgrades specified in Table 2.I.2.

ii. <u>VVM Interface Pad (VIP) (Interfacing Structure) and Top Surface Pad (TSP) (Proximate Structure)</u>

The VIP portion of the ISFSI Pad serves no structural function in supporting the VVM. However, it girdles the Container Shell and underlies the Container Flange to form a leak tight interface, and directs water away from the CEC. The principal functions of the TSP are to provide the riding surface for the loaded transporter and also to enable rainwater to be channeled away from the storage arrays and into the site's storm drain system. The TSP is isolated from the VIP by appropriately located expansion joints to isolate the CEC from any unbalanced loads imparted by the transporter. Similarly, an expansion joint between the CEC and the VIP is incorporated to permit differential movement between the two. The licensing drawing in Section 1.I.5 provides details for the expansion joint and typical drainage and sealing details. Because the sealing is visible and accessible, re-sealing, when and if necessary, is easily accomplished. Thus, continued sealing is assured. A specific brand of sealant is noted on the expansion joint detail, but there are several equivalent* proven sealant materials commercially available that are ideal for this application and the expected ambient conditions.

In summary, the design objective for the VIP and the TSP are: to provide a leak tight interface and to provide a sufficiently inflexible travel surface for the loaded transporter, respectively. The top surface of the VIP, as shown in the 100U licensing drawing package, also serves to keep rain water away from the VVM. The minimum structural design requirements on the VIP and TSP are provided in Table 2.I.2 and the licensing drawing in 1.I.5. The applicable loads on the TSP and VIP are:

1. Dead load (Self weight including settlement effects) (TSP and VIP)
2. Live load (Weight of a loaded cask transporter) (TSP only)

* The definition of the term "equivalent" is provided in the Glossary.

3. Seismic Load (Inertia load from the concrete pad and the transporter under the ISFSI's DBE event) (TSP only).

The applicable load combinations for the structural analysis of the VIP and TSP pursuant to ACI-318(2005) are provided in Table 2.I.11.

The effect of settlement is incorporated in the stress analysis of the TSP using the same procedure as the SFP discussed above. As in the case of the SFP stress analysis, the settlement of the TSP from Dead load (self-weight) relative to the SFP over their Design Life is computed and incorporated in the stress analysis. The maximum permissible settlement of the TSP with respect to the SFP is required to be limited to the value in Table 2.I.2.

The design of the TSP together with the lateral subgrade must also satisfy the allowable bearing capacity requirement of ACI 360R-06 [2.I.8] for slabs on grade. In particular, the total load imparted by the TSP on the lateral subgrade, including the live load and seismic load from the transporter, shall be less than 50 percent of the allowable bearing capacity thereof when the load is applied uniformly.

iii. Lateral Subgrade (Interfacing SSC)

The physical characteristics of the subgrade surrounding the VVM vary from site-to-site. Further, an ISFSI owner may elect to excavate the natural subgrade and replace it with an engineered fill of an appropriate density and composition to fulfill shielding demand. While the surrounding subgrade may not provide a structural support function to the CEC structure, as an interfacing SSC, it plays a role in the loading applied to the CEC under certain scenarios, namely:

a. during an earthquake event;
b. during movement of the cask transporter along the Top Surface Pad;
c. normal storage condition from the natural overburden or under the state of maximum soil saturation (hydraulic buoyancy).

During a seismic event, the subgrade surrounding the VVM may exert a time-varying lateral pressure loading on the Container Shell, which, in principle, may ovalize the Container Shell and possibly bend it like a beam.

During the movement of the cask transporter, which is loaded with the transfer cask (see Supplement 8.I for operational details), the vertical load of the cask transporter results in a lateral pressure on the Container Shell. Although the lateral pressure is apt to be quite small due to the physical restriction on how close to the Container Shell the transporter can ride, mandatory limits on the lateral separation and subgrade properties are necessary to ensure a design with adequate safety margins. Accordingly, the minimum average density and the minimum shear wave velocity in the lateral subgrade surrounding the VVMs have been specified in Table 2.I.2.

The soil overburden pressure on the Container Shell is the third loading category which must be evaluated. Also, the condition of maximum soil saturation applies a hydrostatic pressure on the CEC. The maximum value depends on the depth of the MPC storage cavity and the effective density of the saturated soil.

iv. <u>Impressed Current Cathodic Protection System (ICCPS) (Corrosion Mitigation Measure)</u>

If an ICCPS is required by the technical specifications, it shall be implemented in accordance with the requirements in Supplement 3.I, Subsection 3.I.4.1 and appropriate references. The following general design procedure may be followed:

1. Select the current density to be applied.
2. Compute the total current required to achieve the selected current density.
3. Design the ground bed system or distributed anode system.
4. Select a rectifier of proper voltage and current output.
5. Design all electrical circuits, fittings, and switchgear in accordance with good electrical practice.
6. Locate the cathodic protection test stations.
7. Prepare the necessary drawings and specifications for the project.

An example design is provided in this subsection for illustrative purposes and should not be interpreted as implying to present the best design or the only possible design. Because there are a multitude of ISFSI variables that will bear upon the design of the ICCPS for a particular site including differing ISFSI layouts, certain simplifying assumptions are made throughout the example. The example provides the user with insight on the types of design decisions that will need to be made. For example, because of possible shielding effects between CECs, as well as other SSC obstructions, the design implements a layout with closely distributed anodes to provide more uniform current distribution. Also, the example design implements closed loop electrical connections such that if the wire/cable is severed at any one place, electrical continuity is maintained to all anodes. Another item to be considered during the design phase is whether or not a test station is needed for each and every CEC.

Figure 2.I.1 presents an example ICCPS design layout for a 2x6 Array of VVMs. The ICCPS consists of the following four main subsystems/components:

1) Rectifier
2) Anodes
3) Test Stations
4) Wires and Cables

Figure 2.I.2 presents an example ICCPS test station.

The following is an example computation for determining the required current (approximate dimensions and quantities are used) as applicable to Figure 2.I.1:

Assume a CEC length (determined from "top of grade" to bottom of CEC bottom plate): 219.5 in.
CEC outside diameter: 86 in.
CEC condition: exterior is coated
Coating efficiency: 91.5% (i.e. 8.5% of the coated CEC surface is considered bare metal)
Cathodic Protection: Rectifier and distributed Natural Graphite Anodes with carbonaceous backfill
Soil resistivity: 4,000 ohm/cm^2
Current density: 1 mA/ft^2 exposed metal
Outside area of each CEC: 59,300 in^2 (412 ft^2)
Total area for an array of twelve CECs: 4,944 ft^2
Bare CEC metal exposed: 4,944 ft^2 x 0.085 or 420 ft^2
Current required: 420 ft^2 x 1 mA/ft^2 or 420 mA

The following is additional data applicable to Figure 2.I.1.

Approximate Anode quantity: 11
Approximate Anode size: 5 in dia. x 120 in. long
Approximate Backfill quantity: 6,000 lbs of carbonaceous backfill

The total number of anodes required is determined primarily by the total current requirements of the CEC metal to be protected and the optimum current density of the anode material selected.

Graphite is a semi-consumable anode. Graphite typically has experienced corrosion rates of 1.5 to 2.16 lbs /amp year [2.I.3] or as determined by experiment, 0.08 grams per square meter of anode per amp-hour of current (at 30 C, 40 mA/cm^2 anode current density) [2.I.4]. A computed anode life of less than 40 years is acceptable as long as appropriate measures are taken to facilitate the replacement of anodes during the design phase and appropriate maintenance planning measures are implemented. Use of carbonaceous backfill should be considered since it can substantially lengthen the anode life. Inert (non-consumable) platinized anodes may also be considered.

v. Concrete Encasement (Corrosion Mitigation Measure)

If concrete encasement is used, it shall be implemented in accordance with the requirements in Supplement 3.I, Subsection 3.I.4.1 and appropriate references.

The following points shall also be taken into consideration:

- The effect of the concrete encasement on the ICCPS, if an ICCPS is also implemented.
- The concrete encasement should not interfere with the settlement of the TSP (which provides the transporter support surface) without appropriate evaluation.

vi. Retaining Wall

Because the subgrade within and around an operating 100U ISFSI serves a principal shielding function, it is essential that any excavation activity adjacent to the ISFSI (e.g., to build an extension of the ISFSI), must not disturb the soil in the Radiation Protection Space (RPS) shown in the licensing drawings (Section 1.I.5). A retaining wall at the edge of or beyond the RPS is recommended if an excavation activity is planned adjacent to the RPS boundary while the ISFSI is in active service.

The extent of the RPS is set down to ensure, with sufficient margin of safety, that the ISFSI will continue to meet all relevant safety criteria under all applicable conditions of storage including normal, off-normal, extreme environmental phenomena and accident conditions. For example, the RPS must provide sufficient buffer so that design basis projectiles (large, medium, and penetrant missiles) will not access an MPC stored in a VVM cavity. In this case, as explained in Supplement 3.I, the incident missile is assumed to act when a deep cavity has been excavated contiguous to the RPS and the direction of action of the missile is oriented to achieve maximum penetration of the sub-grade towards the CEC shell.

The retaining wall, as shown in the licensing drawing, shall be keyed to the TSP and the SFP so that it is laterally restrained from movement but does not transmit any bending moment to the SFP or the TSP. The minimum structural design requirements on the retaining wall are provided in Table 2.I.2 and the licensing drawing in 1.I.5.The applicable load combinations for the structural analysis of the retaining wall pursuant to ACI-318(2005) are provided in Table 2.I.11.

For the case where a retaining wall is not installed, no excavation activities associated with the construction of a new underground ISFSI shall take place within a distance from the RPS equal to ten times the planned excavation depth. Alternatively, the Excavation Exclusion Zone (EEZ), defined as the minimum distance from the centerline of a VVM located on the periphery of the ISFSI to where the effect of DBE is sufficiently attenuated such that a full depth excavation will not cause collapse of the lateral sub-grade at the RPS boundary during an earthquake, can be determined by a site specific seismic analysis. If a retaining wall is installed at or beyond the RPS then the wall becomes the EEZ boundary.

2.I.3 Service Conditions and Applicable Loads

The categories of loads on the HI-STORM 100U VVM are identified below. They parallel those for the aboveground systems.

- Normal Condition: dead weight, handling of the Closure Lid, soil overburden pressure from subgrade, live load due to cask transporter movement, snow loads, and buoyancy effect of water saturation of surrounding subgrade and foundation. Most normal condition loadings occur at an ambient temperature denoted as the "normal storage condition temperature"; however, for calculations involving the Closure Lid, a higher temperature is assumed when the VVM carries a loaded MPC since the Closure Lid outlet ducts will be subject to heated air.

- Off-Normal Condition: elevated ambient temperature and partial blockage of air inlets.

- Extreme Environmental Phenomena and Accident Condition: handling accidents, fire, tornado, flood, earthquake, explosion, lightning, burial under debris, 100% blockage of air inlets, extreme environmental temperature, 100% fuel rod rupture, and an accident during construction in the vicinity of a loaded ISFSI.

The design basis magnitudes of the above loads, as applicable, are provided in Tables 2.I.1 and 2.I.5, and are discussed further in the following subsections. Applicable loads for an MPC contained in a VVM or for a HI-TRAC that services a VVM are identical to those already identified in the main body of Chapter 2 and, therefore, are not repeated or discussed within this supplement. However, recognizing that the support of an MPC in a VVM is different from the support provided in an above ground HI-STORM, the design basis dynamic analysis model includes the fuel assemblies, the fuel basket, and the enclosure vessel so that the loads described above are properly distributed within the VVM.

2.I.4 Normal Condition Operating Parameters and Loads

i. Dead Load

The HI-STORM 100U System must withstand the static loads due to the weight of each of its components. As the support provided by the subgrade and the VVM Interface Pad from lateral friction is apt to be negligible, the weight of the Closure Lid is assumed to bear on the Container Flange and the Container Shell; the load to the VVM Support Foundation is transferred through direct bearing action.

ii. Handling Loads

The only instance of a handling load occurs during emplacement or removal of the Closure Lid while the CEC contains a loaded MPC. To provide defense-in-depth, Closure Lid lifting attachments shall meet the design requirements of ANSI N14.6 [2.2.3].

Lift locations for the CEC and the Divider Shell are used for lifting only during construction, and possibly during maintenance and decommissioning of the VVM with no loaded MPC present; therefore, these lifting locations are not subject to the defense-in-depth measures of NUREG-0612. They are therefore considered as a part of the site construction safety plan, site-specific maintenance program, or site decommissioning plan, as applicable, and as such are treated as being outside the scope of this FSAR.

iii. Live Loads

a. Subgrade Pressure Due to Transporter Movement

The properties of the surrounding subgrade and the presence of a loaded cask transporter affect the state of stress in the subgrade continuum. This stress field may produce a lateral compressive load on the Container Shell, which acts together with the effect from soil overburden.

b. MPC Transfer Operation

The VVM must withstand the weight of the loaded HI-TRAC transfer cask and the mating device during MPC transfer operations. Bounding weights for these components are used in the qualifying analysis.

iv. Ambient Temperature

The HI-STORM 100U System is analyzed for the same maximum yearly average ambient air temperature as that used for the aboveground overpacks. This normal operating condition temperature bounds all locations in the continental United States.

v. Snow

An appropriately conservative snow load on the Closure Lid is considered as a potential bounding case (see Table 2.I.1).

vi. Long-Term Settlement

There is no mechanism for an appreciable long-term settlement of Support Foundation Pad from loaded VVMs because the equivalent density of the loaded VVM is nearly equal to the density of the removed subgrade. Therefore, at an ISFSI site, depending on the density of the subgrade, there may be a small mismatch between the mass of the subgrade displaced by the loaded VVM leading to a minor amount of long-term settlement.

The TSP and the VIP are founded on well conditioned subgrade that is typically installed after the CECs are emplaced on the SFP. In addition to its own weight, the sole long-term load is the dead weight of the pads (TSP and VIP) which is evidently insufficient to cause appreciable long-term settlement in a subgrade continuum installed to meet or exceed a specific shear wave velocity and density criterion (see Table 2.I.2). Therefore, the long-term settlement of the TSP and the VIP relative to the SFP is expected to be small. Limiting allowable values of settlement for the SFP and the TSP have been specified in Table 2.I.2 for a conservative stress analysis of the TSP and SFP under the load combinations including the generic Design Basis Earthquake .

The effect of long-term settlement on the SFP and TSP shall be considered as a concurrent load with Dead load in all load combinations in the manner described in Section 2.I.2.

2.I.5 Off-Normal Condition Design Criteria

i. Elevated Ambient Air Temperature

The HI-STORM 100U System must be able to reject the design basis heat load under short-term conditions of elevated ambient air temperature.

ii. Partial Blockage of Inlet Air Ducts

The HI-STORM 100U System must withstand 50% blockage of the inlet air flow area without exceeding allowable temperature and pressure limits.

2.I.6 Environmental Phenomena and Accident Condition Criteria

The extreme environmental phenomena and accident conditions applicable to the HI-STORM 100U System are listed below. The loadings apply to either or both the VVM components and ISFSI structures, as applicable.

i. Handling Accidents (Drops and Tipover)

Because the VVM is situated underground and cannot be moved, drop and tipover events are not credible accidents for this design. The Closure Lid, as discussed in Supplement 1.I, cannot strike the MPC lid due to geometry constraints if it were to undergo a free fall. Further, because the load handling device and lifting equipment are required to meet the defense-in-depth criteria set down in this FSAR, the drop of the Closure Lid or transfer cask during handling operation is termed non-credible (as is the case for the aboveground HI-STORM system MPC transfer operations at the ISFSI).

ii. Fire

The VVM must withstand the effects of a fire that consumes the maximum volume of fuel permitted to be in the fuel tank of the cask transporter. The duration of the fire for the VVM is conservatively assumed to be the same as that used for the aboveground overpacks. As is the case for aboveground overpacks, the fuel is assumed to spill, surround one storage system and burn until it is depleted. Because the VVM is configured to have a surrounding built-in step or spill barrier (see Figure 1.I.3), the spilled fuel will collect and burn over the Top Surface Pad, also referred to as Top-of-Grade (see Figure 1.I.2). Therefore, the location of fuel combustion will be somewhat removed from the CEC. Also, the natural grade in the TSP surface, engineered to direct the rainwater away from the VVMs, will do the same to the spilled fuel, further ameliorating the thermal consequence of the fire to the stored SNF.

The closed-end geometry of the MPC storage cavity ensures that a sustained combustion of the fuel, even if it were to be hypothesized to enter the VVM cavity, is not possible.

The loss of shielding effectiveness due to heat up of the concrete and the surrounding SSCs is primarily due to vaporization of the small amount of volatiles, including the contained moisture present in the concrete. This reduction in shielding is small and is permitted under the regulations. Therefore, the fire analysis of the VVM is focused on determining safety against a structural collapse due to elevation in the structure's metal temperature.

The sole effect of fire on the VVM structure is to raise the metal temperature of the structural members surrounding the shielding concrete in the Closure Lid. The analysis for the fire event accordingly seeks to establish that the load bearing structure will not be weakened by the rise in its metal temperature (and a consequent reduction in the yield and ultimate strength) and result in its structural collapse.

iii. Tornado

The HI-STORM 100U System is protected from the effects of a tornado and accompanying missiles by virtue of its underground configuration. The only VVM component that warrants evaluation for the effects of a tornado-induced missile strike is the Closure Lid, which is made of a steel weldment with encased concrete.

The HI-STORM 100U System is inherently stable under tornado missile impact. The impact of a large missile (1800kg Automobile) is evaluated to determine whether the Closure Lid continues to maintain its required shielding function. Penetration and perforation issues associated with the Closure Lid due to intermediate missiles that constitute the Extreme Environmental Phenomena loads for the HI-STORM 100U system are also addressed. The Closure Lid is analyzed for penetration of a solid steel cylinder traveling at a high speed consistent with the characteristics of the intermediate missile listed in Table 2.2.5. As there is no direct line of sight to the MPC, small missiles are not considered. Also, since a tornado is a short duration event, the effect of extremely high tornado winds on the thermal performance of the VVM would be negligible due to the system's thermal inertia. Therefore, the effect of tornado wind on the thermal performance of the HI-STORM 100U system is not analyzed.

iv. Flood

As discussed in Subsection 1.I.2, the HI-STORM 100U System is engineered to be flood resistant. However, even though the potential water ingress passages are elevated in the HI-STORM 100U (in contrast to the pad level inlet ducts in typical ventilated overpacks), submersion flooding that fills all or a portion of the ducts could occur at certain ISFSI sites located in flood zones. The MPC is designed to withstand 125 feet of water submergence. The VVM will clearly withstand this static head of water above the surface of the ISFSI because all structural members either are not subject to any pressure differential from the flood or are backed by the subgrade, which resists the flood water directly. Full or partial submergence of the MPC is not a concern from a thermal perspective, as discussed in Supplement 1.I, because heat removal is enhanced by the floodwater.

The most severe flooding event from a thermal perspective would be the partial filling of the intake plenum such that airflow is blocked but the MPC is not submerged in water. To mitigate the consequences of this event, the height of the Divider Shell cutouts is purposely located well above the bottom elevation of the MPC. Therefore, if the flood level is just high enough to block air flow, the lower portion of the MPC will be submerged in water. The wetted MPC bottom region serves as an efficient means of heat rejection to the floodwater. This accident event is described in Supplement 11.I.

v. Earthquake

As explained herein and in Subsection 3.I.4.7, the generic seismic loading for the HI-STORM 100U system is established using the combination of an earthquake and soil subgrade properties that maximize the severity of the inertia forces on the ISFSI structures and components.

As required by 10CFR72.102(f), the Design Basis Earthquake for the ISFSI must be specified. For the HI-STORM 100U system, a generic Design Basis Earthquake is specified with horizontal and vertical ZPAs intended to envelope the site-specific DBEs at all U.S. plant sites (See Table 2.I.2). For purposes of the generic seismic analysis in this FSAR, the Design Basis Earthquake for the HI-STORM 100U system is defined by two sets of response spectra specified at the SFP bottom surface elevation and at the TSP top surface elevation, as shown in Figure 2.I.4. These two spectra sets together exhibit the severity of the earthquake experienced by the ISFSI structures and VVM Components and are henceforth referred to as the governing spectra. The two sets of response spectra are obtained from the two-step SHAKE/LS-DYNA seismic response analyses performed using a lower-bound soil shear wave velocity profile (see Figure 2.I.6). This lower bound profile was established in [2.I.10] based on the geotechnical data of typical U.S. nuclear power plant sites. To develop the governing spectra, the input seismic acceleration time history for the SHAKE analysis is derived from the Regulatory Guide 1.60 seismic response spectrum and designated as the rock outcrop motion. The synthetic time history complies with the response spectrum and power density enveloping criteria in SRP 3.7.1 in NUREG-0800, Rev 2. The input acceleration time history is scaled to yield ground surface ZPAs (at the top of grade elevation) specified in Table 2.I.2. The average strain-compatible shear wave velocities of the soil column obtained from the SHAKE analysis are used to specify the minimum shear wave velocity values in Table 2.I.2. The ZPAs of the rock outcropping acceleration that yielded the governing spectra are 0.538 g's for the horizontal direction and 0.483 g's for the vertical direction.

The soil model for the subsequent LS-DYNA seismic response analysis uses the average strain-compatible wave velocities obtained from the SHAKE analysis (i.e., minimum shear wave velocity values in Table 2.I.2) to define the structural characteristics of the soil layers above and below the SFP elevation (see Figure 2.I.5 for sub-grade and under-grade space nomenclature). The acceleration time history at the soil column bottom surface, also obtained from the above-mentioned SHAKE analysis, is used as the input seismic motion for the LS-DYNA seismic response analysis performed in Supplement 3.I. The response spectrum plots shown in Figure 2.I.4 are the results of the LS-DYNA seismic response analysis (in the absence of the ISFSI). The same soil model and input seismic motion used in the LS-DYNA seismic response analysis is used for the LS-DYNA Soil-Structure Interaction (SSI) analysis (with the ISFSI included in the model) in Supplement 3.I.

The combination of weak soil properties and strong earthquake, as specified in Table 2.I.2 and Figure 2.I.4 for the structural evaluation of the underground ISFSI, has been selected to ensure that the Design Basis Earthquake response spectra at the ISFSI location will uniformly envelope those at most U.S. nuclear plants and that the Design Basis structural evaluation for the "100U" system is performed conservatively based on the lower bound support from the sub-grade and the under-grade. Thus, the HI-STORM 100U system can be deployed in most U.S. nuclear power plant sites without the need for a site-specific analysis to satisfy the requirements of 72.212. Specifically, a candidate 100U ISFSI site will be exempt from a detailed SSI analysis if the seismic response analysis for the site (using SHAKE or similar program) can demonstrate that the following two criteria are met:

1. The site's response spectra at both TSP and SFP elevations are enveloped by the Design Basis Earthquake response spectra shown in Figures 2.I.4-A and 2.I.4-B, respectively;

2. The soil properties of the candidate site are greater than the minimum values specified in Table 2.I.2.

In order to satisfy the first criterion, the site must consider multiple time history sets as input to the seismic response analysis based on the guidelines set forth in SRP 3.7.1 [2.I.12] and ASCE 4-98 [2.I.11]. The site's response spectra at both the TSP and SFP elevations must be bounded by the Design Basis Earthquake response spectra in Figure 2.I.4 for all acceleration time histories sets used as input.

For the case where only one of the above two criteria is not satisfied, a site-specific evaluation under 10CFR72.212 is permitted. Typical scenarios that warrant a site specific evaluation are discussed below:

<u>Scenario A</u>: The site's response spectra are not completely enveloped by the Design Basis Earthquake response spectra in Figure 2.I.4. However, the site's overall earthquake strength, represented by the resultant ZPA (see Table 2.I.2 for definition) is bounded by that of the Design Basis Earthquake at both TSP and SFP elevations.

While the ZPA represents the strength of the earthquake (in terms of the maximum value of the seismic acceleration time history), the shape of the seismic response spectrum is affected by many factors such as the overall stiffness of the site and the stiffness profile of soil layers. Therefore, for the same input seismic time history at the base of the soil column, a stiffer site could have a peak response that is not enveloped by the Design Basis Earthquake response spectrum (as demonstrated in the SHAKE parametric study results presented in Table 2.I.4, where the only difference between the two analyzed cases is the stiffness (i.e., shear wave velocity) of the soil column). Although it is expected that the 100U system would exhibit a greater safety margin against the earthquake loading at the stiffer subgrade/undergrade site, a site-specific evaluation under 10CFR72.212 is the appropriate vehicle to confirm the structural integrity in this situation.

Scenario B: The strain compatible wave velocity of the soil in Space B and/or Space D of the ISFSI site (see Figure 2.I.5) is less than the required minimum value specified in Table 2.I.2.

Typically, Spaces B and D (in Figure 2.I.5) contain native soils whose properties are not affected by the ISFSI construction. More importantly, the loaded VVMs are not directly supported by the soil in the two spaces. Therefore, it is reasonable to assume that a small reduction of soil stiffness in these two spaces would not significantly modify the structural response of the VVM system. Structural compliance through a site specific analysis is assured if the ZPA of the DBE is well below the Design Basis value set down in this FSAR (Figure 2.I.4).

The site-specific safety analysis, if performed, shall follow the methodology set down in Supplement 3.I. In addition, since the soil and rock configuration varies from site to site, the total depth of the soil model for site-specific analysis shall be determined following the guideline in Section 3.3.3.2 of ASCE 4-98 [2.I.11]. Uncertainties in SSI analysis for a candidate 100U ISFSI site shall be accounted for by varying the best estimate low strain shear modulus of the substrates between the best estimate values times (1+c) and the best estimate value divided by (1+c). If sufficient, adequate soil investigation data is available, the mean and standard deviation of the low strain shear modulus shall be established for every soil layer. The value of c may be established so that it will cover the mean plus or minus one standard deviation for every layer; however, the minimum value for c shall be no less than 0.5. If sufficient data is not available to determine a statistically meaningful mean and standard deviation, then the value for c shall be no less than 1.0.

The qualification of the ISFSI under the system's DBE event involves the following safety determinations:

1. Compliance of the VVM components (Divider shell, CEC shell, etc.) to the applicable stress/deformation limits specified in Table 2.I.6.
2. Strength compliance of the ISFSI reinforced concrete structures under ACI -318(2005) load combinations listed in Table 2.I.11.

A candidate 100U ISFSI site that does not meet the requirement discussed above for seismic qualification shall not be allowed for the consideration of a 100U general license.

vi. Explosion

The HI-STORM 100U System must withstand the pressure pulse due to a design basis explosion event. The effect of overpressure due to an explosion near the VVM is evaluated. The overpressure design value applied to the Closure Lid outer shell surface is intended to bound all credible explosion events because no combustible material is permitted to be stored near the VVM, and all materials of construction are engineered to be compatible with the operating environment. However, site-specific explosion scenarios that are not evidently bounded by the design basis explosion load considered herein (see Table 2.I.1) shall be evaluated under the provisions of 10CFR72.212.

vii. Lightning

The HI-STORM 100U System must withstand a lightning strike without a significant loss in its shielding capability. The effect of a lightning strike on the VVM is the same as that described for the aboveground overpack design, even though the likelihood of a lightning strike on the VVM is lower due to its low height above grade. Lightning is treated as an Extreme Environmental Phenomena event in Supplement 11.I. Because of its non-significant structural effect on the VVM, it is not considered as a load that warrants analysis in Supplement 3.I.

viii. Burial Under Debris

The burial under debris event for the HI-STORM 100U System is bounded by the evaluation performed for the aboveground overpacks, as discussed in Supplement 4.I.

ix. 100% Blockage of Air Inlets

The blockage of the entire inlet air flow area is analyzed as an accident event and is described in Supplement 11.I and analyzed in Supplement 4.I.

x. Extreme Environmental Temperature

An extremely high ambient air temperature is analyzed as an extreme environmental event and is described in Supplement 11.I and analyzed in Supplement 4.I.

xi. 100% Fuel Rod Rupture

This loading condition is specific to the MPC thermal evaluation and treated in Supplement 11.I.

2.I.7 Codes, Standards, and Practices to Ensure Regulatory Compliance

There is no U.S. or international code that is sufficiently comprehensive to provide a completely prescriptive set of requirements for the design, manufacturing, and structural qualification of the VVM. The various sections of the ASME Codes, however, contain a broad range of specifications that can be assembled to provide a complete set of requirements for the design, analysis, shop manufacturing, and field erection of the VVM. The portions of the ASME Codes that are invoked for the various elements of the VVM design, analysis, and manufacturing activities are summarized in Table 2.I.3.

The ASME Boiler and Pressure Vessel Code (ASME Code) Section III, Subsection NF Class 3, 1995 Edition, with Addenda through 1997 [2.2.1], is the applicable code to determine stress limits for the metallic structural components of the VVM when required by the acceptance criteria listed in Table 2.I.5. Table 2.I.3 summarizes considerations for design, fabrication, materials, and inspection. The permitted material types and their permissible temperature limits for long-term use are listed in Table 2.I.8. Manufacturing requirements are set down in licensing and design drawings.

ACI-318(2005) [2.I.5] is the applicable reference code to establish applicable limits on unreinforced concrete (in the Closure Lid), which is subject to secondary structural loadings. Appendix 1.D contains the design, construction, and testing criteria applicable to the plain concrete in the VVM's Closure Lid. The load combinations applicable to the TSP, SFP, and the retaining wall, pursuant to ACI-318(05) are summarized in Table 2.I.11. Since the VIP carries no load except for the self-weight and is thicker than the TSP, the structural evaluation of the VIP is not necessary. Applicable sections of ACI-318(2005) should be used in the design of the interfacing SSCs and proximate structures.

The selection of the ISFSI site shall be made with due consideration of the potential of liquefaction. The host plant's criteria with respect to liquefaction for siting the Part 50 structures shall be used.

As mandated by 10CFR72.24(c)(3) and §72.44(d), Holtec International's quality assurance program requires all constituent parts of an SSC subject to NRC's certification under 10CFR72 to be assigned an ITS category appropriate to its function in the control and confinement of radiation. The ITS designations for the constituent parts of the HI-STORM 100U VVM, using the guidelines of NUREG-CR/6407 [2.0.5], are provided in Table 2.I.8.

The aggregate of the citations from the codes, standards, and generally recognized industry publications invoked in this FSAR, supplemented by the commitments in Holtec's quality assurance procedures, provide the necessary technical framework to ensure that the as-installed VVM would meet the intent of §72.24(c), §72.120(a) and §72.236(b). As required by Holtec's QA Program (discussed in Chapter 13), all operations on ITS components must be performed under QA validated written procedures and specifications that are in compliance with the governing citations of codes, standards, and practices set down in this FSAR. For activities that may be performed by others, such as site construction work to install the VVM, Holtec International requires that all activities be formalized in procedures and subject to the CoC holder's as well as the ISFSI owner's review and approval.

An ITS designation is also applied to the interfacing SSCs (such as the Support Foundation), which requires that all quality assurance measures set down in Holtec's Quality Assurance Procedure Manual be complied with by the entity performing the site construction work. In this manner, the compliance of the as-built VVMs with its engineered safety margins under all design basis scenarios of loading is assured.

2.I.8 Service Limits

No new service limits are defined for the HI-STORM 100U System beyond those described in Subsection 2.2.5.

2.I.9 Loads and Acceptance Criteria

Subsections 2.I.4, 2.I.5, and 2.I.6 describe the loadings for normal, off-normal, and extreme environmental phenomena and accident conditions, respectively, for the HI-STORM 100U System. Tables 2.I.1 and 2.I.2, respectively, provide the design loads and seismic load parameters in terms of ZPA values for a bounding analysis using the methodology of Subsection 3.I.4.7.

Bounding load cases that are significant to the structural performance of the VVM and require evaluation are compiled in Table 2.I.5 using information provided in Sections 2.I.4, 2.I.5, and 2.I.6. Supplement 3.I contains a description of the evaluations, establishes the evaluation methodology, and provides evaluation results that demonstrate compliance of the VVM to the applicable load cases and acceptance criteria described below. The load cases and acceptance criteria are explained in subsequent paragraphs and summarized in Table 2.I.5. Table 2.I.6 summarizes the acceptance criteria for the CEC and internals under extreme environmental events.

Each loading case in Table 2.I.5 is distinct in respect of the sub-component of the VVM that it affects most significantly. The acceptance criteria consist of demonstrating that (i) radiation shielding does not degrade under normal and off-normal conditions of storage loadings, (ii) the system does not deform under credible loading conditions in a manner that would jeopardize the subcritical condition or retrievability of the MPC, and (iii) the MPC maintains confinement. For accident condition loadings, any permissible degradation in shielding must be shown to result in dose rates sufficiently low to permit recovery of the MPC from the damaged cask, including unloading if necessary, and loss of function must be readily visible, apparent or detectable.

The above set of criteria, extracted from NUREG-1536, is further particularized in a more conservative form for each applicable loading case in this subsection.

Load Case 01: Buoyant Force

This loading case pertains to the scenario wherein a VVM has been built, but the Closure Lid and MPC are not yet installed. Strictly speaking, this condition is not important to storage safety because the MPC is not present. However, considerations of long-term service life warrant that a minimum weight CEC, subject to the maximum buoyant force of water under an assumed hypothetical condition of submergence in water with a head equal to the length of the CEC, does not float. This evaluation sets a minimum additional weight (usually on a temporary cover) that will be set in place during construction to protect the CEC from construction debris, to provide for construction worker safety, and to insure that the CEC does not suffer uplift from buoyant forces. In addition, the Bottom Plate of the CEC must have sufficient flexural strength such that under a buoyant uplift pressure, its primary bending stress intensity remains below the ASME Level D allowable stress intensity at the reference metal temperature (assumed to be same as the extreme environmental condition temperature specified in Table 2.I.1 of this FSAR).

Load Case 02: Dead Load plus Design Basis Explosion Pressure

The dead weight loading, explained in Paragraph 2.I.4(i) is accentuated by the design basis explosion loading defined in Paragraph 2.I.6(vi). The explosion load is stated in terms of an equivalent static pressure. The affected sub-components are:

a. The Container Shell, subjected to a compressive state of stress under the combined effect of dead weight of the Closure Lid and surface pressure on the Closure Lid under the explosion event.

b. The Closure Lid, subject to self-weight and the Closure Lid surface pressure under the explosion event.

Other VVM components are not in the direct path of this loading. The explosion pressure envelops other mechanical loads such as snow and flood. Load Case 02, therefore, is a bounding load combination that conservatively subsumes a number of normal and extreme environmental phenomena loads. As this load case is intended to bound any normal condition, Level A stress limits are applicable to this case based on reference metal temperatures that bound all mechanical loading scenarios.

Load Case 03: Tornado Missile Impact

The Closure Lid is the only exposed portion of the VVM. Therefore, the tornado-borne missile strikes must be postulated to occur on the lid. The only other affected VVM part is the Container Flange, which prevents lateral sliding of the lid.

When subject to a tornado missile strike, the Closure Lid must not be dislodged, resulting in a direct line of sight from the top of the MPC to the outside. For the intermediate missile, the Closure Lid must resist full penetration. Finally, any CEC deformation from the compressive axial impulse due to the missile strike must not prevent MPC retrievability.

Load Case 04: Design Basis Seismic Event

The Design Basis Seismic Event is classified as an extreme environmental phenomenon. As such the Level D service condition limits are applicable to the Code components, such as the MPC Enclosure Vessel. The MPC Enclosure Vessel and fuel basket have been qualified to a 60g deceleration limit in the HI-STAR 100 (Docket Nos. 72-1008, 71-9261); this deceleration exceeds the expected deceleration from a seismic event. However, to ensure an accurate structural evaluation of the VVM, the evaluation of the response of the VVM to the design basis seismic event shall include a detailed model of the MPC, the fuel basket, and the contained fuel; this model, referred to as the Design Basis Seismic Model, should capture impacts between the fuel and the fuel basket, between the fuel basket and the MPC, and between the MPC and applicable components of the VVM.

The CEC shell is subject to performance-based limits, which require that the deformation of the CEC does not prevent MPC retrievability, does not cause loss of MPC confinement, and that the system remains subcritical. This is accomplished by demonstrating that after the seismic event, permanent ovalization of the Container Shell and/or Divider Shell does not result in a geometry that precludes retrievability of the MPC and that the impact loadings on the MPC due to its rattling inside the CEC do not cause a breach of the MPC confinement boundary.

The Divider Shell's sole function is to direct the airflow inside the CEC cavity and to hold MPC Guides that serve to restrain the MPC from excessive rattling motion during an earthquake event. The MPC guides welded to the Divider Shell are subject to compressive impacts from the "hard points" on the MPC (the approximately 2.5-inch thick baseplate at the bottom and the 9.5-inch thick lid at the top). The MPC tubular guides are engineered to serve as "impact limiters" to minimize the local plastic strains in the MPC Confinement Boundary.

Finally, because the MPC Enclosure Vessel is designed to meet ASME Section III, Subsection "NB" (Class 1) stress intensity limits, and the earthquake is categorized as a "Level D" event, the primary stress intensities in the MPC Enclosure Vessel must meet Level D limits. The primary stress intensity in the MPC shell is the maximum longitudinal flexural stress intensity, which is compared against the primary membrane stress intensity limit for the material (Alloy X) at the applicable service temperature. The fuel basket is a multi-flange 3-D beam structure, designed to meet the stress limits of Subsection "NG" of the Code. The maximum longitudinal primary stress intensity in the basket, calculated from the 3-D fuel basket/fuel assembly model, must be less than the corresponding Level D condition limit at the service temperature. In addition to the primary stress based limits it is also necessary to demonstrate that the transverse bending stress in any panel normalized over the length of the fuel basket is less than the Level D primary stress limit.

The limits on the primary stresses in the MPC components for the DBE condition are also applicable to other Level D (faulted) events. Dynamic analysis using a 3-D detailed model of the MPC (which includes the Confinement Boundary, the internal fuel basket, and the fuel assemblies inside the basket) is the vehicle for performing the structural qualification. In addition to the primary stress limits, the local strain in the Confinement Boundary due to the impact between the MPC and the MPC guides under the Design Basis Earthquake requires evaluation.

Table 2.I.5 summarizes the above discussion in tabular form.

Load Case 05: Closure Lid Handling

The Closure Lid lifting attachments shall meet the strength limits of ANSI N14.6 for heavy load handling. The metal load bearing parts shall satisfy the requirements of Reg. Guide 3.61 for primary stresses near the lifting locations and shall satisfy ASME NF Level A limits away from the lifting locations.

Yield and ultimate strength values used in the stress compliance demonstration per ANSI N14.6 shall utilize confirmed material test data through either independent coupon testing or material suppliers' CMTR or COC, as appropriate.

Load Case 06: Design Basis Fire Event

The exposed portion of the VVM, namely the Closure Lid, will experience the heat input and temperature rise under the fire event. The balance of the VVM, because of its underground location, will be subject to only a secondary temperature increase.

It is required to demonstrate that the structural collapse of the Closure Lid cannot occur due to the reduction of its structural material's (low carbon steel) strength at the elevated temperatures from the fire.

Load Case 07: CEC Loading From Surrounding Subgrade

The CEC is subject to a lateral pressure from the soil in the non-seismic condition. This pressure is affected by the presence of a loaded cask transporter adjacent to the CEC. The CEC must be shown to provide adequate resistance to this loading.

This load case tends to ovalize the CEC; the maximum primary membrane plus bending stress is limited to the material yield strength under normal conditions of storage.

In evaluating the structural safety margins in Supplement 3.I for the load cases described above, design data for the interfacing SSCs presented in Table 2.I.2 is used as applicable.

2.I.10 Safety Protection Systems

The HI-STORM 100U System, featuring the VVM with the stored MPC, provides for confinement, criticality control, and heat removal for the stored spent nuclear fuel in the manner of the aboveground overpacks. The VVM provides better shielding and protection from environmental events, such as tornado missiles, because of its underground configuration. The information in Section 2.3 also applies to the HI-STORM 100U System, with the recognition that the air ventilation system is modified. Instead of the ambient air entering through inlet ducts at the bottom, the cooling air enters the circumferentially symmetric passage at the top of the VVM and is directed to the bottom of the VVM cavity along a radially symmetric annulus (Figure 1.I.4). However, the mechanism of heat transfer from the MPC to the cooling air is identical to the aboveground overpack designs.

The HI-STORM 100U System is completely passive requiring no active components or instrumentation to perform its design functions. Temperature monitoring or scheduled visual verification of the integrity of the air passages is used to verify continued operability of the VVM heat removal system, as set down in the system's Technical Specification.

2.I.11 Decommissioning Considerations

The HI-STORM 100U VVM is specifically engineered to facilitate convenient decommissioning. As discussed in Supplement 1.I, the component most proximate to the active fuel and, hence, likely to be the most activated, is the Divider Shell. The Divider Shell is not welded to the CEC structure; therefore, it can be conveniently removed for decommissioning. The CEC structure can be removed by excavating the surrounding subgrade. Alternatively, the cavity can be filled with suitable fill materials and the CEC left in place. While the above discussion is unique to the VVM design, the information in Section 2.4 pertaining to decommissioning of other HI-STORM models is also applicable to the VVM. Even if the decision is made to dispose of all activated material, the VVM, due to differences in its geometry and construction (particularly, use of the native soil as the biological shield to the extent possible) will result in less steel and concrete to be disposed of. In the aggregate, it is estimated that less material will need to be disposed of to decommission a VVM ISFSI in comparison to an ISFSI containing aboveground overpacks.

Finally, the activation estimate in Table 2.4.1 for the aboveground overpack inner shell is conservatively applicable to the VVM steel shell enclosure.

2.I.12 Regulatory Compliance

Pursuant to the guidance provided in NUREG-1536, the foregoing material in this supplement provides:

i. a complete set of principal design criteria for the VVM as mandated by 10CFR72.24I(1), §72.24(c)(2), §72.120(a) and §72.236(b);

ii. a clear identification of VVM structural parts subject to a fully articulated design subject to certification under 10CFR72 and of interfacing SSCs;

iii. the required set of limiting critical characteristics of the interfacing SSCs to ensure that the VVM will render its intended function under all design basis scenarios of operation;

iv. a complete set of requirements premised on well-recognized codes and standards to govern the design and analysis (to establish safety margins) and manufacturing of the VVM; and

v. a table containing cross-reference between the applicable 10CFR72 requirements and the location in this FSAR where the fulfillment of each specific requirement is demonstrated.

It is noted that the requirements of 10CFR72 do not preclude the use of an underground storage system such as the HI-STORM 100U. The VVM concept, while not specifically mentioned in the regulatory guidance literature associated with implementing the requirements in 10CFR72 (i.e., NUREG-1536), meets and exceeds the intent of the guidance in that it provides an enhanced protection of the stored spent nuclear fuel and a significantly reduced site boundary dose, enables a more convenient handling operation, and presents a much smaller target for missiles/projectiles compared to an aboveground storage system.

2.I.13 <u>References</u>

The references in Section 2.6 apply to the VVM to the extent that they are appropriate for use with an underground system.

[2.I.1] NACE Standard RP0104-2004 "The Use of Coupons for Cathodic Protection Monitoring Applications", NACE International.

[2.I.2] NACE Standard TM0101-2001 "Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Tank Systems", NACE International.

[2.I.3] Federal Construction Council Technical Report No. 32, Cathodic Protection As Applied to Underground Metal Structures", National Academy of Sciences – National Research Council, Publication 741, 1959.

[2.I.4] Rabah, M.A., et al., "Electrochemical Wear of Graphite Anodes during Electrolysis of Brine," *Carbon*, Vol. 29, No. 2, pp. 165-171, 1991.

[2.I.5] ACI-318(2005), Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05), Chapter 22, American Concrete Institute, 2005.

[2.I.6] Holtec Position Paper, DS-338, "A Methodology to Compute the Equivalent Elastic Properties of the Subgrade Continuum to Incorporate the Effect of Long-Term Settlement," A.I. Soler and C. Bullard (2010) (Holtec Proprietary)

[2.I.7] Basic Soils Engineerings, B.H.Hough, Second Edition.

[2.I.8] ACI 360R-06, Design of Slabs on Grade, American Concrete Institute, 2006.

[2.I.9] "2009 International Building Code," International Code Council, Inc.

[2.I.10] NUREG/CR-6865, "Parametric Evaluation of Seismic Behavior of Freestanding Spent Fuel Dry Storage Systems," U.S. Nuclear Regulatory Commission, February 2005.

[2.I.11] ASCE 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary, American Society of Civil Engineers, 2000.

[2.I.12] NUREG-0800, SRP 3.7.1, "Seismic Design Parameters", USNRC, Revision 3, March 2007.

[2.I.13] N.M. Newmark, "Seismic Design Criteria for Structures and Facilities: Trans-Alaska Pipeline System," proceedings of U.S. national Conference on Earthquake Engineering, Ann Arbor, Michigan, June 18-20, 1975.

[2.I.14] USNRC Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Responses Analysis," Revision 2, July 2006.

TABLE 2.I.1
LOADS, CRITERIA, APPLICABLE REGULATIONS, REFERENCE CODES, AND STANDARDS FOR THE VVM

Type	Criteria or Value and Reference Location in the FSAR	Basis, Regulation and Reference Code/Standard
Life:		
Design Life	40 yrs, Section 3.I.4	-
License Life	20 yrs, Section 3.I.4	10CFR72.42(a) & 10CFR72.236(g)
Structural:		
Design & Fabrication Codes: Foundation Pad; VVM Interface Pad and Top Surface Pad	ACI-318(05)	10CFR 72.24
Unreinforced Concrete Stress Limits (Closure Lid)	Applicable Sections of ACI-318(05)	10CFR72.24(c)(4)
Structural Steel	Section 2.I.7, Tables 2.I.5, 2.I.6	10CFR72.24(c)(4)
VVM Closure Lid Dead Weight†:	Table 3.I.1	R.G. 3.61
Design Internal Pressure	Atmospheric, Supplement 1.I	Ventilated Module
Response and Degradation Limits	Section 3.I.4	10CFR72.122(b), (c)
Corrosion Allowance	1/8" on surfaces directly in contact with subgrade	Standard industry practice
Thermal:		
Maximum Design Temperatures:		
Closure Lid Concrete		
Through-Thickness Section Average (Normal)	Table 1.D.1	ACI 349-85, Appendix A, (Paragraph A.4.3)
Through-Thickness Section Average (Off-Normal and Accident)	Table 1.D.1	ACI 349-85, Appendix A, (Paragraph A.4.2)
Structural Steel	Table 2.I.8	ASME Code, Section II, Part D
VVM Divider Shell Thermal Insulation	Heat transfer resistance $\geq$ 4 hr-ft^2-°F/Btu. Must be stable at temperatures $\leq$ 800°F	N/A
Confinement:	N/A, Provided by MPC; Supplement 7.I	10CFR72.128(a)(3) and 10CFR72.236(d) & (e)
Retrievability: Normal/Off-Normal/Accident	No damage that precludes MPC retrieval or threatens subcriticality of fuel. MPC maintains confinement, Supplement 3.I	10CFR72.122(f), (h), (1), & (l)

† All weights listed in Table 3.I.1 are bounding weights. Actual weights will be less, and will vary based on as-built dimensions of the components, fuel type, and the presence of fuel spacers and non-fuel hardware, as applicable.

TABLE 2.I.1 (continued)
LOADS, CRITERIA, APPLICABLE REFERENCE REGULATION/CODES AND STANDARDS FOR HI-STORM 100U VVM

Type	Criteria or Value and Reference Location in the FSAR	Basis, Regulation and Reference Code/Standard
Criticality:	N/A; Provided by MPC; Supplement 6.I	10CFR72.124 and 10CFR72.128(a)(2)
Radiation Protection/Shielding:		
Normal/Off-Normal	Provide capability to meet controlled area boundary dose limits under 10CFR72 for all normal and off-normal conditions; Supplement 5.I	10CFR72.104 and 10CFR72.212
	Ensure dose rates on and around the VVM during MPC transfer and lid installation operations are ALARA; Supplement 10.I	10CFR20
Accident or Conditions of Extreme Environmental Phenomena	Meet controlled area boundary dose limits in regulations for all accidents; Supplement 5.I	10CFR72.106
Design Bases:		
Spent Fuel Specification	Table 2.0.1; Section 2.I.1	10CFR72.236(a)
Normal Design Event Conditions:		
Ambient Outside Temperature:	-	-
Max. Yearly Average	80°F; Subsection 2.2.1.4	ANSI/ANS 57.9
Live Load†:		
Loaded HI-TRAC 125D and Mating Device	Table 3.I.1, Subsection 2.I.9	R.G. 3.61
Dry Loaded MPC	Table 3.I.1, Subsection 2.I.9	R.G. 3.61
Cask Transporter	Table 3.I.1, Subsection 2.I.9	-
Handling:	Subsection 2.I.4	-
VVM Closure Lid Lift Points	Subsection 3.I.4	NUREG-0612 ANSI N14.6
Minimum Temperature During Closure Lid Handling Operations	0°F; Subsection 2.2.1.2	ANSI/ANS 57.9
Snow and Ice Load	100 lb/ft^2; Subsection 2.I.4	ASCE 7-88
Wet/Dry Loading	Dry; Supplement 1.I, 8.I	-
Storage Orientation	Vertical; Supplement 1.I	-

† Weights listed in Table 3.I.1 are bounding weights. Actual weights will be less, and will vary based on as-built dimensions of the components, fuel type, and the presence of fuel spacers and non-fuel hardware, as applicable.

TABLE 2.I.1 (continued)
LOADS, CRITERIA, APPLICABLE REFERENCE REGULATION/CODES AND STANDARDS FOR HI-STORM 100U VVM

Type	Criteria or Value and Reference Location in the FSAR	Basis, Regulation and Reference Code/Standard
Off-Normal Design Event Conditions:		
Ambient Temperature:	Subsection 2.I.5	-
Minimum	-40°F; Subsection 2.2.2.2	ANSI/ANS 57.9
Maximum	100°F; Subsection 2.2.2.2	ANSI/ANS 57.9
Partial Blockage of Air Inlets	50% blockage of air inlet flow area; Supplement 4.I	-
Design Basis Accident Events and Conditions:		
Drop Cases:		
End Drop	Not credible; Subsection 2.I.6	In-ground VVM is not lifted
Tipover	Not credible; Subsection 2.I.6	In-ground VVM is constrained by subgrade and foundation
Fire:	-	-
Duration	217 seconds; Supplement 11.I	10CFR72.122(c)
Temperature	1475°F; Supplement 11.I	10CFR72.122(c)
Fuel Rod Rupture	See Table 2.0.1; Subsection 2.2.3.8	-
Air Flow Blockage	100% blockage of air inlet flow area; Subsection 2.I.6	10CFR72.128(a)(4)
Explosive Overpressure External Differential Pressure	10 psi steady state; Subsection 2.I.6 and Table 2.2.1	10CFR72.128(a)(4)
Extreme Environmental Phenomenon Events and Conditions:		
Flood:	Subsection 2.I.6	-
Height	125 ft	R.G. 1.59
Velocity	N/A; Supplement 1.I	In-ground VVM is not subject to tipover or sliding. Loads on the Closure Lid are bounded by missile impact loads.
Max. Earthquake	Table 2.I.2, Figure 2.I.4	10CFR72.102(f)
Tornado:	Subsection 2.I.6	-

TABLE 2.I.1 (continued)
LOADS, CRITERIA, APPLICABLE REFERENCE REGULATION/CODES AND STANDARDS FOR HI-STORM 100U VVM

Type	Criteria or Value and Reference Location in the FSAR	Basis, Regulation and Reference Code/Standard
Tornado-Borne Missiles:		
i. Automobile	Ensure shielding, subcriticality and retrievability MPC maintains confinement Subsection 2.I.6 and Supplement 3.I	NUREG-1536
▪ Weight	Table 2.2.5	NUREG-0800
▪ Velocity	Table 2.2.5	NUREG-0800
ii. Rigid Solid Steel Cylinder (intermediate tornado missile)	Ensure shielding, subcriticality and retrievability, MPC maintains confinement	NUREG-1536
▪ Weight	Table 2.2.5	NUREG-0800
▪ Velocity	Table 2.2.5	NUREG-0800
iii. Steel Sphere	Subsection 2.I.6	NUREG-1536 In-ground VVM has no penetrations that provide line-of-sight to MPC
▪ Weight	Table 2.2.5	NUREG-0800
▪ Velocity	Table 2.2.5	NUREG-0800
Burial Under Debris	Maximum decay heat load and adiabatic heat-up; Subsection 2.I.6	-
Lightning	Bounded by aboveground evaluation (resistance heat-up); Subsection 2.I.6	In-ground VVM contains less metal
Extreme Environmental Temp.	125°F; Subsection 2.I.6 and Table 2.2.2	-
Load Cases for Structural Qualification:	Subsection 2.I.9 and Table 2.I.5	ANSI/ANS 57.9 and NUREG-1536

TABLE 2.I.2 DESIGN DATA FOR HI-STORM 100U ISFSI			
	Item	**Value(Minimum or nominal, as applicable)**	**Comment**
1.	Support Foundation Pad, VVM Interface Pad and Top Support Pad, and Retaining Wall	▪ Minimum Concrete density = 145 lb/ft^3 ▪ Minimum concrete compressive strength @ ≤ 28 days = 4,500 psi ▪ Grade 60 Rebar - Minimum yield strength of rebar = 60,000 psi; rebar is #11@9" (each face, each direction) ▪ Minimum concrete cover on rebar per section 7.7.1 of ACI-318(05)	See Licensing Drawings in Section 1.I.5 for detailed concrete pad/wall thickness.
2.	Depth averaged density of subgrade in Space A (see Figure 2.I.5), lb/ft^3	120	A lower average density value may be used in shielding analysis in Supplement 5.I for conservatism.
3.	Depth averaged density of subgrade in Space B (see Figure 2.I.5), lb/ft^3	110	A lower average density value may be used in shielding analysis in Supplement 5.I for conservatism.
4.	Depth depth averaged density of subgrade in Space C (see Figure 2.I.5), lb/ft^3	120	Not required for shielding.
5.	Depth depth averaged density of subgrade in Space D (see Figure 2.I.5), lb/ft^3	120	This space will typically contain native soil. Not required for shielding.
6.	Strain compatible effective shear wave velocity in Space A, V ft/sec (see Note 1)	500	This space will typically contain engineered fill.
7.	Strain compatible effective shear wave velocity in Space B, V ft/sec (see Note 1)	450	This space will typically contain native soil.
8.	Strain compatible effective shear wave velocity in Space C, V ft/sec (see Note 1)	485	This space may be remediated with vertical reinforcement such as pilings to enhance V.

TABLE 2.I.2 (continued)
DESIGN DATA FOR HI-STORM 100U ISFSI

	Item	Value	Comment
9.	Strain compatible effective shear wave velocity in Space D, V ft/sec (see Note 1)	485	This space will typically contain native soil.
10.	Design Basis Earthquake	Ground surface spectra per Figure 2.I.4-A with horizontal ZPA, a_H and vertical ZPA, a_V as: $a_H = 1.0g$ $a_V = 0.75g$ and foundation surface spectra per Figure 2.I.4-B.	Horizontal and vertical spectra shown in Figures 2.I.4-A and 2.I.4-B are based on 5% damping. Following the Newmark 100-40-40 response combination technique [2.I.13] endorsed by the Regulatory Guide 1.92 [2.I.14], the *resultant ZPA* for a 3-D earthquake site is defined as: $a_R = a_1 + 0.4a_2 + 0.4a_3$, where a_1, a_2 and a_3 are the site's ZPAs in three orthogonal directions and $a_1 \geq a_2 \geq a_3$. Hence, the DBE *resultant ZPAs* at ground surface and foundation surface elevations are 1.3 g's (=1.0×1.0g's + 0.4×0.75 g's) and 1.228 g's (=1.0×0.94g's + 0.4×0.72 g's), respectively.
11.	Maximum permissible long-term settlement of the SFP	0.2 inches	
12.	Maximum permissible long-term settlement of the TSP with respect to the SFP	0.4 inches	

Note 1:
Strain compatible shear wave velocities in each space at an ISFSI site (see Figure 2.I.5) shall be computed using the guidance provided in Section 16 of the International Building Code, 2009 Edition [2.I.9]. The equivalent wave velocity is defined so that the wave transit time for an equivalent homogeneous material of the same total depth is the same as the actual layered substrate.

$$V = \frac{d}{\sum \frac{d_i}{v_i}}$$

d_i = thickness of i^{th} layer within the region (ft.);
v_i = strain compatible shear wave velocity of i^{th} layer within the region (ft./sec.);
d = total thickness of substrate region (e.g. 20', 80')
V = Equivalent Strain Compatible Shear Wave Velocity for substrate thickness "d".

TABLE 2.I.3
REFERENCE ASME CODE PARAGRAPHS FOR VVM PRIMARY LOAD BEARING PARTS

	Item	Code Paragraph[†]	Explanation and Applicability
1.	Definition of primary and secondary members	NF-1215	-
2.	Jurisdictional boundary	NF-1133	The "intervening elements" are termed interfacing SSCs in this FSAR.
3.	Certification of material	NF-2130(b) and (c)	Materials shall be certified to the applicable Section II of the ASME Code or equivalent ASTM Specification.
4.	Heat treatment of material	NF-2170 and NF-2180	-
5.	Storage of welding material	NF-2400	-
6.	Welding procedure	Section IX	-
7.	Welding material	Section II	-
8.	Loading conditions	NF-3111	-
9.	Allowable stress values	NF-3112.3	-
10.	Rolling and sliding supports	NF-3424	-
11.	Differential thermal expansion	NF-3127	-
12.	Stress analysis	NF-3143 NF-3380 NF-3522 NF-3523	Provisions for stress analysis for Class 3 plate and shell supports and for linear supports are applicable for Closure Lid and Container Shell, respectively.
13.	Cutting of plate stock	NF-4211 NF-4211.1	-
14.	Forming	NF-4212	-
15.	Forming tolerance	NF-4221	Applies to the Divider Shell and Container Shell
16.	Fitting and Aligning Tack Welds	NF-4231 NF-4231.1	-
17.	Alignment	NF-4232	-
18.	Storage of Welding Materials	NF-4411	-
19.	Cleanliness of Weld Surfaces	NF-4412	Applies to structural and non-structural welds
20.	Backing Strips, Peening	NF-4421 NF-4422	Applies to structural and non-structural welds
21.	Pre-heating and Interpass Temperature	NF-4611 NF-4612 NF-4613	Applies to structural and non-structural welds
22.	Non-Destructive Examination	NF-5360	Invokes Section V
23.	NDE Personnel Certification	NF-5522 NF-5523 NF-5530	-

[†] All references to the ASME Code refer to applicable sections of the 1995 edition with addenda through 1997.

TABLE 2.I.4
SHAKE PARAMETRIC STUDY OF THE EFECT OF SUBGRADE PROPERTIES ON SOIL RESPONSES AT 100U ISFSI TOP & BOTTOM ELEVATIONS

Elevation & Direction	Acceleration Response	Value (g's)	
		Lower Bound Shear Wave Velocity Profile (see Figure 2.I.6)	Upper Bound Shear Wave Velocity Profile (see Figure 2.I.6)
TSP Top Surface Horizontal Direction	ZPA	1.008	0.897
	Peak	3.851	4.040
SFP Bottom Surface Horizontal Direction	ZPA	0.945	0.790
	Peak	3.590	3.848
TSP Top Surface Vertical Direction	ZPA	0.751	0.539
	Peak	3.912	2.377
SFP Bottom Surface Vertical Direction	ZPA	0.724	0.523
	Peak	3.674	2.314

TABLE 2.I.5
LOAD CASES AND ACCEPTANCE CRITERION APPLICABLE TO VVM COMPONENTS

Case I.D.	Bounding Loading	Affected Sub-Component	Applicable Data		Acceptance Criterion
			Magnitude of Loading (Ref. Table I.D.)	Value of Coincident Metal Temperature used (Deg. F)	
01	Condition with no MPC or Closure Lid installed; buoyancy from a water head equal to the distance between TOG and TOF.	• Temporary Cover	Buoyant Force From CEC Displaced Volume	125	The minimum weight of the anti-buoyancy cover is 16,000lb.
		• CEC Bottom Plate	< 8 psi	125	Maximum primary bending stress intensity in the CEC Bottom Plate must be below Level D limit.
02	Normal operation condition; dead load plus design basis explosion pressure	• Container Shell structure	2.1.1; 3.I.1	125	Primary stresses do not exceed applicable Level A stress limits of ASME Subsection NF (or Level D limits with explosion)
		• Closure Lid	2.I.1	350	
03	Design basis missile	Closure Lid	2.I.1 and 2.2.5	350	Closure Lid does not collapse, is not dislodged from the cavity, and is not perforated by the missile.
04	Design basis earthquake	Container Shell	Figure 2.I.6	125	After the DBE event, MPC retrievability, subcriticality and confinement must not be compromised. Additional criteria for the CEC and its contents are defined in Table 2.I.6.
05	Closure lid handling	Lid Lift Lugs; all metal structure in Lid	1.15 x Closure Lid Weight (From Table 3.I.1)	125	ANSI N14.6 limits based on yield or ultimate strength including magnified inertia loads. Meet Reg. Guide 3.61 and Level A limits as applicable. (see Section 2.I.9)

TABLE 2.I.5 (continued)
LOAD CASES AND ACCEPTANCE CRITERION APPLICABLE TO VVM COMPONENTS

Case I.D.	Bounding Loading	Affected Sub-Component	Applicable Data		Acceptance Criterion
			Magnitude of Loading (Ref. Table I.D.)	Limiting Value of Coincident Metal Temperature (Deg. F)	
06	Design basis fire	Closure Lid	2.I.1	800	The Closure Lid structure does not collapse under its dead weight due to elevated metal temperatures.
07	CEC loading from subgrade	Container Shell	Calculated in 3.I	125	Service A stress limit for NF Class 3 plate and shell structure for the maximum "body extensive" membrane plus bending stress (body extensive defined as the region whose characteristic dimension exceeds 2.5 SQRT (R*T), where R and T are, respectively, the radius and thickness of the CEC shell.

Note 1. Structural loads and acceptance criteria for each load case are further explained in Section 2.I.9.
Note 2: Materials of construction are identified in Table 2.I.8.
Note 3: Design attributes of the VVM are explained in Section 1.I.2 and details are presented in the drawings in Section 1.I.5.
Note 4: The limiting value of coincident metal temperature is used to establish material properties and allowable stress (or stress intensity) when applicable.

TABLE 2.I.6
ACCEPTANCE CRITERIA FOR THE HI-STORM 100U VVM AND INTERNALS UNDER EXTREME ENVIRONMENTAL CONDITIONS

Component	Calculated Value	Allowable Limit
CEC Container Shell and Divider Shell	Radial gap between CEC Shell and Divider Shell Insulation after the seismic event	Nominal Gap (based on OD of Divider Shell Insulation and ID of CEC Shell) must remain open at end of event.
MPC Guides	Maximum compressive load	Minimum of limiting buckling load or ultimate load
MPC Shell	Longitudinal flexural stress intensity in shell wall from bending of the MPC shell as a beam. The local true strain in the MPC shell in the region of MPC guide/MPC impact.	ASME Level D primary membrane stress intensity limit The local strain from impact must be less than 10%, which has been established as a conservative limit in [3.I.31]
MPC Fuel Basket	Primary flexural stress intensity in basket panel from bending of the fuel basket as a beam	ASME Level D primary membrane stress intensity limit
MPC Fuel Basket	Maximum transverse bending stress in most heavily loaded basket panel, averaged over the panel length	ASME Level D primary membrane + bending stress intensity limit

Table 2.I.7
Intentionally Deleted

TABLE 2.I.8
PERMISSIBLE MATERIALS FOR HI-STORM 100U VVM COMPONENTS AND ISFSI STRUCTURES

	Primary Function	Part	ITS Category	Material (note6)	Normal Storage (Long-Term Limit)	Max. Permissible Temperature (°F) Off-normal, extreme environmental phenomena, and accident conditions	Special Surface Finish/ Coating (note 1)	Interfacing Matl. (if dissimilar)
1	Shielding	Closure Lid Concrete	C	Shielding Concrete per Appendix I.D (note 2)	300 (note 3)	350 (note 3)	NA	Steel
2	Shielding	Closure Lid Steel	C	ASTM A516, Gr. 70, A515 Gr. 70 or equivalent	800 (note 4)	800 (note 4)	(note 5)	Concrete/Elastomer
3	Structural	CEC (Container Shell, Bottom Plate and Container Flange)	C	ASTM A516, Gr. 70, A515 Gr. 70 or equivalent	800 (note 4)	800 (note 4)	(note 5)	Subgrade/Concrete
4	Thermal	Insulation	C	Commercial	800	800	NA	Steel
5	Thermal	Inlet/Outlet Vent Screens and associated hardware	NITS	Carbon steel, stainless steel, aluminum, a polymeric fabric capable of 400°F (min.) service temperature or commercial	800 (note 4) if all metallic 400 otherwise	800 (note 4) if all metallic 400 otherwise	(note 5)	variable
6	Thermal	Outlet Vent Cover and associated hardware	NITS	Carbon steel, stainless steel, aluminum or commercial	800 (note 4)	800 (note 4)	(note 5)	variable
7	Thermal	Divider Shell and Divider Shell Restraints	C	ASTM A516, Gr. 70, A515 Gr. 70 or equivalent	800 (note 4)	800 (note 4)	(note 5)	Insulation

TABLE 2.I.8 (continued)
PERMISSIBLE MATERIALS FOR HI-STORM 100U VVM COMPONENTS AND ISFSI STRUCTURES

	Primary Function	Part	ITS Category	Material (note 6)	Max. Permissible Temperature (°F)		Special Surface Finish/ Coating (note 1)	Interfacing Matl. (if dissimilar)
					Normal Storage (Long-Term Limit)	Off-normal, extreme environmental phenomena, and accident conditions		
8	Structural	Upper and Lower MPC Guides	C	ASTM A516, Gr. 70, A515 Gr. 70 or equivalent	800 (note 4)	800 (note 4)	(note 5)	-
9	Structural	MPC Bearing Pads	C	Carbon Steel (with stainless steel liners)	800 (note 4)	800 (note 4)	(note 5)	Stainless steel
10	Shielding and Physical Protection to the CEC	VVM Interface Pad (VIP)	B	Reinforced Concrete Per ACI-318 (2005)	150	350	N/A	Steel
11	Shielding and Physical Protection	Top Surface Pad (TSP)	B	Reinforced Concrete Per ACI-318 (2005)	150	350	N/A	—
12	Shielding and Physical Protection	Subgrade Surrounding the VVMs	B	Engineered fill, natural soil, or treated soil	150	350	N/A	Steel or Concrete
13	Structural Support	Support Foundation Pad (SFP)	C	Reinforced Concrete per ACI-318 (2005)	150	350	N/A	Soil, rock, mud mat, piling, etc., as appropriate
14	Shielding and Physical Protection	Retaining Wall (if used)	B	Reinforced Concrete Per ACI-318 (2005)	150	350	N/A	—

Note 1 Materials identified by a supplier's trademark may be replaced with an equivalent product after an appropriate evaluation of acceptability.
Note 2 All requirements are identical to the shielding concrete in aboveground HI-STORMs.
Note 3 Limit per Appendix 1.D.
Note 4 Permissible temperature limit from ASME Code, Section II, is used as guidance to define all long and short-term loading limits. The metal temperature limits do not apply to the fire event (see Subsection 2.I.6).
Note 5 Surface preservative per Subsection 3.I.4.
Note 6 Materials listed as "or equivalent" may be replaced with "equivalent materials" as defined in Table 1.0.1. The critical characteristics for these materials are given in Table 2.I.9.

TABLE 2.I.9
CRITICAL CHARACTERISTICS OF EQUIVALENT MATERIALS USED IN THE VVM COMPONENTS

Designated Material	Item	Critical Characteristic
ASTM A515 or A516, Gr. 70	Yield Strength	Yield strength vs. Temperature data must exceed values from appropriate tables for 515/516 Gr.70 materials in ASME Code, Section II, Part D at all applicable temperatures. Applicable Code year is the same as used for the above ground HI-STORM.
	Ultimate Strength	Ultimate strength vs. Temperature data must exceed values from appropriate tables for 515/516 Gr.70 materials in ASME Code, Section II, Part D at all applicable temperatures. Applicable Code year is the same as used for the above ground HI-STORM.
	Elongation	Elongation must equal or exceed value(s) for 515/516 Gr. 70
	Charpy Impact	Values that measure resistance to impact must equal or exceed corresponding values for 515/516 Gr. 70.

TABLE 2.I.10 CRITICAL CHARACTERISTICS OF MATERIALS REQUIRED FOR SAFETY EVALUATION OF STORAGE AND TRANSPORT SYSTEMS				
	Property	**Type**	**Purpose**	**Bounding Acceptable Value**
1.	Minimum Yield Strength	S	To ensure adequate elastic strength for normal service conditions	Min.
2.	Minimum Tensile Strength	S	To ensure material integrity under accident conditions	Min.
3.	Young's Modulus	S	For input in structural analysis model	Min.
4.	Minimum elongation of $\delta_{min.}$' %	S	To ensure adequate material ductility	Min.
5.	Impact Resistance at ambient conditions	S	To ensure protection against crack propagation	Min.
6.	Maximum allowable creep rate	S	To prevent excessive deformation under steady state loading at elevated temperatures	Max.
7.	Thermal conductivity (minimum averaged value in the range of ambient to maximum service temperature, t_{max})	T	To ensure that the basket will conduct heat at the rate assumed in its thermal model	Min.
8.	Minimum Emissivity	T	To ensure that the thermal calculations are performed conservatively	Min.
9.	Specific Gravity	S (and R)	To compute weight of the component (and shielding effectiveness)	Max. (and Min.)
10.	Thermal Expansion Coefficient	T (and S)	To compute the change in basket dimension due to temperature (and thermal stresses)	Min. and Max.
11.	Boron-10 Content	R	To control reactivity	Min.

TABLE 2.I.11
LOAD COMBINATIONS FOR THE TOP SURFACE PAD, VVM INTERFACE PADS, SUPPORT FOUNDATION PAD, AND THE RETAINING WALL PER ACI-318 (2005)

Load Combination	
LC-1	1.4D
LC-2	1.2D + 1.6L
LC-3	1.2D + E + L

where:
D: Dead Load including long-term settlement effects.
L: Live Load
E: DBE for the Site

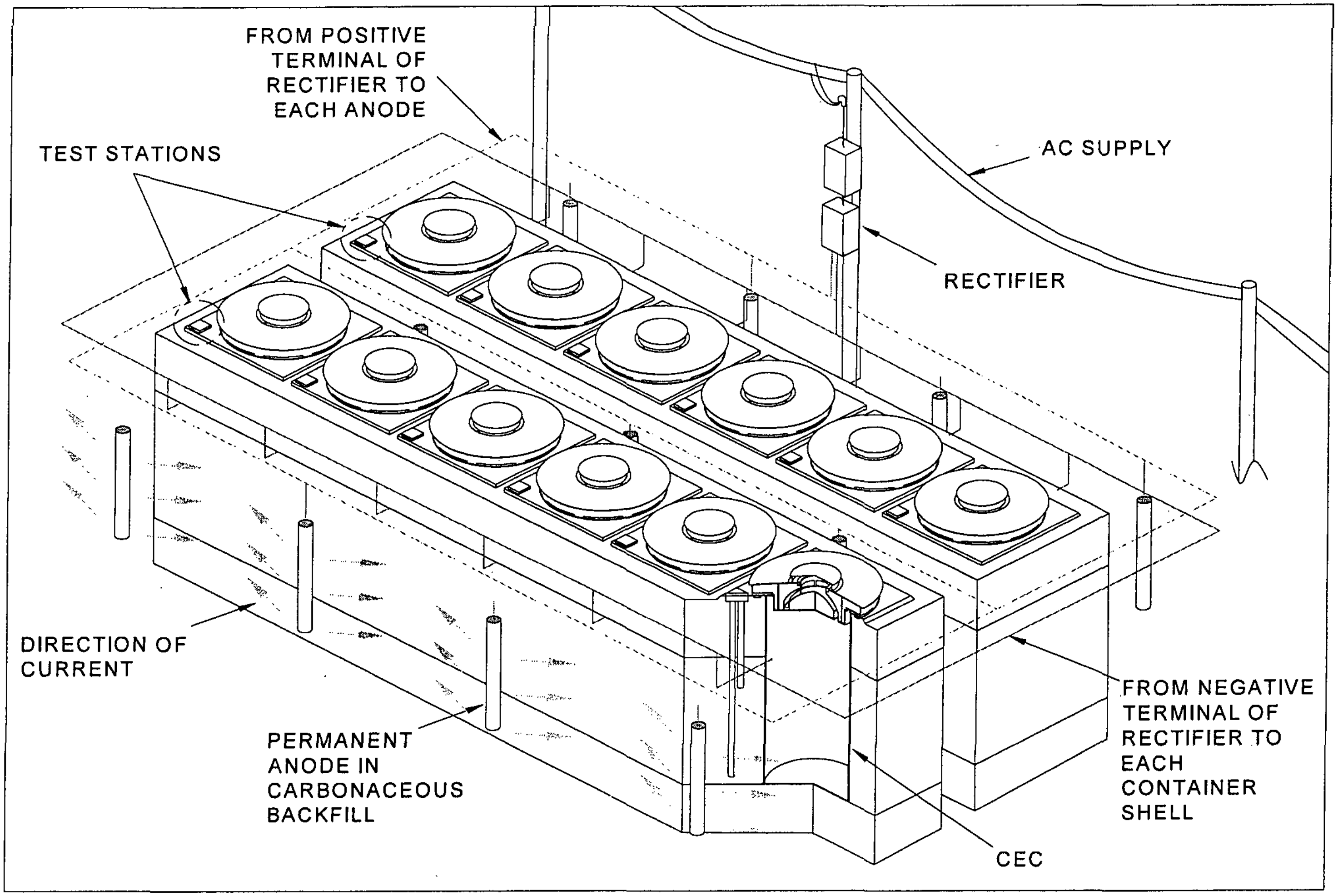


FIGURE 2.I.1: HI-STORM 100U SYSTEM EXAMPLE ICCPS DESIGN – 2 X 6 ARRAY DESIGN LAYOUT*

* The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Expansion joints between the VVM Interface Pad and the Top Surface Pad are not shown in this figure.

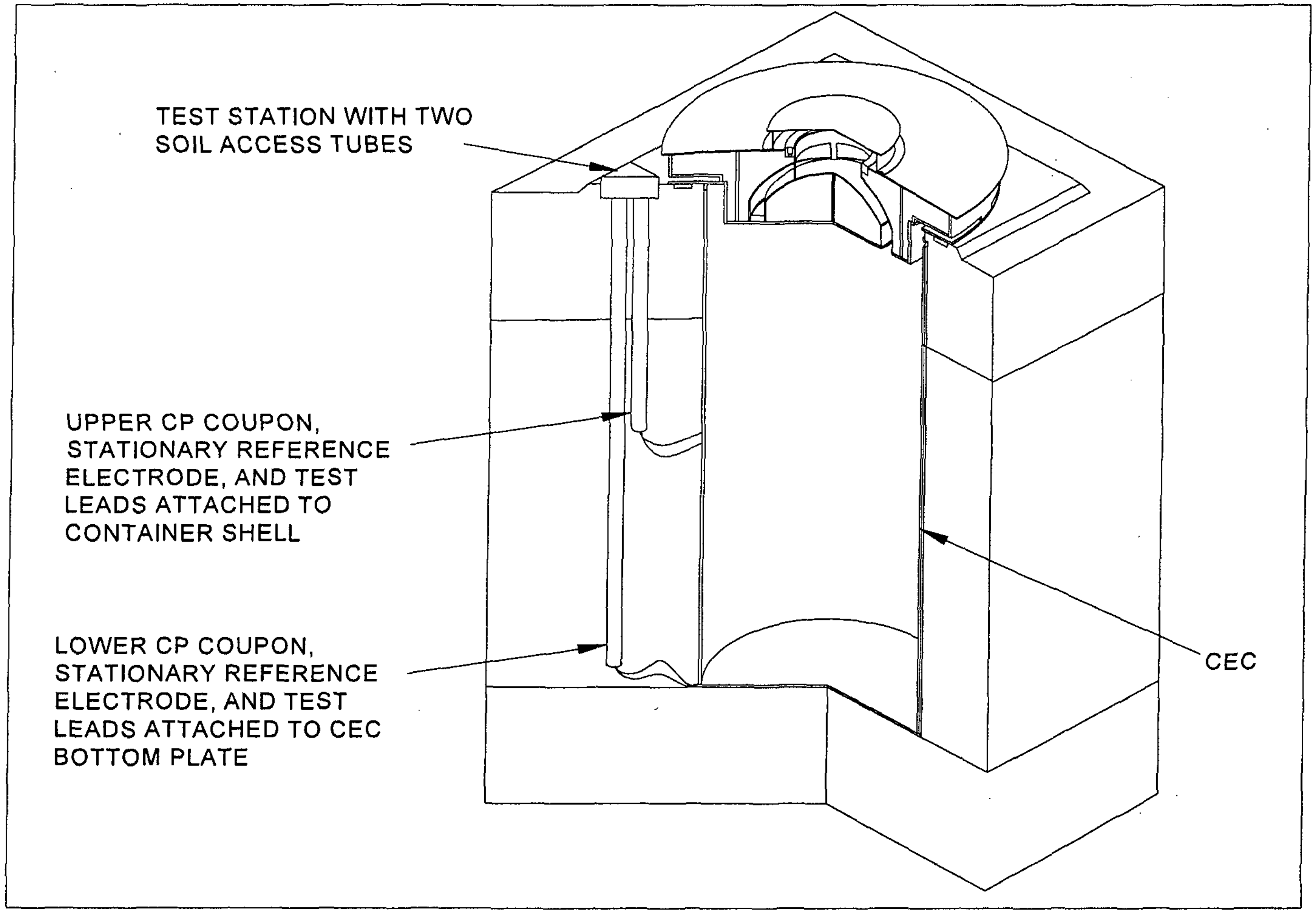


FIGURE 2.I.2: HI-STORM 100U SYSTEM EXAMPLE ICCPS DESIGN – TEST STATION*

*The design features of the HI-STORM 100U System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Expansion joints between VVM Interface Pad and Top Surface Pad are omitted from this figure.

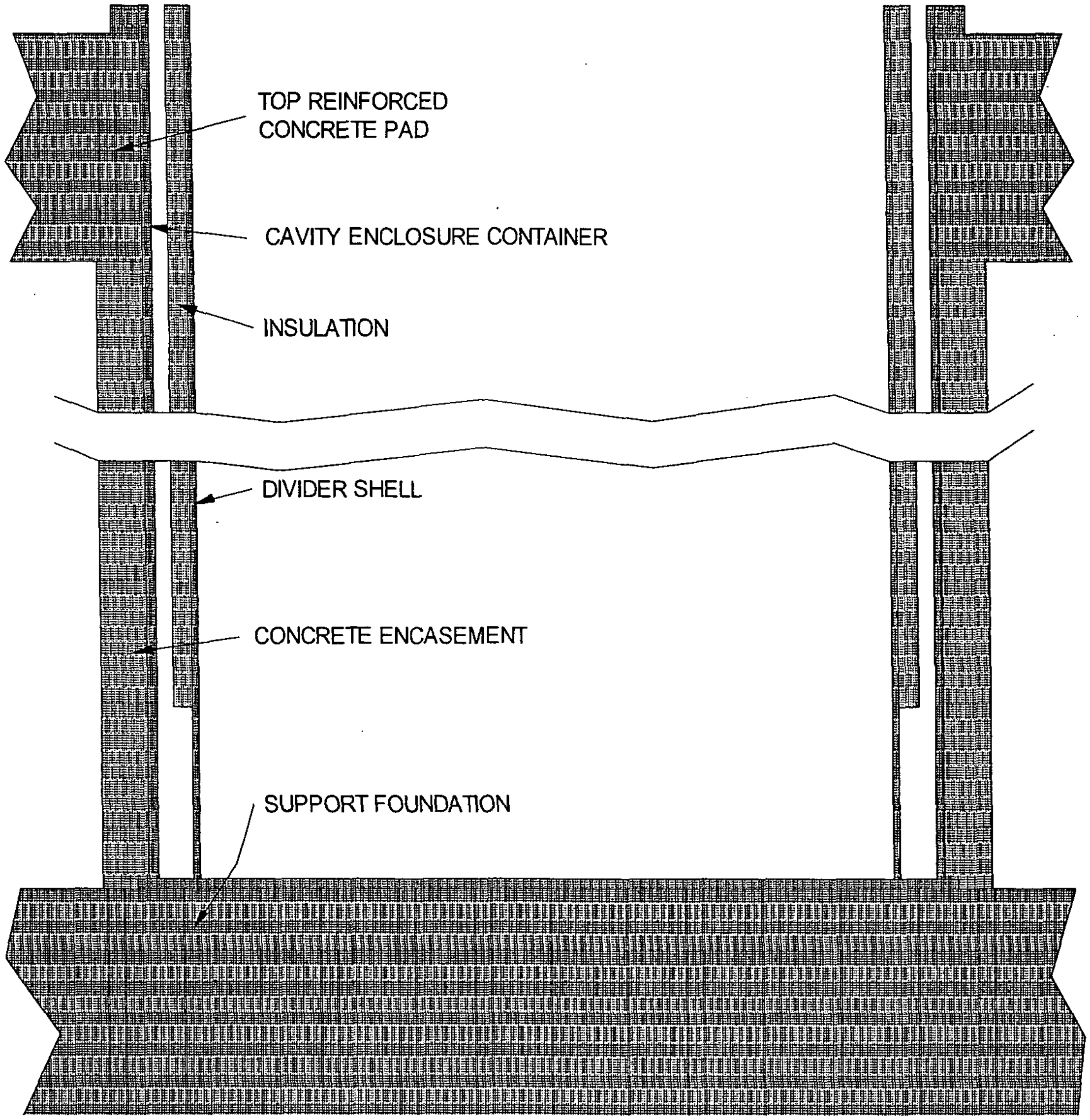
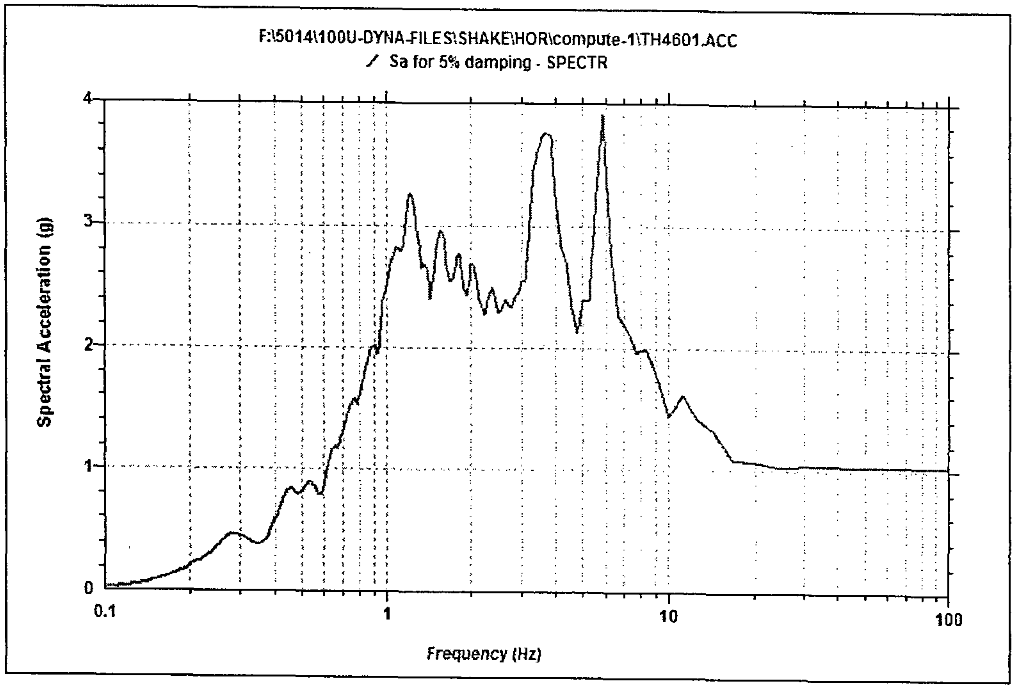
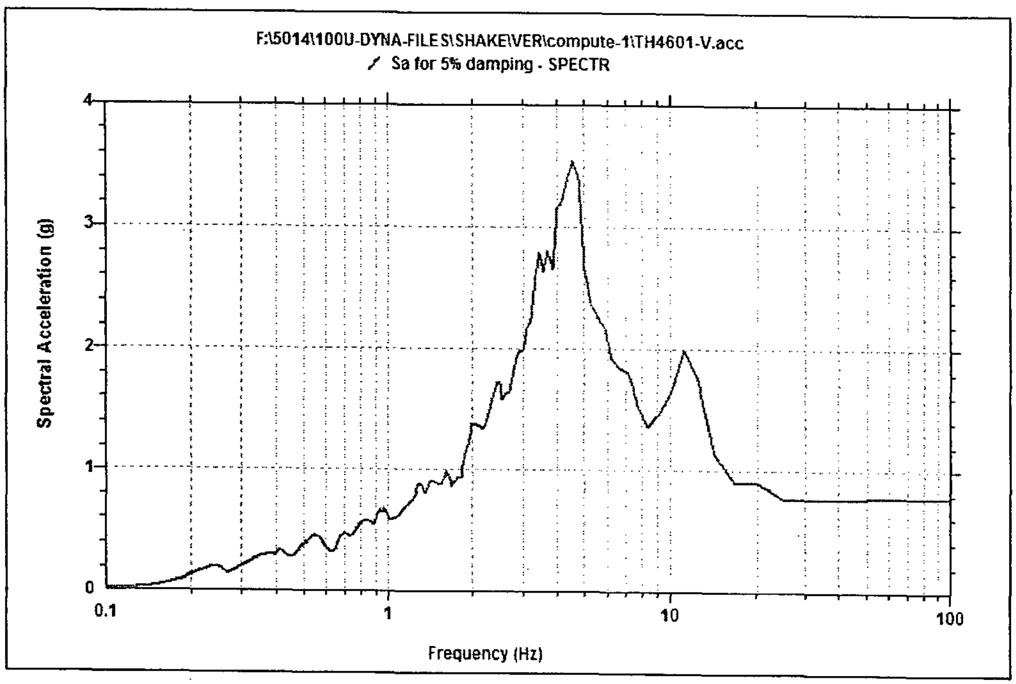


FIGURE 2.I.3: TYPICAL CONCRETE ENCASEMENT OF THE CEC

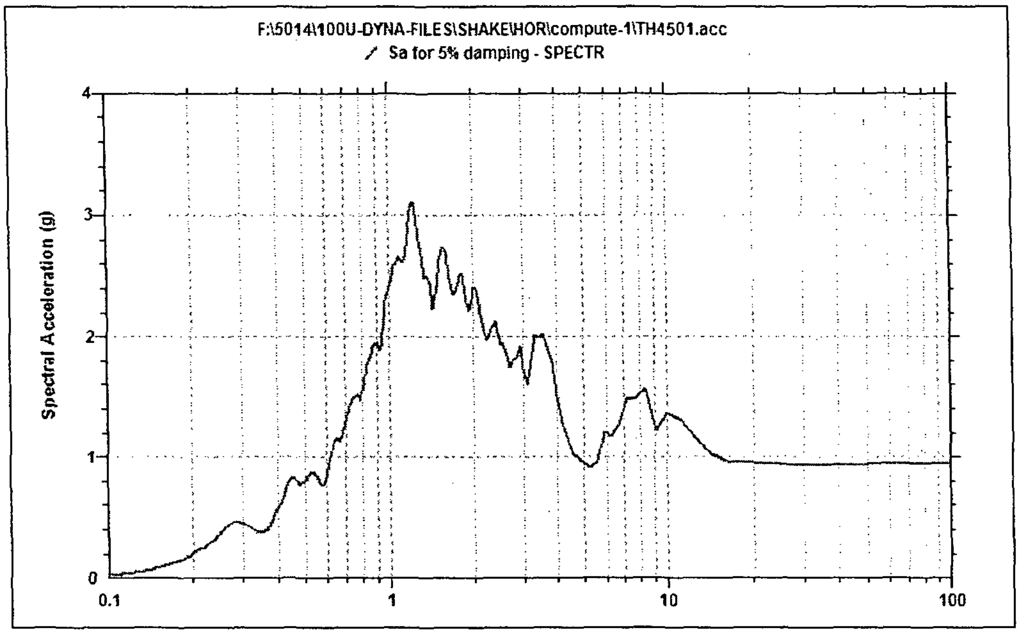


(a)

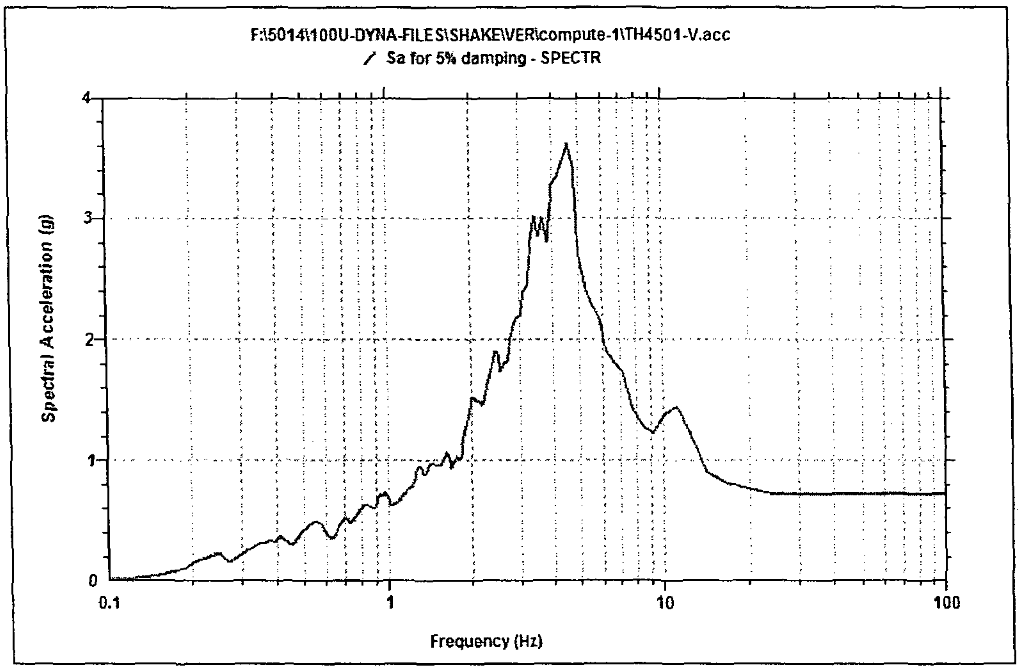


(b)

FIGURE 2.I.4-A: DESIGN BASIS SPECTRUM AT THE GROUND SURFACE (TOP OF TSP) ELEVATION
(a) HORIZONTAL DIRECTION; (b) VERTICAL DIRECTION



(a)



(b)

FIGURE 2.I.4-B: DESIGN BASIS SPECTRUM AT THE 100U FOUNDATION SURFACE (BOTTOM OF SFP) ELEVATION
(a) HORIZONTAL DIRECTION; (b) VERTICAL DIRECTION

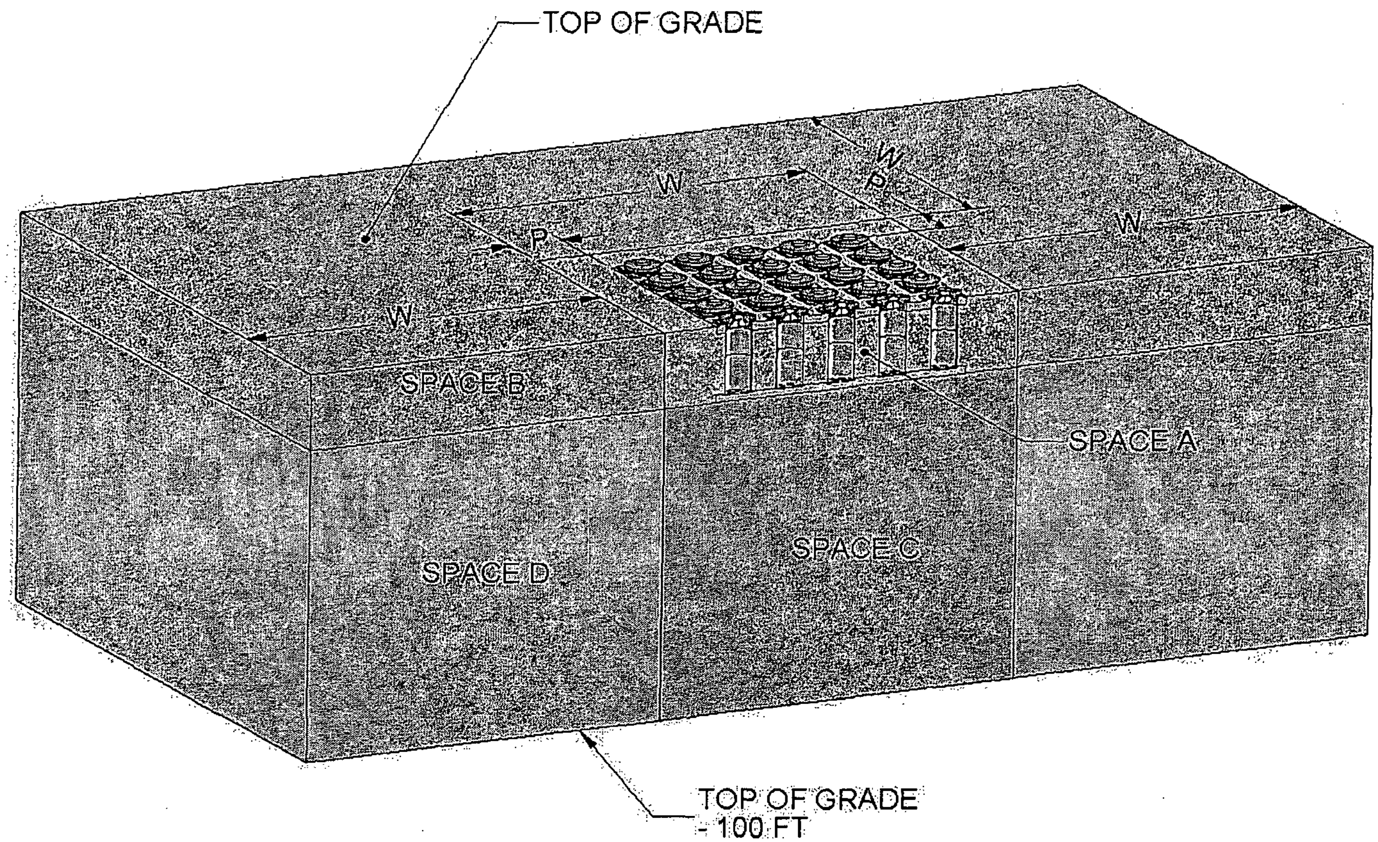


FIGURE 2.I.5 SUB-GRADE AND UNDER-GRADE SPACE NOMENCLATURE

Note: The figure shows a 5 by 5 array with a slice through the centerline of the first row of VVMs facing the reader. Space A is the lateral subgrade space in and around the VVMs which may be excavated and refilled with engineered fill. Space B is the lateral subgrade that extends by the amount W around the ISFSI where W is the characteristic dimension of the ISFSI. Space C is the undergrade below the SFP. Space D is the undergrade surrounding Space C. P is the distance to the Retaining wall.

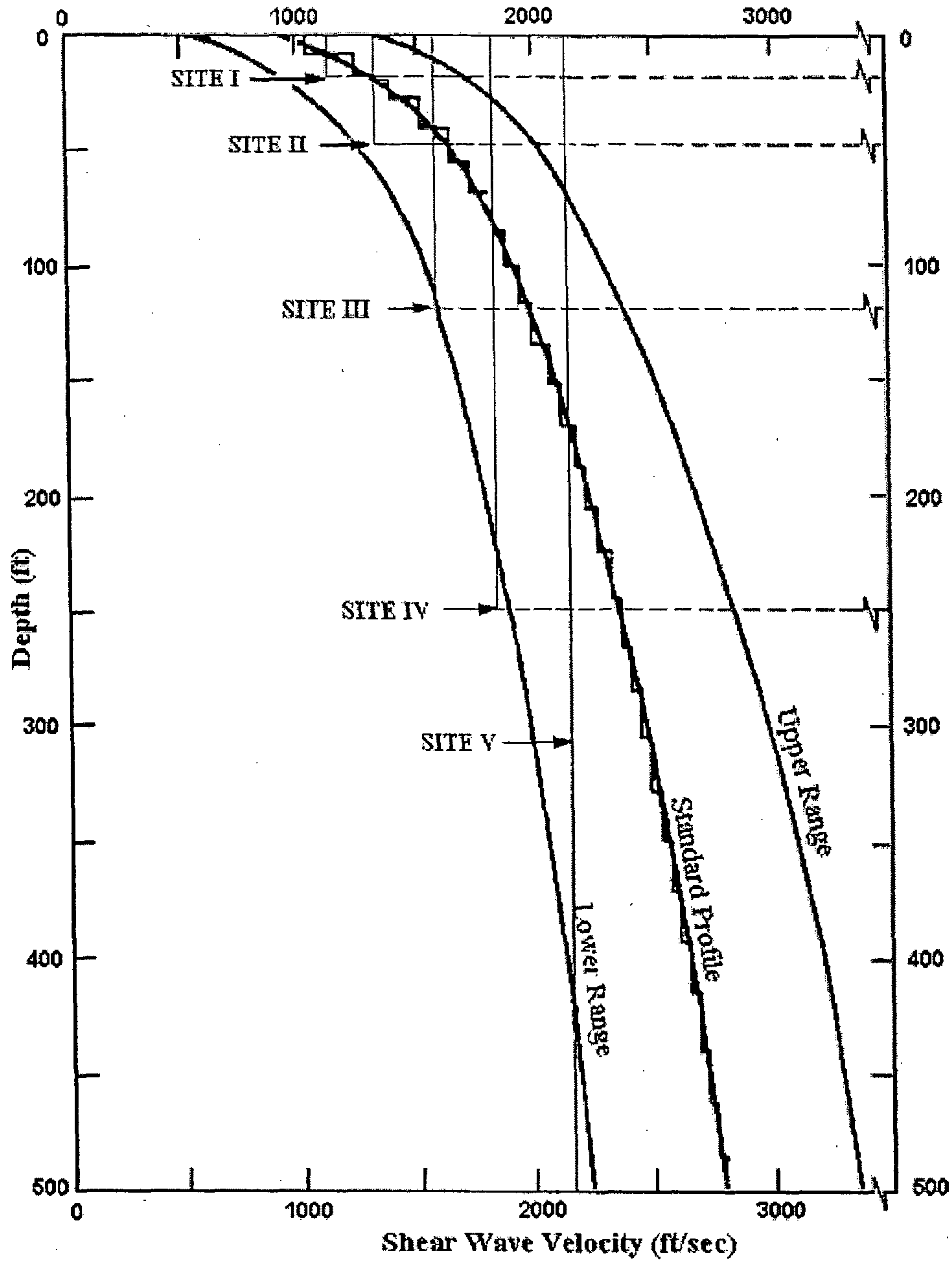


FIGURE 2.I.6 TYPICAL SHEAR WAVE VELOCITY PROFILES FOR NUCLEAR POWER PLANT SITES (REPRODUCED FROM FIGURE I-1 OF [2.I.10])

SUPPLEMENT 3.I

STRUCTURAL EVALUATION FOR THE HI-STORM 100U SYSTEM

3.I.0 OVERVIEW

In this supplement, the structural adequacy of the HI-STORM 100U Vertical Ventilated Module (VVM) is evaluated pursuant to the guidelines of NUREG-1536. The organization of technical information in this supplement mirrors the format and content of Chapter 3 except that it only contains material directly pertinent to the HI-STORM 100U VVM.

The HI-STORM 100U VVM serves as the storage space for the loaded MPC and consists of the CEC (the Container Shell, the Divider Shell and MPC Guides, and a welded Bottom Plate), and a lid consisting of plain concrete encased in structural steel arranged to provide appropriate inlet and outlet air passages (the Closure Lid). These individual components are collectively referred to as VVM Components. Interfacing SSCs that surround and support the VVM, as well as proximate structures, collectively referred to as ISFSI Structures are explained in Supplement 2.I. Section 1.I.2 contains a complete description of the VVM components and ISFSI Structures (accompanied by appropriate figures) and their respective functions within the HI-STORM 100U ISFSI. The essential design details of both the VVM Components and the ISFSI Structures are set down in the licensing drawing in Supplement 1.I. The design basis loadings for the facility are provided in Supplement 2.I. The applicable codes, standards, and practices governing the structural analysis of the HI-STORM 100U module, as well as the design criteria, are also presented in Supplement 2.I. Throughout this supplement, in the context of the VVM components, the term "*safety factor*" is defined as the *ratio of the allowable stress (load) or displacement for the applicable load combination to the maximum computed stress (load) or displacement.*

For the ISFSI Structures made of reinforced concrete, the safety factor is defined as the ratio of the ultimate moment (or shear) capacity to the actual maximum moment (or shear) developed under the factored load combination.

MPC structural integrity has been evaluated in Chapter 3. In this supplement, the integrity of the MPC, due to its rattling motion inside the VVM storage cavity during a seismic event (a new loading condition in the underground storage configuration) is considered.

3.I.1 STRUCTURAL DESIGN

3.I.1.1 Discussion

The HI-STORM 100U system consists of three principal components: the Multi-Purpose Canister (MPC), the HI-STORM 100U storage module, herein denoted as the Vertical Ventilated Module (VVM), and the HI-TRAC transfer cask. This supplement to Chapter 3 presents the structural evaluation of the VVM Components for the applicable load cases summarized in Supplement 2.I (Table 2.I.5). In Section 3.I.4, the safety factors for each load case for the VVM Components are quantified. In addition, the safety evaluation of the ISFSI Structures is carried out using the factored load combinations from ACI-318(2005) (see Table 2.I.11). Summary tables of bounding safety factors are provided for governing load combination for the ISFSI Structures. A licensing drawing for the HI-STORM 100U VVM is provided in Section 1.I.5. Table 2.I.1 provides a listing of the applicable regulations and codes and standards for the VVM Components and the ISFSI structures. The design of the VVM components and the ISFSI Structures is fully articulated in the licensing drawing and Table 2.I.2. The applicable Design Basis Earthquake is defined by the free field spectra shown in Figure 2.I.4.

3.I.1.2 Design Criteria

Design (and acceptance) criteria for the HI-STORM 100U VVM Components and the ISFSI structures are summarized in Tables 2.I.1 and 2.I.6.

3.I.1.3 Loads

Individual loads, applicable to the HI-STORM 100U System, are defined in Sections 2.I.4, 2.I.5 and 2.I.6, and the load cases applicable to the VVM Components are summarized in Table 2.I.5. Table 2.I.11 contains load combinations applicable to the ISFSI Structures (reinforced concrete structures) in the HI-STORM 100U ISFSI.

3.I.1.4 Allowables

Allowable stresses for carbon steel and Alloy X used in the structural components of the HI-STORM 100U and the stored MPC are provided in Sections 3.1 and 3.3. The relevant data from those sections are reproduced here, as Tables 3.I.3 (a)-(d) to make the supplement self-contained.

3.I.1.5 Brittle Fracture

Brittle fracture considerations for HI-STORM 100U are bounded by HI-STORM 100 and 100S because of the VVM's underground configuration, and the use of the same material types and thicknesses as in the aboveground overpacks.

3.I.1.6 Fatigue

The HI-STORM 100U system is not subject to significant long-term cyclic loads. Therefore, failure due to fatigue is not a concern for the HI-STORM 100U system.

3.I.1.7 Buckling

The CEC Container Shell is the only component of the VVM subject to axial compression. However, since the shell is backed by a substrate, welded to a Bottom Plate at its base, and surrounded by the ISFSI Pad at the top, instability is not considered credible. The Divider Shell does not experience any axial compressive stress that might induce buckling.

3.I.2 WEIGHTS AND CENTERS OF GRAVITY

Table 3.I.1 provides bounding weights of the individual HI-STORM 100U components.

The locations of the calculated centers of gravity (C.G.s) are presented in Table 3.I.2 and are computed using the bounding weights. All centers of gravity are located on the VVM centerline.

Bounding weight values for the CEC and the Closure Lid include an overage on the weight generated by the CAD drawing package.

3.I.3 MECHANICAL PROPERTIES OF MATERIALS

Tables 2.I.3 and 2.I.8 list applicable codes, materials of construction, and ITS designations for all functional parts in the HI-STORM 100U system except for the MPC and its internals, which remain unchanged (listed in Table 2.2.6).

3.I.3.1 VVM Steel Properties

Applicable material property and allowable stress tables in Chapter 3 for the VVM are reproduced in Tables 3.I.3 (a)-(c) for convenience.

3.I.3.2 Unreinforced Concrete

The primary function of the unreinforced concrete in the HI-STORM 100U VVM Closure Lid is shielding. Unreinforced concrete is not considered as a primary load-bearing (structural) member. However, its ability to withstand compressive, bearing and penetrant loads under the design basis and various service conditions is analyzed. The allowable bearing strength of plain concrete for normal loading conditions is calculated in accordance with ACI-318 (2005) [2.I.5]. Table 3.I.4 provides a bearing limit consistent with the concrete compressive strength in the same table. The procedure specified in ASTM C-39 is utilized to verify that the assumed compressive strength will be realized in the actual in-situ pours. Unless specifically called out in Table 3.I.4, Appendix 1.D provides requirements on unreinforced concrete.

3.I.3.3 Reinforced Concrete

Reinforced concrete is used in the construction of the ISFSI Structures, namely, the retaining wall, the TSP, the VIP, and the SFP. All reinforced concrete load bearing structures in the HI-STORM 100U ISFSI will conform to stress criteria of ACI-318(2005).

3.I.4 GENERAL STANDARDS FOR CASKS

In this section, new or additional material applicable to the HI-STORM 100U system is included. Section 3.4 contains all required information associated with the MPCs and with the HI-TRAC transfer cask and is not repeated here. Results reported in this supplement section are generally applicable only to the HI-STORM 100U VVM.

3.I.4.1 Chemical and Galvanic Reactions

In order to provide reasonable assurance that the VVM will meet its intended Design Life of 40 years (the License Life is 20 years) and perform its intended safety function(s), chemical and galvanic reactions and other potentially degrading mechanisms must be accounted for in its design and construction.

The HI-STORM 100U VVM is a buried structure and as such chemical and galvanic reactions and other potentially degrading factors are, in some respects, more challenging than for aboveground models. Although the CEC is not a part of the MPC containment boundary, it should not corrode to the extent where localized in-leakage of water occurs or where gross general corrosion prevents the component from performing its primary safety function. In the following, considerations in the VVM's design and construction consistent with the applicable guidance provided in ISG-15 [3.I.3] are summarized.

All VVM components are galvanically compatible. Except for the CEC exterior surfaces, all steel surfaces of the VVM are lined and coated with the same surface preservative that is used in the aboveground HI-STORM overpacks. (The surface preservative used to protect HI-STORM 100S steel surfaces is a proven zinc rich inorganic/metallic material that protects galvanically and has self healing characteristics for added assurance). All exposed surfaces interior to the VVM, as stated in Supplement 1.I, are accessible for the reapplication of surface preservative, if necessary.

The steel Divider Shell requires insulation to perform its primary thermal function. The insulation selected shall be suitable for high temperature and high humidity operation and shall be foil faced, jacketed or otherwise made water resistant to ensure the required thermal resistance is maintained in accordance with Supplement 4.I. The high zinc content in the coating of the Divider Shell provides protection for both the Divider Shell and the jacketing or foil from any potential galvanic corrosion concerns. With respect to radiation resistance, the insulation blanket does not contain any organic binders. The damage threshold for ceramics is known to be approximately $1x10^{10}$ Rads. Chloride corrosion is not a concern since chloride leachables are limited and sufficiently low and the Divider Shell is not made from stainless steel [3.I.20]. Stress corrosion cracking of the foil or jacketing, whether made from stainless steel or other material is not an applicable corrosion mechanism due to minimal stresses derived from self-weight. The foil or jacketing and attachment hardware shall either have sufficient corrosion resistance (e.g. stainless steel, aluminum or galvanized steel) or shall be protected with a suitable surface preservative. The insulation is adequately secured to prevent significant blockage of the ventilation passages in case of failure of a single attachment (strap, clamp, bolt or other attachment hardware). The following table provides the acceptance criteria for the selection of insulation material for the Divider Shell and ranks them in order of importance.

Acceptance Criteria for the Selection of the Insulation Material	
Rank	**Criteria**
1	Adequate thermal resistance
2	Adequate high temperature resistance
3	Adequate humidity resistance
4	Adequate radiation resistance
5	Adequate resistance to the ambient environment
6	Sufficiently low chloride leachables
7	Adequate integrity and resistance to degradation and corrosion during long-term storage

Kaowool® ceramic fiber insulation [3.I.20] is selected as one that satisfies the acceptance criteria to the maximum degree. The Kaowool® insulation material provides excellent resistance to chemical attack and is not degraded by oil or water. Alternatively, a Holtec approved equivalent that meets the acceptance criteria set forth in the table above may be used.

The CEC Container Shell, which is exposed to the substrate, requires additional pre-emptive measures to prevent corrosion, if the substrate is of aggressive chemistry. This subsection provides a description of corrosion mitigation measures required to be implemented to protect the HI-STORM 100 VVM. Because the guiding principle in the HI-STORM systems is to target a service life of 100 years so as to guarantee a design life of 40 years, these corrosion prevention measures are in addition to the preemptively incorporated standard corrosion allowance of 1/8-inch applied to the subterranean parts of the CEC in direct contact with the surrounding substrate. Calculation of the required CEC Container Shell and Bottom Plate thicknesses on a site-specific basis may indicate the availability of an additional corrosion reserve.

Soil Corrosivity and Corrosion Mitigation Measures for the Exterior of the CEC

Corrosion mitigation of the exterior of the CEC warrants special consideration for the following reasons: (i) inaccessibility of the exterior coated surface after installation (ii) potential for a highly aggressive (i.e., corrosive) soil environment at certain sites, and (iii) potential for a high radiation field. Since the buried configuration will not allow for the reapplication of surface preservative, corrosion mitigation measures shall be determined after careful evaluation of the soil's corrosivity at the user's ISFSI site.

To evaluate soil corrosivity, a "10 point" soil-test evaluation procedure, in accordance with the guidelines of Appendix A of ANSI/AWWA C105/A21 [3.I.4], will be utilized. The classical soil evaluation criteria in the aforementioned standard focuses on parameters such as: 1) resistivity, 2) pH, 3) redox (oxidation-reduction) potential, 4) sulfides, 5) moisture content, 6) potential for stray current, and 7) experience with existing installations in the area. Using the procedure outlined in ref. [3.I.4], the ISFSI soil environment corrosivity is categorized as either "mild" for a soil test evaluation resulting in 9 points or less or "aggressive" for a soil test evaluation resulting in 10 points or greater. The following table details the corrosion mitigation measures that shall be implemented based on soil environment corrosivity:

Implementation of Corrosion Mitigation Measures			
Soil Environment Corrosivity	**Corrosion Mitigation Measures**		
	Coating (see note i)	Concrete Encasement (see note ii)	Cathodic Protection (see note iii)
Mild	Required	Choice of either concrete encasement or cathodic protection; or both	
Aggressive	Required	Optional	Required
Notes: i. An acceptable exterior surface preservative (coating) applied on the CEC. ii. Concrete encasement of the CEC external surfaces to establish a high pH buffer around the metal mass. iii. A suitably engineered impressed current cathodic protection system (ICCPS)			

The corrosion mitigation measures tabulated above are further detailed in the following subsections:

i. Coating

In addition to the corrosion allowance, the CEC shall be coated with a radiation resistant surface preservative designed for below-grade and/or immersion service. Inorganic and/or metallic coatings are sufficiently radiation resistant for this application; therefore, radiation testing is not required [3.I.5]. Organic coatings such as epoxy, however, must have proven radiation resistance [3.I.5] or must be tested without failure to at least 10^7 Rad. Radiation resistance to lower radiation levels is acceptable on a site-specific basis. Radiation testing shall be performed in accordance with ASTM D 4082 [3.I.6] or equivalent. The coating should be conservatively treated as a Service Level II coating as described in Reg. Guide 1.54 [3.I.7]. As such, the coating shall be subjected to appropriate quality assurance in accordance with the applicable guidance provided by ASTM D 3843-00 [3.I.8]. The coating should preferably be shop applied in accordance with manufacturer's instructions and, if appropriate, applicable guidance from ANSI C 210-03 [3.I.9]. The Keeler & Long polyamide-epoxy coating, according to the manufacturer's product data sheet [3.I.10], is pre-tested to radiation levels up to $1x10^9$ Rads without failure. The following table provides the acceptance criteria for the selection of coatings for the exterior surfaces of the CEC and ranks them in order of importance.

Acceptance Criteria for the Selection of Coatings	
Rank	**Criteria**
1	suitable for immersion and/or below grade service
2a	compatible with the ICCPS (if used) • adequate dielectric strength • adequate resistance to cathodic disbondment

Acceptance Criteria for the Selection of Coatings	
Rank	**Criteria**
2b	compatible with concrete encasement (if used) • adequate resistance to high alkalinity
3	adequate radiation resistance
4	adequate adhesion to steel
5	adequate bendability/ductility/cracking resistance/abrasion resistance
6	adequate strength to resist handling abuse and substrate stress

The Keeler & Long polyamide-epoxy coating is selected as one that satisfies the acceptance criteria to the maximum degree. Alternatively, a Holtec approved equivalent that meets the acceptance criteria set forth in the table above may be used.

ii. Concrete Encasement

The CEC concrete encasement shall provide a minimum of 5 inches of cover to provide a pH buffering effect for additional corrosion mitigation. The above concrete cover thickness has been conservatively determined for a 100-year service life in a strongly aggressive environment based on the concrete corrosion/degradation data provided in the literature [3.I.12, Table 5.3] (1.2 mm/yr surface depth failure rate). The required 5 inch minimum thickness is more conservative than that recommended in ACI Codes, such as ACI 318 [3.3.2], which call for up to 3 inches of concrete cover over steel reinforcement in aggressive environments. Considering that the concrete encasement is restricted to mild soil environments (unless used in conjunction with cathodic protection) and has a non-structural role, the 5 inch concrete encasement thickness is considered more than sufficient to provide reasonable assurance that a 40 year service life can be achieved. The lowest part of the CEC sits in a recessed region of the Support Foundation with an annular gap normally filled with substrate. If present, the CEC concrete encasement slurry will fill this annular gap during construction.

The function of the concrete encasement is for corrosion mitigation only; however, cracks larger than hairline cracks may significantly reduce its effectiveness. To control size and population of cracks, concrete reinforcement is included. The following reinforcement methods may be applied:

a. Fiber reinforcement: Fiber reinforcement may be of several materials, including steel, glass and plastic (polypropylene). The selection of the fiber reinforcement material shall be such that adequate resistance to radiation and high alkalinity is maintained. If using steel fibers, adequate damage protection of the CEC coating shall be ensured during concrete placement per written procedures. Steel fiber shall be implemented using written procedures and the applicable guidance from ACI 544.3R [3.I.25] or a similar consensus code or standard. Fiber reinforcement materials other than steel shall be implemented using written procedures, manufacturer recommendations and applicable guidance from ACI, ASCE and/or ASTM. One such document is ASTM C1116-03 [3.I.26].

b. Steel wire reinforcement: Steel wire reinforcement shall be implemented in accordance with written procedures and the guidance from ACI 318 [3.3.2] or more recent version. For corrosion protection, the steel wire reinforcement shall have a concrete cover of approximately 2 to 3 inches from the interfacing substrate.

Regardless of reinforcement method, the material selected shall be corrosion resistant or otherwise appropriately coated (e.g. epoxy coated steel wire) for corrosion resistance.

The concrete encasement shall be installed in accordance with Holtec approved procedures following applicable guidance from the ACI code (e.g. ACI 318 [3.3.2]), as appropriate, for commercial concrete. Installation procedures shall address mix designs (incorporating Portland cement), testing, mixing, placement, and reinforcement, with the aim to enhance concrete durability and minimize voids and micro-cracks.

iii. Impressed Current Cathodic Protection System (ICCPS)

For a particular ISFSI site, the user may choose to either extend an existing ICCPS to protect the installed ISFSI, or to establish an autonomous ICCPS. The initial startup of the ICCPS must occur within one year after installation of the VVM to ensure timely corrosion mitigation. In addition, the ICCPS should be maintained operable at all times after initial startup except for system shutdowns due to power outages, repair or preventive maintenance and testing, or system modifications. Because there are a multitude of ISFSI variables that will bear upon the design of the ICCPS for a particular site, the essential criteria for its performance and operational characteristics are set down in this FSAR, which the detailed design work for each ISFSI site must follow.

Design Criteria for the Impressed Current Cathodic Protection System
a. The cathodic protection system shall be capable of maintaining the CEC at a minimum (cathodic) potential as required by NACE Standard RP0285-2002 [3.I.21].
b. The ICCPS shall include provisions to infer its proper operation and effectiveness on a periodic basis.
c. The system shall be designed to mitigate corrosion of the CEC for its design life.
d. The cathodic protection system design, installation, operation, testing, and maintenance shall follow the applicable guidelines of: - 49CFR195 Subpart H "Corrosion Control", Oct. 1, 2004 edition [3.I.13] - NACE Standard RP0285-2002 "Corrosion Control of Underground Storage Tank Systems by Cathodic Protection" [3.I.21]

The following standards and/or publications may also be utilized for additional guidance in the design, installation, operation, testing, and maintenance of the ICCPS as needed (in case of conflict, the guidelines of item d above shall prevail):

- API RP1632, "Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems" [3.I.22]
- NACE RP0169-96, "Control of External Corrosion on Underground or Submerged Piping Systems" [3.I.23]
- 49CFR192 Subpart I "Requirements for Corrosion Control", Oct. 1, 2004 edition [3.I.24]
- Other standards or publications referenced by any of the above three standards and publications.

Records of system operating data necessary to adequately track the operable status of the ICCPS shall be maintained in accordance with the user's quality assurance program.

Finally, the surface preservative used to coat the CEC must meet the requirements described in (i) above but must also be compatible with cathodic protection and resistant to the alkaline conditions created by cathodic protection and/or concrete encasement. Organic coatings, such as the Keeler & Long coating selected for (i) above, are inherently compatible with both cathodic protection [3.I.11] and concrete [3.I.10].

3.I.4.2 Positive Closure

There are no quick-connect/disconnect ports in the confinement boundary of the HI-STORM 100U system. Because the only access to the MPC is through the VVM Closure Lid, which weighs well over 10 tons, inadvertent opening of the VVM cavity is not feasible.

3.I.4.3 Lifting Devices

As required by Reg. Guide 3.61, lifting operations applicable to the VVM lid are analyzed. Because of the nature of the HI-STORM 100U system, lid placement or removal may occur with a loaded MPC inside the VVM cavity; these are the sole operations requiring analysis in accordance with Reg. Guide 3.61 and are examined in this supplement.

As discussed in Subsection 3.4.3, the lifting component itself (the four lift lugs) must meet the primary stress limits prescribed by ANSI N14.6-1993; the welds in the load path, near the lifting holes, are required to meet the condition that stresses remain below yield under three times the lifted load (per Reg. Guide 3.61). Further, for additional conservatism, away from the lifting location, the ASME Code limit for the Level A service condition applies.

The lifting analysis results summarized below include a 15% inertia amplifier.

HI-STORM 100U VVM Closure Lid Lifting Analysis (Load Case 05 in Table 2.I.5)

The four lifting lugs are analyzed to ANSI N14.6 stress limits using simple strength of materials calculations. Each of four lugs is considered as a cantilever beam attached to the lid and carries 25%

of the lid weight. The bending moment and shear force at the root of the cantilever (where it is attached to the lid) is computed and the maximum stress is compared with the minimum of the yield strength/6 or the ultimate strength/10. As required, increasing the lid weight by 15% includes inertia effects. Using the calculated bending moment and shear force at the root of the lug, the structural evaluation of the weld attaching the lug to the lid is performed and compared with the requirements of Regulatory Guide 3.61. The results from these two calculations demonstrate that the required safety factors are substantially greater than 1.0 (exceeding the requirements of ANSI N14.6 and Reg. Guide 3.61, respectively). The details of the calculations are presented in the calculation package supporting this submittal [3.I.27]. Lifting slings that attach to the lugs shall be sized to meet the safety factors set forth in ANSI B30.3.

To evaluate the global state of stress in the lid body, a finite element model of the lid, which includes contact interfaces between steel and concrete, is constructed to evaluate the state of stress under lifting conditions. Figure 3.I.1 shows the constructed ANSYS finite element model. The lifted scenario is simulated by fixing the four lifting locations at the lift lug sling attachment location, and applying an appropriate weight density to match the lifted weight. The results are evaluated for satisfaction of normal condition (ASME Level A) limits at the appropriate locations.

The table below summarizes key results obtained from the lifting analyses for the HI-STORM 100U VVM Closure Lid for a bounding set of input design loads.

HI-STORM 100U VVM Lid Lifting Analyses (Load Case 05 in Table 2.I.5)			
Item	Calculated Value	Allowable	Safety Factor
Bending of Lift Lugs (kip)(ANSI N14.6)	4.000	5.275	1.32 (see Note 1)
Shear in Lift Lugs (kip)(ANSI N14.6)	1.609	3.165	1.97 (see Note 1)
Load in Welds Near Lifting Lugs (kip) (Reg. Guide 3.61)	5.657	6.33	1.12 (see Note 2)
Primary Stress in Lid (ksi)(ASME Level A Limit)	< 10	26.25	> 2.63
Note 1: Computed safety factors represent the margin over that required by ANSI N14.6-1993 (0.1 x ultimate load). Note 2: Computed safety factor is based on 60% of yield strength for base metal and represents margin over limit set by Reg. Guide 3.61.			

It is concluded that all structural integrity requirements are met during a lift of the HI-STORM 100U VVM Closure Lid. All factors of safety, using applicable criteria from the ASME Code Section III, Subsection NF for Class 3 plate and shell supports, from USNRC Regulatory Guide 3.61, and from ANSI N14.6, are greater than 1.0.

3.I.4.4 <u>Heat</u>

a. <u>HI-STORM 100U VVM Stresses Under Transporter Loading and Substrate Overburden (Load Case 07 in Table 2.I.5)</u>

During HI-STORM 100U system loading, a HI-TRAC transfer cask with a fully loaded MPC is placed over a HI-STORM 100U VVM using a specially designed transporter and a lifting device meeting "single-failure proof" requirements, as applicable. The transfer cask is connected to the CEC using an ancillary mating device (see Figure 3.I.4). Although a handling accident is not credible, the CEC must possess the capacity to support any transporter loads imposed at and below the substrate surface during the short time when the transporter is positioned over a VVM cavity and carrying the weight of the loaded HI-TRAC (i.e., before the HI-TRAC is placed on the mating device). This loading condition leads to a maximum sub-surface lateral pressure on the CEC shell which may potentially cause its ovalization. This configuration also includes the loaded transporter traveling over a previously loaded VVM on its way to an empty CEC.

Table 3.I.1 gives the essential data on the representative transporter including its loaded weight and its track length and width (i.e., size of the load patch (Figure 3.I.5)). The average normal pressure, at the transporter track and TSP interface is computed by dividing the weight of the loaded transporter by the total area of the two load patches.

To determine the stress and displacement field in the CEC due to the combined action of the loaded transporter and the soil overburden, a 3-D ANSYS model of a VVM (see Figure 3.I.2) is prepared. The finite element model has the following attributes:

- The soil is modeled as an elastic continuum with properties specified in Tables 2.I.2 and 3.I.5. The VVM Interface Pad (VIP), which is separated from the Top Surface Pad (TSP) by a construction joint, is unaffected by the deflection of the TSP under the transporter weight. The VIP essentially is a dead weight on the soil column below and is appropriately incorporated in the model. To appropriately model the VIP within the confines of a linearly elastic construct, it is represented by a material with a very low Young's Modulus, but the correct weight density. This modeling assumption provides the appropriate weight on the substrate from the VIP but provides no additional strength to the TSP or to the CEC.

- The minimum CEC pitch from the licensing drawing is used.

- The TSP, shown in the licensing drawings, is represented by its appropriate elastic properties (Table 3.I.4).

- The soil mass surrounding the ISFSI is assumed to be constrained from expansion across the planes of symmetry (so as to maximize the Poisson compression load on the CEC). The bottom of the soil continuum extends to the SFP.

- The CEC shell is assumed to have its nominal un-corroded thickness; the stress and strain results are subsequently adjusted to reflect the postulated corrosion allowance (see Table 2.I.1).

- To linearize the problem, the soil is assumed to be bonded to all interfacing surfaces.

The results of the stress analysis are pictorially shown in Figure 3.I.11 where stress intensity in the CEC is plotted. As can be seen from this figure, the maximum primary stress intensity value is 1,390 psi based on the nominal shell thickness of 1 in. Accounting for the corrosion allowance in the CEC shell, the maximum stress intensity (essentially bending in nature) is appropriately adjusted to 1,816 psi ((1 in/0.875 in)^2 x 1390 psi). When compared with the Level A stress limit from ASME code Section III, Subsection NF (per Table 2.I.5), the maximum computed stress intensity provides a factor of safety:

$$SF = \frac{allowable}{actual} = \frac{26.25}{1.82} = 14.4$$

Because the stresses in the CEC shell remain elastic, no reduction in the diametral opening of the CEC due to plastic deformation is indicated. Therefore, the retrievability of the MPC is assured.

b. <u>HI-STORM 100U Lid Integrity Evaluation for Normal plus Explosion Loads, CEC Container Shell Evaluation Under Bounding Vertical Load (Load Case 02 in Table 2.I.5), and Design Basis Fire (Load Case 06 in Table 2.I.5)</u>

The VVM Closure Lid rests on the CEC and resists vertical loads, arising from dead weight, and from induced loadings from explosions, from seismic accelerations, and from tornado missile impact. In this subsection, the analysis considers only the normal loading condition plus the steady pressure bounding the explosion pressure (see Table 2.I.1). The finite element model shown in Figure 3.I.1 is used to obtain this solution; the Closure Lid vertical support is now all around and is provided by the CEC Container Shell Flange (instead of by the lift lugs). The stresses from the solution are compared, per the criteria in Table 2.I.5, with allowable stress values for plate and shell structures as provided in ASME Section III Code, Subsection NF. The allowable stress intensity is per Table 3.I.3 (c) for Level D conditions at a bounding temperature of 350°F.

The vertical load on the Container Shell ring flange, which can be computed from equilibrium, does not bound the vertical load under normal conditions when the Closure Lid is removed and replaced by a loaded HI-TRAC plus a Mating Device. The bounding vertical load during the transfer operation is an input for the evaluation of the Container Shell for this load case using Strength of Materials methodology. Key results from the analysis of the Closure Lid under the normal loading condition plus the steady pressure, and the follow-on analysis of the corroded Container Shell under the bounding vertical load (during the MPC transfer operation) are summarized in the following table:

Stress Analysis of the Closure Lid and CEC Container Shell Under Bounding Vertical Load During Normal Operations (Load Case 02 in Table 2.I.5)			
Item	Bounding Value from calculations	Allowable Limit	Safety Factor
Maximum Primary Principal Stress Anywhere in Lid (ksi)	< 12.0	59.65(Level D Stress Intensity Limit) 26.25 (Level A Stress Limit)	> 4.97* > 2.19*
CEC Container Ring Flange Weld (kips)	< 300	3,018	> 10.06
Compression Stress in CEC Container Shell Under Bounding Vertical Load (ksi)	< 1.425**	17.5	> 12.28

* The results from the analysis are presented in terms of principal stresses for simplicity. Safety factors are determined by comparison with the Level D stress intensity limits (Table 3.I.3(c)), or with Level A stress limits (Table 3.I.3 (b)). Regardless of the measure used, the safety factors are large.

** The bounding compressive stress is based on a fully corroded shell thickness and also conservatively includes the full weight of the CEC in addition to the bounding load at the top.

From the above results, it is concluded that there is minimum structural demand on the HI-STORM 100U Closure Lid and CEC Container Shell during normal operation (even if the explosion pressure is conservatively considered as a normal condition).

With respect to the fire event (Load Case 06 in Table 2.I.5), where the Closure Lid steel temperature rises to the limit set in Table 2.I.5, it is noted from Tables 3.I.3 (a) and (b) that the Level A stress limit is reduced to 0.68 of the room temperature value, the yield strength is reduced to 0.66 of its room temperature value, and the ultimate strength is reduced to 0.92 of its room temperature value. From the stress values obtained in the lid (even with the explosion 10 psi surface pressure load included), it is evident that a total collapse of the lid due to reduction of the ultimate strength is not credible.

Seismic loading on the VVM is considered in Subsection 3.I.4.7 (Load Case 04 in Table 2.I.5). Subsection 3.I.4.8 considers tornado missile impact (Load Case 03 in Table 2.I.5).

iv. Stress Calculations – ISFSI Structures

The 100U ISFSI consists of plate-type reinforced concrete structures whose minimum section strength properties are defined by Table 2.I.2 and the licensing drawings. The ISFSI is supported by the subgrade underneath the SFP, which may include pilings, if required, to meet the effective stress wave velocity in Table 2.I.2. The loadings on the ISFSI are:

a. Dead load of the VVM and the concomitant effect of settlement over the Design Life of the system. (D in Table 2.I.11). The method to incorporate the effect of long-term settlement of the subgrade underneath the SFP (may also be referred to as the undergrade), described in Subsection 2.I.2, is used. This method essentially consists of using the deflection properties of the different layers to define equivalent elastic properties of the subgrade underneath the SFP. In the finite element analysis of the SFP, the degraded elastic properties of the subgrade underneath the SFP are utilized to account for the effect of long-term settlement. The long-term settlement of the subgrade underneath the TSP and VIP is also considered in a similar manner.

   The Dead load on the SFP from the weight of the loaded VVM's nearly equals the weight of the earth removed. Therefore, the long-term settlement of the SFP is expected to be quite small. Likewise, the dead load on the TSP and the VIP is relatively small (from self-weight of the pads).
   The retaining wall under excavated condition (see Subsection 2.I.2) supports the soil overburden pressure (classified herein as Dead load).

b. Live load from the loaded transporter acts directly on the TSP (see Figure 3.I.4 and 3.I.5). This load also adds to the overall load on the SFP (L in Table 2.I.11). The load from the transporter is the sole live load applicable to the ISFSI structures. For structural qualification, the loaded transporter (live load) is assumed to be situated over the centrally located cavity.

c. Seismic load is computed using the methodology presented in Subsection 3.I.4.7. This load, denoted as E in Table 2.I.11, is the aggregate of the peak dynamic load exerted on the ISFSI less the dead weight. For conservatism, the load E is applied as a static load in the stress analysis of ISFSI structures even though it is impulsive in nature.

Paragraph 3.I.4.7.3 contains details on the stress analysis of the ISFSI structures to demonstrate ACI code compliance.

3.I.4.5 Cold

Due to its subterranean configuration, the structural components of the VVM are relatively protected from extremes in the ambient temperature in comparison to the HI-STORM 100 or 100S overpacks. Therefore, no new analyses are identified for the HI-STORM 100U system.

3.I.4.6 Flood

The buried configuration of the HI-STORM 100U system renders it immune from sliding under the action of a design basis flood. No new analyses are needed for an actual extreme environmental event.

Although the condition does not necessarily arise due to a flood, a limiting uplift scenario where the VVM CEC is in place and the surrounding substrate produces a buoyant force by unspecified means is considered. For this condition (Load Case 01 in Table 2.I.5), the limiting uplift condition determines the minimum weight that needs to be in place to prevent uplift during construction. This could be in the form of a temporary cover. The upward directed buoyant force exerted on the CEC cavity is computed assuming a weight density of water and compared with the dead weight of the CEC. Under the postulated condition, the net uplift load (Buoyant Force – Weight of CEC) can be calculated. The required temporary weight that is needed to produce a net downward force is calculated in [3.I.27] and specified in Table 2.I.5.

For the case of a loaded VVM with the Closure Lid in place, or for an empty CEC with the Closure Lid in-place, the buoyant force is less than the vertical download, so there is no uplift.

Should the full buoyant force develop from any means, a lateral pressure load is imposed on the CEC bottom plate. Conservatively assuming an empty VVM, the full buoyant force provides a pressure causing bending of the CEC Bottom Plate, which is partially restrained against rotation by the CEC shells (note that in a loaded VVM, the MPC also helps to support the Bottom Plate of the CEC as its weight causes the central shim to act as a support for the Bottom Plate of the CEC). The stress intensity resulting from CEC Bottom Plate bending is compared to the Level D allowable stress intensity. Using the solutions for maximum stress in a clamped and simply supported plate, and averaging the results from the two solutions to approximately account for the rotational restraint provided by the CEC Container Shell, gives the following bounding safety factor for stress in the bottom plate under the postulated buoyancy loading:

Allowable Stress = 66,875 psi (Table 3.I.3(c) @ 125°F per Table 2.I.5). Safety factor is calculated to be greater than 4.0.

3.I.4.7 Seismic Event - HI-STORM 100U (Load Case 04 in Table 2.I.5)

The HI-STORM 100U system, plus its contents, may be subject to the Design Basis Earthquake (DBE) defined by the response spectra in Figure 2.I.4. As mentioned in supplement 2.I and further explained in this subsection, the DBE has been defined for the 100U ISFSI to insure that the operative spectra (Figure 2.I.4) essentially envelope the corresponding site DBE spectra at virtually all US sites. Because the VVM is buried in the substrate, tip-over of the VVM is not credible. The entire VVM can move laterally with the surrounding and supporting substrate.

Under the action of lateral seismic loads, the CEC Container Shell globally acts as a beam-like structure supported on a foundation driven by the site seismic accelerations. During a seismic event, the lateral loading on the CEC consists of:

i) Inertia force from CEC self-weight
ii) Inertia forces from the Closure Lid self-weight
iii) Inertia forces from the self weight of the VIP
iv) Interface forces from the rattling of the MPC within its confines of the CECand the rattling of the contents inside the MPC
v) Interface forces from the subgrade and from the SFP

The CEC Container Shell develops longitudinal stresses as it bends like a beam to resist the input seismic loads. In addition, the CEC Container Shell tends to ovalize under the loads. Both effects are captured in the seismic analysis.

The Design Basis Seismic Model (DBSM) used to perform the safety analysis of the 100U ISFSI under the Design Basis Earthquake (DBE) defined by Figure 2.I.4 is described in the following.

3.I.4.7.1 Design Basis Seismic Model

Parametric studies were performed to support the initial certification of the HI-STORM 100U VVM. These studies defined the Design Basis Seismic Model. In particular, a non-linear dynamic model on LS-DYNA was found to produce much greater response and internal stresses than a linear analysis on SASSI. Further, a 5x5 VVM array model was standardized for dynamic analysis purposes. Accordingly, LS-DYNA is used for all required dynamic analysis of the VVM array. The DBSM consists of three discrete models, namely:

1. A VVM Array Model used to characterize the interaction of the ISFSI with the surrounding soil continuum. This is performed using a 5x5 VVM array (see Figure 3.I.3-B).

2. A VVM Array Model for the optional 100U design where retaining walls are in place (see Figure 3.I.3-C). The lateral subgrade beyond the retaining wall is assumed to be removed all the way down to the bottom of the SFP, which conservatively represents an excavation configuration.

3. A single VVM model with a detailed simulation of the internal parts of the VVM to obtain an accurate characterization of the stress/displacement field (see Figure 3.I.3-D).

The seismic analysis consists of three discrete steps, namely:

A. Soil-structure model development.
B. Use of the VVM Array Model to determine the bounding dynamic loads applied to the ISFSI Structures.
C. Use of the Single VVM Model to compute stresses in the VVM Components.

A. Soil–Structure Model Development

i. Based on the lower bound shear wave velocity profile of US nuclear power plants (Figure 2.I.6), a two-step earthquake response analysis using the computer code SHAKE2000 and LS-DYNA is performed to establish a bounding seismic loading condition for the 100U underground fuel storage system. The Design Basis Earthquake for the HI-STORM 100U system thus obtained is defined by the seismic response spectra at both the ground surface and the ISFSI foundation surface elevations as shown in Figure 2.I.4. The input seismic acceleration time history used in the first step (SHAKE) analysis is derived from the

Regulatory Guide 1.60 seismic response spectrum and designated as the rock outcrop motion. The input acceleration time history is scaled to yield ground surface ZPAs (at the top of grade elevation) specified in Table 2.I.2. The 1-D SHAKE analysis model consists of 21 native soil layers of the 100U ISFSI site with a total thickness of 101 ft; the top of the 6th soil layer is aligned with the bottom of the SFP. The total soil depth of the SSI Model is about five times the height of the underground ISFSI (Due to the limitation of the linear code, a further increase of the soil depth in the SHAKE model leads to questionable seismic response results in the case of a strong seismic motion and weak soil properties). The averaged strain compatible shear wave velocity is 450 ft/s for the soil layers above the SFP and is 485 ft/s for the layers below the SFP, which has been set as the lower-bound soil design data in Table 2.I.2 for a candidate 100U ISFSI site. The finite element soil model in the second step (LS-DYNA seismic response analysis) uses the average strain-compatible wave velocities obtained from the SHAKE analysis to represent the soil layers above and below the SFP elevation. The acceleration time history at the soil column bottom surface, also obtained from the SHAKE analysis in the first step, is used as the input seismic motion for the LS-DYNA seismic response analysis. The response spectrum plots shown in Figure 2.I.4 are the results of the LS-DYNA seismic response analysis.

Figure 3.I.3-A shows the LS-DYNA soil model for the seismic response analysis. Note that the lateral dimension of the ISFSI soil model is significantly greater than that of the ISFSI. The periphery nodes of the soil model space at the same elevation are constrained to move together to simulate the seismic response of the semi-infinite space of soil. According to the numerical study on various lateral boundary conditions of the finite element soil model [2.I.10], this lateral boundary condition, also known as a "slave boundary condition", is appropriate to predict the soil response in a seismic event. The same soil model and input seismic motion used in the LS-DYNA seismic response analysis will be used for the LS-DYNA soil-structure interaction analysis for the 100U ISFSI loaded with VVMs. The boundaries of the soil model are sufficiently away from the ISFSI pads to ensure that structural response of the ISFSI will not be significantly affected.

ii. The spectra in Figure 2.I.4 define the seismic input against which the spectra at a candidate ISFSI site should be compared to determine whether the generic analysis in this FSAR is bounding or additional site specific analysis set down per sub-section 2.I.6 are required.

iii. Consistent with the sketch in Figure 2.I.5, the 100U soil-structure LS-DYNA model consists of loaded VVMs, concrete pads, and soil spaces with properties as defined in Tables 2.I.2 and 3.I.4. The ISFSI model is developed based on a 5×5 VVM configuration, which has previously been approved under LAR 1014-6 and is considered to be appropriate for capturing the effect of the ISFSI size on the structural analysis results. Depending on the purpose of the analysis, the 100U soil-structure model may include 5x5 fully loaded VVMs or just one loaded VVM. Similarly, a loaded Vertical Cask Transporter (VCT) may be considered in the model to obtain the bounding load applied to the TSP and to demonstrate the seismic stability of the loaded VCT. For the optional ISFSI design including a retaining wall, the soil-structure model is developed based on the governing configuration where the subgrade outside the retaining wall is excavated all the way to the depth of the SFP elevation. Therefore, a total of three 100U soil-structure LS-DYNA models (see Figures 3.I.3-B to 3.I.3-D) are developed to perform the design basis earthquake analysis.

iv. The corrosion of the CEC is considered by using a reduced thickness (i.e., 1/8" thinner than the nominal thickness) in the soil-structure LS-DYNA models.

v. Proper element size and time step controls in the dynamic model are implemented following the guidance in references [3.I.28] and [3.I.29].

B. VVM Array Model

The object of the VVM Array model is to obtain conservative values of the loads on the ISFSI structures under the Design Basis Earthquake (Figure 2.I.4). The VVM Array model has the following essential attributes:

i. The MPC is represented by a solid rigid cylinder of mass equal to its total mass. This means that all internal masses will move in unison and the inertia forces of the MPC are maximized, which will conservatively result in greater impact loads applied to MPC guides and the CEC base plate.
ii. The Divider Shell and the CEC shell are modeled as elastic shells but the Closure Lid and the Lid Ring are simulated as rigid bodies. Note that the combination of elastic shells and rigid lid ring used in the finite element model has little effect on the load path between the Divider Shell and the CEC flange during the seismic event.
iii. The ISFSI pads (i.e., TSP, SFP, etc.) are simulated as a flexible plate-type structure, as is the retaining wall, if used. The retaining wall is added to the finite element model in the optional ISFSI design case (see Table 3.I.6).
iv. The SFP is fully loaded with a 5×5 VVM array.
v. A loaded VCT is assumed to be located at the center of the fully populated ISFSI except for the case with retaining walls. The VCT, along with the carried transfer cask, is modeled as a freestanding rigid body.
vi. The elastic material model is used for all ISFSI concrete structures except for the TSP, which is characterized by an inelastic concrete model to account for energy dissipation in the concrete due to the impact loading from the loaded VCT. For the case where cracking of the concrete needs to be considered, the Young's Modulus of the SFP is reduced to 50% of its nominal value per the guidance in Section 3.4 of [3.I.29].

C. Single VVM Model

The Single VVM model is used to perform the safety evaluation of the VVM components and the stored MPC under the Design Basis Earthquake. The applicable acceptance criteria are provided in Table 2.I.6. To conservatively evaluate the structural integrity of the VVM components, the Young's Modulus for the SFP is assumed to be equal to 50% of its nominal value. This is prompted by the results of VVM Array Model runs (see Table 3.I.7), which indicate that the VVM Components experience amplified responses if the reduced modulus is used for the SFP.

The Single VVM model complies with the provisions set forth in the following:

i. The SFP is loaded with only one VVM at the edge of the SFP. A loaded VCT, modeled as a freestanding rigid body, is conservatively assumed to be located above the center of the loaded VVM.
ii. The Cavity Enclosure Container (CEC) is discretized by an appropriate finite element grid to simulate its Container Shell and Bottom Plate, the Divider Shell, and the MPC guides in an explicit manner. The true stress-strain relationship of the material is used to obtain the realistic deformation of these structural members.
iii. The MPC shell, baseplate, and top lid are modeled using sufficient element discretization so that the peak primary stresses of the MPC components under the seismic loading condition can be captured for structural evaluation.
iv. The fuel basket is modeled with thin shell finite elements arrayed to simulate inter-cell connectivity in an explicit manner.
v. Nominal small gaps between the fuel basket and the MPC are explicitly modeled, as is the nominal gap between the MPC and the CEC at the upper and lower MPC guide locations.
vi. Each fuel assembly is represented by an equivalent homogeneous, isotropic prismatic beam of an equivalent elastic modulus whose fundamental lateral natural frequency accords with that of the actual fuel assembly. A bounding fuel assembly weight is used and the fuel basket is assumed to be fully populated with fuel assemblies.
vii. The seismic responses of MPC structural components are simulated using the elastic material model so that the stress results can be directly compared with the corresponding ASME NB stress limits.

3.I.4.7.2 Qualification of VVM Components

The CEC Components and parts of the MPC subject to significant loadings during the DBE event are:

a. CEC shell and Divider Shell (subject to ovalization)
b. MPC shell (bending of the shell as a beam, resulting in axial membrane stress in the shell)
c. MPC top and bottom guides
d. Lateral loading on the fuel basket panels.
e. Localized strain in the MPC shell (due to impact of the MPC with the MPC guides attached to the Divider Shell)

The safety analysis of each component under the DBE event is summarized below:

a. CEC shell and Divider Shell: Maximum radial deformation of the two shells is tracked for the single VVM simulation scenario in Table 3.I.6. The ratio of the original ovalization to the actual ovalization gives the safety factor:

$$Safety\ Factor = \frac{Permissible\ radial\ displacement}{Maximum\ computed\ radial\ displacement\ \ from\ Figure\ 3.I.23}$$

$$= \frac{2.5''}{0.1325''} = 18.86$$

b. Primary stress in the MPC shell: The maximum stress intensity in the MPC shell is computed under the single VVM simulation scenario. The allowable stress intensity for this case corresponds to the Level D condition. The safety factor is computed as:

$$Safety\ Factor = \frac{Level\ D\ allowable\ Stress\ Intensity\ \ from\ Table\ 3.I.3(d)}{Maximum\ computed\ primary\ Stress\ Intensity\ \ from\ Figure\ 3.I.24}$$

$$= \frac{42{,}000\,psi}{12{,}860\,psi} = 3.26$$

c. Top and Bottom MPC Guides: The maximum lateral load bearing capacity of the top and bottom plate guides is computed in Supplement 4 of Reference [3.I.27]. The maximum dynamic impact loads from the single VVM model can be extracted from the impact load time history results shown in Figure 3.I.25. The safety factor is calculated as:

$$Safety\ Factor = \frac{MPC\ Guides\ Lateral\ Load\ Bearing\ Capacity}{Maximum\ MPC\ to\ MPC\ Guides\ Contact\ Force}$$

$$= \frac{4.41\times10^{5}\,lb}{108{,}826\,lb} = 4.05$$

For the tubular MPC top guide design, the MPC impact analysis documented in Supplement 11 of Reference [3.I.27] demonstrates that the tube guide would not experience any global plastic deformation under the Design Basis Earthquake condition. This means that there is no risk of progressive flattening of the guide tubes from repetitive impacts during the seismic event.

d. Loading on the Fuel Basket panel: The fuel basket panels are qualified to withstand 45 g's of lateral acceleration (during the non-mechanistic tip-over event). The maximum fuel g-load predicted by the LS-DYNA simulation is 2.5 g's as shown in Figure 3.I.26. The factor of safety, therefore, will be equal to the ratio of the two. Hence,

$$Safety\ Factor = \frac{45}{2.5} = 18$$

e. Maximum Local Strain in the Confinement Boundary in the Impact Region:

The small clearance between the MPC and the MPC guides can lead to a high localized strain in the region of the shell where the impact from rattling of the canister under a seismic event occurs. The extent of local strain from impact is minimized by locating the MPC guide in the vertical direction such that the mid-height of the impact footprint is aligned with the bottom surface of the closure lid. Thus the location of impact is removed from the lid-to-shell weld junction. It is necessary to insure that the maximum value of the local (true) strain in the shell (confinement boundary) region of impact is well below the failure strain. For this purpose, the recommendation in [3.I.31] is used. The methodology for computing the local strain is presented in the following and applied to the seismic problem analyzed in this subsection.

A finite element model of the MPC suitable for implementation in LS-DYNA is prepared with special emphasis on the top region of the canister where a very fine grid is employed. All elements have elasto-plastic and large strain capability. The solid elements in the lid and the lid-to-shell weld are of type 2 (fully integrated) and those in the shell are type 16 (fully integrated). The integration across the shell wall employs the maximum number of points available in LS-DYNA (10 points). A mesh sensitivity study has been performed using a finer grid size for the MPC shell to verify that the results are converged.

The MPC contents, namely the fuel basket and the SNF, are modeled exactly as set forth in the DBSM in the foregoing (articles (iii.), (iv.), and (v.) in Subsection 3.I.4.7.1 C Single VVM Model). To define a conservative scenario of MPC/MPC guide impact, the velocity time history of the top of the MPC is surveyed from the dynamic analysis of the VVM using the DBSM. The maximum velocity thus obtained is assumed to exist as the initial condition in the LS-DYNA simulation. This assumption is most conservative because it assumes that the cyclic motion transmitted by the earthquake does not detract from the canister's momentum before impact occurs (observations show that the canister slows down by the earthquake's cyclic energy input, thus significantly lessening the severity of the impact). In addition, the MPC guide is fixed at its base, which conservatively ignores the deformation of the divider shell and therefore maximizes the impact. The finite element model is shown in Figure 3.I.12. To implement the above model, the search for the maximum velocity in the dynamic solution yielded less than 24.7 in/sec as shown in Figure 3.I.27. Applying an initial velocity of 26.0 in/sec as the initial condition to the above model provided the strain field shown in Figure 3.I.13 for the tubular guide design. The impact between the MPC and the MPC top guides results in an MPC shell maximum plastic (true) strain of less than 1.52×10^{-2} in/in for the tubular guide design and 3.1×10^{-2} in/in for the optional plate guide design (see Calculation 11 of

[3.I.27]), respectively, which are only a small fraction of the acceptable value (0.1) per [3.I.31]. Therefore the integrity of the confinement boundary is assured.

3.I.4.7.3 Strength Qualification of the ISFSI Structure

Under the Design Basis Earthquake (Figure 2.I.4), the loads exerted on the Support Foundation Pad and the Top Surface Pad (as illustrated in Figure 3.I.4) are obtained from the LS-DYNA SSI simulations listed in Table 3.I.6. Table 3.I.7 lists the peak ISFSI interface loads obtained from various LS-DYNA runs listed in Table 3.I.6. In order to incorporate an additional margin of safety in the ISFSI structural analysis, these unfiltered dynamic bounding interface loads are directly used for the structural evaluation of ISFSI components as shown in Table 3.I.8. The use of the bounding loads is in keeping with a similarly bounding value of settlement specified for the strength analysis of the SFP and the TSP (see Table 2.I.2).

The SFP and TSP shall meet the minimum structural requirements set down in Table 2.I.2 and the licensing drawings. The SFP and TSP are required to satisfy ACI-318 (2005) strength limits under all applicable load combinations (Table 2.I.11).

Likewise, the retaining wall, if used, shall meet the minimum concrete and rebar requirements provided in Table 2.I.2 and the licensing drawings. The site specific design may utilize a thicker and more heavily reinforced wall, if necessary, at user's option.

Table 3.I.8 provides the loading data used in the strength analysis of the ISFSI structures. The following discrete analyses are required:

(i) Compute the long-term settlement of the undergrade supporting the SFP assuming all VVM locations are loaded for the entire Design Life: Determine the "effective" elastic modulus of the subgrade under the SFP to simulate the effect of settlement in the structural analyses model. As discussed in Section 2.I.4, the long-term settlement of the undergrade from the loaded VVMs and the dead weight of the SFP is very small because the combined equivalent density of the loaded VVM's and the SFP is nearly equal to the density of the excavated subgrade.

(ii) Compute the long-term settlement of the subgrade under the TSP/VIP relative to the SFP from subgrade weight in addition to the dead weight of the TSP and VIP. Determine the "effective" elastic modulus of the subgrade between the TSP/VIP and the SFP to simulate the effect of long term settlement in the structural analyses model. As discussed in Section 2.I.4, the long-term settlement of the well conditioned subgrade under the TSP is appreciably small because of the small long-term loadings acting on the TSP.

(iii) Prepare a finite element model of the pads in ANSYS and determine the stress field under the factored Dead and Live loads with the settlement based "degraded" elastic moduli.

(iv) Compute the stress field in the pads under factored seismic loads using dynamic elastic modulus corresponding to the minimum shear wave velocity of the subgrade specified in Table 2.I.2.

(v) Use the bounding peak loads listed in Table 3.I.8 to compute the stress fields in the pads

(SFP and TSP) from the DBE.

(vi) Combine the factored loads and determine the total stress resultants. Compare with the respective section strengths to establish the factors of safety for the SFP and TSP.

(vii) Compute the bearing stress (or load) on the subgrade under the TSP using the combined factored loads from the transporter and the TSP/VIP and compare with the corresponding allowable limit to establish the safety factor for the subgrade under the TSP.

A comprehensive summary of the analyses and the associated margins of safety are discussed below:

The structural evaluation of the HI-STORM 100U ISFSI is performed using the commercial computer code ANSYS [3.I.33]. The constituents of the ISFSI namely the Support Foundation Pad (SFP), the subgrade under the support foundation pad (the undergrade), the Top Surface Pad (TSP) and the subgrade lateral to the CEC under the TSP are all modeled using linear elastic SOLID45 elements. The VVM interface pad (VIP), which carries no load except for its self-weight, is conservatively omitted in the model. The boundary retaining walls of the ISFSI are conservatively omitted in the finite element model thereby neglecting any vertical stiffness otherwise provided by the retaining walls. The element mesh is intentionally kept fine in the areas of load application on the SFP and the TSP. For convenience of load application, the footprint of the CEC base on the SFP is carefully articulated in the finite element model. The substrate under the SFP is terminated at approximately 101.0 ft below the TSP, which is consistent with the Design Basis Seismic Model discussed in Subsection 3.I.4.7.1. The "base" model (loading configuration I) considers that all the storage locations in ISFSI are populated and experience identical peak vertical seismic loading equal to the maximum load obtained from the LS-DYNA SSI solution discussed previously. Because of the symmetric geometry and loading, quarter symmetric finite element model is sufficient to represent the fully loaded ISFSI. Figure 3.I.14 shows the finite element model of HI-STORM 100U ISFSI. The "degraded" elastic moduli of the subgrade under the SFP and the subgrade between the TSP and SFP is appropriately computed to account for the long-term settlement effects as described in Subsection 2.I.4. The long-term settlement and the "effective" subgrade elastic moduli are derived using the governing soil characteristics following guidelines from [2.I.6]. Table 3.I.5 lists the bounding subgrade characteristics and the concomitant elastic moduli effective under dynamic loading. To address different loading patterns on the ISFSI and for completeness, additional partially loaded ISFSI configurations are considered in the evaluations. The partial configurations include a two row loaded ISFSI (two rows of VVM locations adjacent to the symmetry line are loaded), a single row loaded ISFSI (the middle row of VVM locations is loaded) and a single VVM loaded ISFSI (a single VVM location centered near the periphery of the ISFSI is loaded). Figures 3.I.20 through 3.I.22 illustrate the partial loading configurations for the ISFSI. These are hereinafter referred to as loading configurations II, III, and IV, respectively.

Symmetric boundary conditions are established at the planes of symmetry for the base model (Fully populated ISFSI). To simulate the material continuity (or constraints simulating the presence of retaining wall) at the extreme boundary surface of the substrate under the SFP, translations are constrained at the lateral face of the sub-grade. The extreme bottom surface of the model is fixed representing the bedrock (or competent soil) elevation.

The following individual load steps are considered in the analysis:

1. Bounding peak load transmitted by the VVM as determined from the LS-DYNA SSI analysis is applied as an effective pressure on the footprints of the CEC base at all VVM locations.
2. The load from the transporter is applied as a normal pressure (see Figure 3.I.15) over the transporter load patch on the TSP. The transporter is assumed to be positioned over the central VVM cavity.
3. The dead weight from the retaining wall(s) and the VIP are applied as normal pressures on the SFP under the wall(s) and on the substrate elements directly beneath the VIP.
4. In-plane tensile loads on the SFP and TSP from the retaining wall are applied as lateral pressures on the SFP and TSP boundaries.
5. To simulate the self weight of the modeled portion of the ISFSI, a 1g gravity load is applied. The densities of the various constituents are appropriately input in the model to accurately reflect the individual component weights.

It must be noted that the structural analysis of the ISFSI conservatively considers the peak dynamic loads from the LS-DYNA SSI analysis. However, it shall be permitted to use equivalent static loads obtained by removing high frequency components that would not contribute to the structural response using appropriate filters.

Since the peak loads from the LS-DYNA SSI analyses are substantially larger in comparison to the dead and live loads, the load combination LC-3 from Table 2.I.11 governs for the ISFSI structural evaluation. However, the analyses are carried out for load combinations LC-2 and LC-3, and the corresponding results substantiate that the load combination LC-3 is governing.

Figures 3.I.16 through 3.I.19 depict the maximum in-plane stresses in the ISFSI concrete structures (viz. SFP and TSP) for the governing load combination LC-3 for all the ISFSI configurations analyzed. The in-plane axial and bending stress on the SFP and the TSP elements are post-processed to compute the equivalent moments. The induced moments are compared to the respective moment capacities to determine the corresponding factor of safety. Table 3.I.10 summarizes the results for the SFP and the TSP respectively for all ISFSI configurations analyzed.

The minimum flexure safety factor is observed on the TSP under the loading configuration IV which remains above 1.0. In this loading configuration, the peak load from the LS-DYNA SSI analysis acting on one transporter track (bearing on the TSP) is conservatively applied as static load on both the transporter footprints, thereby significantly overloading the TSP. The results from the SSI analysis indicate maximum sum load of 1.426E6 lbf from both Transporter tracks on the TSP at any instant of time. The results also show a peak instantaneous load of 1.148E6 lbf under any Transporter track while the load under the other Transporter track is about 1/10 of the instantaneous peak load (i.e. 1.148E5 lbf). Thus, applying the peak load from SSI analysis on both the transporter footprints is very conservative resulting in low margin of safety. Moreover, an additional ANSYS run using the peak load (1.148E6 lbf) under one transporter track and the instantaneous load under the other track (1.148E5 lbf), shows a minimum safety factor of 1.1 on the TSP. All other loading configurations show substantial safety margins. As mentioned previously, the peak dynamic loads obtained from the LS-DYNA SSI analyses from a DBE event are of impulsive nature. Use of the peak loads for static structural evaluations of the ISFSI is evidently conservative. Furthermore, no credit is taken for the Dynamic Increase Factor of 25% for flexure and 10% for shear permitted by [3.I.32] in the strength qualification of reinforced concrete.

The Table 3.I.11 summarizes the punching shear safety factor for the SFP and TSP. The minimum punching shear safety factor occurs on the TSP under the Transporter seismic load, and is well above 1.0.

The peak transporter load on the TSP from the LS-DYNA SSI analyses plus the load from the TSP are used to compute the maximum bearing stress in the substrate surface under the TSP. According to ACI-360 [2.I.8], the bearing stress can be calculated by uniformly distributing the load over the entire bearing area of the pad. For conservatism, the bearing stress calculation for the 100U sub-grade is performed using a bearing area significantly less than that of the smallest TSP (i.e., the TSP of one-VVM ISFSI). The maximum bearing stress in the sub-grade (Table 3.I.12) is smaller than the presumptive bearing stress limit, resulting in minimum safety factor above 2.0 imposed by the ACI code [2.I.8].

The evaluation of the CEC shell under the loads from the transporter load in addition to the subgrade overburden is presented in Subsection 3.I.4.4.

Finally, the structural integrity of the retaining wall is evaluated for the Design Basis Earthquake loading condition; the structural demand to the wall under normal operational conditions is small and therefore not structurally governing. Since the retaining wall is connected with the TSP and SFP through keys, it can be treated as a simply supported plate (along its top and bottom edges) in the structural analysis. Therefore, the wall essentially experiences bending stress in the DBE event due to lateral soil pressure. The maximum bending moment of the retaining wall, which can be determined based on Figure 3.5-1 of Reference [3.I.28] or based on the retaining wall stress results obtained from the LS-DYNA SSI analysis for Case 3 in Table 3.I.6 (both approaches yield approximately the same result), is shown in Table 3.I.10 to be well below the bending capacity of the wall.

3.I.4.8 Tornado Missile Evaluation

3.I.4.8.1 HI-STORM 100U Lid Integrity Evaluation for Tornado Missile Strike (Load Case 03 in Table 2.I.5)

Design basis tornado missiles are specified in Table 2.2.5. The Closure Lid is the only above ground component of the VVM; therefore, missile impact analyses focus on this component. Large and intermediate tornado missiles are assumed to strike the center top surface of the lid at the design basis speed (see Table 2.2.5). For both missile analyses, a finite element model of the Closure Lid is employed (using dimensions from licensing drawings and applicable material properties), and includes contact between concrete and steel (see Figure 3.I.1). LS-DYNA is used to perform dynamic simulations of the impacts to demonstrate that neither missile completely penetrates the composite structure. The ANSYS model shown in Figure 3.I.1 is simplified to develop an input file for the LS-DYNA simulation. Elastic-Plastic Material 24 is used for the steel and Material 72 is used for the concrete. For a conservative result, engineering stress relations for the lid steel work are used with an assumed ultimate strain of 21% (per ASME Code, Sec. II, Part A). As LS-DYNA expects that true stress-strain data is input, the use of true stress-strain data, to obtain a more realistic result, is permitted (if appropriate justification is provided for the true stress-strain relation). The solution obtained using engineering stress strain data is clearly conservative in that material failure is set at the engineering ultimate strain limit rather than reflecting the true strain at failure, which will be considerably larger. A strain rate effect is incorporated by increasing the yield and ultimate strengths by a maximum of 50% (depending on the rate) as suggested by data for SA-36 steel [3.I.19]. This is the same strain rate increase used in the evaluations to assess the performance of the aboveground HI-STORM when impacted by a jet fighter aircraft [3.I.16]. A time history normal pressure loading is applied over the metal annular region around the outlet opening to simulate the large missile, and the global deformation damage to the lid is assessed. The formula from "Topical Report – Design of Structures for Missile Impact", BC-TOP-9A, Rev. 2, 9/74 [3.I.17] is used to establish appropriate pressure-time data. For the speed and mass associated with the large missile, the impact force-time curve has the form

F(t) = 0.625 sec/ft x 184.8 ft/sec x 4000 lb x sin (20t) = 462,000 lb x sin (20t) for t< 0.0785 sec.
= 0 for t >= 0.0785 sec.

This representation of the large missile impact load is appropriate as recent full-scale impact testing of a modern passenger vehicle demonstrates. Figure 3.I.6 shows the force-time history from the full-scale test of a full-size Ford passenger vehicle [3.I.18]. The test was performed at an impact speed of 35 mph and the vehicle had approximately the same weight as the design basis large deformable missile. Since the force is directly proportional to the pre-impact momentum, an estimate of the peak force at 126 mph for the vehicle is obtained by a simple ratio of the impact velocities and missile mass. Estimating the peak value from the plot produces a resulting peak force of 496,000 lb, which is the same order of magnitude as the peak value predicted from the Bechtel Topical Report, although the shape and duration of the curve is different. The results from the analysis using the load-time function from the Bechtel formula show no significant lid damage from the large missile strike on the lid because of the concrete backing. Inspection of the result concludes that the deformed shape after the event does not preclude lid removal, the lid remains in-place, and the MPC has not been impacted. The maximum lid vertical deflection during the strike is less than 0.1 inch and there are a few local regions of permanent effective plastic strain. The details of this calculation are found in [3.I.27]. The large missile impact is not the bounding strike because of the large area of impact and significant energy loss that occurs when the vehicle is crushed upon impact; the rigid, intermediate missile imparts more local and global damage to the Closure Lid.

The impact of the intermediate missile is conservatively simulated as a rigid 8" diameter cylindrical steel bar weighing 275 lb (per Table 2.2.5), traveling at 126 mph and striking the Closure Lid at the most vulnerable location, which is through the top vent opening. The strike can be at either the center of the inner shield dome or slightly off-center so as to miss the central steel connecting bar.

In order to strike the MPC top lid, the intermediate missile must penetrate the steel weldment and encased concrete (see licensing drawings in Section 1.I.5). Figures 3.I.7 and 3.I.8 show the intermediate impact scenarios considered. Figures 3.I.9 and 3.I.10 show the lid state at the time of maximum bottom plate vertical displacement. For both cases, no dislodgement of the lid is indicated and plastic strains occur only in the immediate vicinity of the strike. A summary of results that bound the computed results for the two intermediate missile strikes is presented in Table 3.I.9.

Next, consider that the intermediate or large missile is traveling horizontally and strikes the side of the Closure Lid. A large missile strike at this location with a horizontal orientation is most likely not credible because of the low profile of the lid. The large missile would rotate as it broke up, resulting only in a glancing blow to the lid. However, an evaluation of the Closure Lid flange ring in either missile side strike is needed to ensure that the Closure Lid will not be driven sideways under the impact and separate from the CEC. A key structural element is the weld connecting the Closure Lid restraint ring to the Closure Lid. The capacity of the welds in the load path that resist the lateral impact load is:

Closure Lid Weld Capacity = 8,381,000 lb.

This capacity is computed assuming a limiting weld stress of 60% of the ultimate tensile strength of the base material. In any of the evaluated missile strikes from above, the peak impact load (filtered at 350 Hz (see similar filtering in the HI-STAR 100 transport license)) does not exceed 1,200,000 lb. Interface loads from top impacts are expected to bound impact loads from side impacts because of the geometry involved; therefore, the safety factor on the CEC Container Shell flange ring, acting to hold the lid in-place, is:

SF (flange ring) = Closure Lid Weld Capacity/ Filtered Peak Impact Load > 6.9

Finally, a small missile entering the outlet duct will not damage the MPC because there is no direct line-of-sight to the MPC, and even if it arrives at the MPC, it will have undergone multiple impacts with the duct walls, and can only impact the thick MPC lid. Therefore, MPC damage from the small missile is not credible.

An assessment of all simulation results concludes that the postulated missile strikes will not preclude MPC retrievability, will not cause loss of confinement, and will not affect criticality. In no scenario, does the lid become dislodged.

3.I.4.8.2 Tornado Missile Protection during Construction

The number of VVMs in a HI-STORM 100U ISFSI may vary depending on a user's need. While there is a minimum spacing (pitch) requirement (see licensing drawing in Subsection 1.I.5), there is no limitation on the maximum spacing. Furthermore, a module array may have a non-rectangular external contour such as shown in the licensing drawing with a trapezoidal contour. Finally, an ISFSI may be constructed in multiple campaigns to allow the user to align the VVM cavity construction schedule with the plant's fuel storage needs. Any ISFSI constructed in one campaign shall have the following mandatory perimeter protection features:

i. The Radiation Protection Space (RPS) shall extend to an appropriate distance beyond the outer surface of the CEC shell (see licensing drawing in Subsection 1.I.5). Calculations have been performed (see [3.I.27]) that confirm that a 10' distance beyond the outer surface of the CEC shell is sufficient to prevent the 8" diameter rigid cylindrical missile (defined in Table 2.I.1 and is the most penetrating of the missile types considered in this FSAR) from contacting the CEC shell should this missile strike the exposed cut from the adjacent construction. The penetration analysis conservatively assumed a subgrade with minimum resistance to missile penetration and the formulation described in [3.I.30].

ii. Unless a retaining wall (see licensing drawing) has been built to confine and retain the subgrade at the boundary of the RPS (or beyond) in the particular direction of excavation, an Excavation Exclusion Zone (EEZ) shall be defined within which any excavation activity during an operating ISFSI is prohibited (see Subsection 2.I.2). The retaining wall is the EEZ boundary if the retaining wall is located at or beyond the RPS.

3.I.4.9 HI-STORM 100U VVM Service Life

The VVM is engineered for 40 years of design life, while satisfying the conservative design requirements defined in Supplement 2.I. For information supporting the 40 year design life addressing chemical and galvanic reactions as well as other potentially degrading factors see Subsection 3.I.4.1. Requirements for periodic inspection and maintenance of the HI-STORM 100U VVM throughout the 40-year design life are defined in Supplement 9.I. The VVM is designed, fabricated, and inspected under the comprehensive Quality Assurance Program discussed in Chapter 13.

3.I.5 FUEL RODS

No new analysis of fuel rods is required for storage of an MPC in a HI-STORM 100U VVM.

3.I.6 SUPPLEMENTAL DATA

3.I.6.1 Additional Codes and Standards Referenced in HI-STORM 100 System Design and Fabrication

No additional Codes and Standards are added for the HI-STORM 100U system.

3.I.6.2 Computer Programs

ANSYS 5.7, 7.0, 9.0, 11.0, and LSDYNA (previously known as DYNA3D) [3.I.2] are used for the finite element analyses prepared by Holtec and summarized in this supplement.

ANSYS

ANSYS is a public domain code, well benchmarked code, which utilizes the finite element method for structural analyses. It can simulate both linear and non-linear material and geometric behavior. It includes contact algorithms to simulate surfaces making and breaking contact, and can be used for both static and dynamic simulations. ANSYS has been independently QA validated at Holtec International. In this FSAR submittal, ANSYS is used within [3.I.27] and the element size used in the application follows the recommendation of the code developers.

LS-DYNA

LS-DYNA is a nonlinear, explicit, three-dimensional finite element code for solid and structural mechanics. It was originally developed at Lawrence Livermore Laboratories and is ideally suited for study of short-time duration, highly nonlinear impact problems in solid mechanics. LS-DYNA is commercially available and has been independently validated at Holtec following Holtec's QA procedures for commercial computer codes. This code has been used to analyze the Non-Mechanistic Storage tip-over for the HI-STORM 100 Part 72 general license. In this supplement, the code is used to establish the performance of the HI-STORM 100U under a design basis seismic event, and to evaluate the response to a design basis missile.

LS-DYNA is currently supported and distributed by Livermore Software. Each update is independently subject to QA validation at Holtec.

3.I.6.3 Appendices Included in Supplement 3.I

None.

3.I.6.4 Calculation Packages

A calculation package [3.I.27] containing the structural calculations supporting Supplement 3.I has been prepared and archived according to Holtec International's Quality Assurance Program (see Chapter 13), and submitted with this application. A second calculation report [3.I.14], documenting the SASSI analyses, has been prepared by a Holtec subcontractor under the subcontractor's QA program.

3.I.7 COMPLIANCE WITH NUREG-1536

The material in this supplement for the HI-STORM 100U system provides the same information as previously provided for the aboveground HI-STORM 100 systems. Therefore, to the extent applicable, the information provided is in compliance with NUREG-1536.

3.I.8 REFERENCES

The references in Section 3.8 apply to the VVM to the extent that they are appropriate for use with an underground system. The additional references below are specific to Supplement 3.I.

[3.I.1] SHAKE2000, A Computer Program for the 1-D Analysis of Geotechnical Earthquake Engineering Problems, G.A. Ordonez, Dec. 2000.

[3.I.2] LS-DYNA, Version 971, Livermore Software, 2006.

[3.I.3] USNRC Interim Staff Guidance (ISG-15), "Materials Evaluation", Revision 0, January 2001.

[3.I.4] ANSI/AWWA C105/A21.5-99, "American National Standard (ANSI) for Polyethylene Encasement for Ductile-Iron Pipe Systems".

[3.I.5] M. B. Bruce and M. V. Davis, "Radiation Effects on Organic Materials in Nuclear Plants", Final Report, 1981. (Prepared by Georgia Institute of Technology for EPRI)

[3.I.6] ANSI D 4082-02, "American National Standard (ANSI) Standard Test Method for Effects of Gamma Radiation on Coatings for Use in Light Water Nuclear Power Plants".

[3.I.7] USNRC Regulatory Guide (RG-1.54), "Service Level I, II and III Protective Coatings Applied to Nuclear Power Plants, Revision 1, July, 2000.

[3.I.8] ANSI D 3843-00, "American National Standard (ANSI) Standard Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities".

[3.I.9] ANSI C 210-03, "American National Standard (ANSI) Standard Practice for Liquid-Epoxy Coating Systems for the Interior and Exterior of Steel Water Pipelines".

[3.I.10] Keeler & Long Inc. Product Data Sheet for Kolor-Proxy™ Primer KL3200 Series, Product Code KL3200.

[3.I.11] Samuel A. Bradford, "Practical Handbook of Corrosion Control in Soils", ASM International and CASTI Publishing Inc., 2004.

[3.I.12] L. M. Poukhonto, "Durability of Concrete Structures and Constructions – Silos, Bunkers, Reservoirs, Water Towers, Retaining Walls", A. A. Balkema Publishers, 2003.

[3.I.13] 49CFR Part 195 Subpart H "Corrosion Control", Title 49 of the Code of Federal Regulations, Oct, 1 2004 Edition, Office of the Federal Register, Washington, D.C.

[3.I.14] HI-2084023, SSI Analysis of HI-STORM 100U Using SASSI, Rev. 0 (a Subcontractor report prepared for Holtec by International Civil Engineering

Consultants, Rev. 2, April 2008) (Holtec Proprietary) .

[3.I.15] S. Stojko, Application of DYNA3D to Non-Liner Soil Structure Interaction (SSI) Analysis of Retaining Wall Structures, International LS-DYNA3D Conference, March 1993.

[3.I.16] ASLB Hearings, Private Fuel Storage, LLC, Docket # 72-22-ISFSI, ASLBP 97-732-02-ISFSI, February 2005.

[3.1.17] Topical Report – Design of Structures for Missile Impact", BC-TOP-9A, Rev. 2, Bechtel Corporation, 9/74

[3.I.18] SAE Technical Paper 2000-01-0627, Development and Validation of High Fidelity Vehicle Crash Simulation Models, S.W. Kirkpatrick, Applied Research Associates, Inc.

[3.I.19] H. Boyer, Atlas of Stress Strain Curves, ASM International, 1987, p.189.

[3.I.20] Thermal Ceramics Inc., Product Data Sheet for Blanket Products (Kaowool® Blanket).

[3.I.21] NACE Standard RP0285-2002 "Corrosion Control of Underground Storage Tank Systems by Cathodic Protection", NACE International.

[3.I.22] API RP1632, "Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems", American Petroleum Institute.

[3.I.23] NACE RP0169-96, "Control of External Corrosion on Underground or Submerged Piping Systems", NACE International.

[3.I.24] 49CFR Part 192 Subpart I "Requirements for Corrosion Control, Title 49 of the Code of Federal Regulations, Oct, 1 2004 Edition, Office of the Federal Register, Washington, D.C.

[3.I.25] ACI 544.3R-93 (or latest), Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete.

[3.I.26] ASTM C1116-03 (or latest) Standard Specification for Fiber-Reinforced Concrete and Shotcrete

[3.I.27] HI-2053389, Calculation Package Supporting Structural Evaluation of HI-STORM 100U, Revision 9, September 2010, (Holtec Proprietary)

[3.I.28] ASCE 4-98, Seismic Analysis of Safety-Related Nuclear Structures and

Commentary, American Society of Civil Engineers, 2000.

[3.I.29] ASCE/SEI 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, American Society of Civil Engineers, 2005.

[3.I.30] Sandia National Laboratory Contractor Report SAND97-2426, Penetration Equations, C.Y. Young, Applied Research Associates, Inc., Albuquerque NM 87110.

[3.I.31] Doug Ammerman and Gordon Bjorkman, "Strain-Based Acceptance Criteria for Section III of the ASME Boiler and Pressure Vessel Code", Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2007, October 21-26, 2007, Miami, Florida, USA.

[3.I.32] ACI-349 (2001), Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-01) and Commentary (ACI 349R-01), Appendix C, American Concrete Institute, 2001.

[3.I.33] ANSYS 11.0, ANSYS Inc., 2007.

TABLE 3.I.1

HI-STORM 100U BOUNDING WEIGHT DATA

Item	Bounding Weight (lb)
MPCs	
• Without SNF	See Table 3.2.1
• Fully loaded with SNF and Fuel Spacers	90,000
HI-STORM 100U VVM	
• Closure Lid (with shielding concrete)	24,000
• CEC (empty without Closure Lid)	33,000
• Maximum Loaded Weight (with bounding MPC)	147,000
Loaded Transporter (Typical)	
• Carrying a loaded HI-TRAC	400,000
• Empty	160,000
• Length & width of each load patch (2 load patches per transporter)	197.1875 inch by 29.5 inch
• Computed average normal pressure on two load patches	34.4 psi
Loaded HI-TRAC and Mating Device	275,000

Note 1: CEC and Closure Lid include an overage up to 5%.
Note 2: Transporter weight is based on representative units used in the industry.

TABLE 3.I.2

CENTER OF GRAVITY DATA FOR THE HI-STORM 100U SYSTEM

Component	**Height of CG Above Datum (in)**
MPC	See Table 3.2.3
HI-STORM 100U VVM CEC (empty without Closure Lid)	108.7
HI-STORM 100U VVM Closure Lid	20.26
Note: Datum for CEC is at the top surface of the foundation; datum for Closure Lid is at bottom surface of baseplate of lid.	

TABLE 3.I.3 (a)*
RELEVANT MATERIAL PROPERTIES FOR THE HI-STORM 100U
Yield, Ultimate, Linear Thermal Expansion, Young's Modulus

Temp. (Deg. F)	**SA516 and SA515, Grade 70**			
	S_y	**S_u**	**α**	**E**
-40	38.0	70.0	---	29.95
100	38.0	70.0	5.53 (5.73)	29.34
150	36.3	70.0	5.71 (5.91)	29.1
200	34.6	70.0	5.89 (6.09)	28.8
250	34.15	70.0	6.09 (6.27)	28.6
300	33.7	70.0	6.26 (6.43)	28.3
350	33.15	70.0	6.43 (6.59)	28.0
400	32.6	70.0	6.61 (6.74)	27.7
450	31.65	70.0	6.77 (6.89)	27.5
500	30.7	70.0	6.91 (7.06)	27.3
550	29.4	70.0	7.06 (7.18)	27.0
600	28.1	70.0	7.17 (7.28)	26.7
650	27.6	70.0	7.30 (7.40)	26.1
700	27.4	70.0	7.41 (7.51)	25.5
750	26.5	69.3	7.50 (7.61)	24.85
800	25.3	64.3	7.59 (7.71)	24.2

* Footnotes in corresponding table in Section 3.3 apply to the values in parentheses.

TABLE 3.I.3 (b)
DESIGN AND LEVEL A: ALLOWABLE STRESS FROM ASME NF

Material : **SA516 Grade 70, SA515 Grade 70**
Service Conditions: **Design and Level A Stress**
Item: **Stress**

Temp. (Deg. F)	Classification and Value (ksi)		
	S	Membrane Stress	Membrane plus Bending Stress
-20 to 650	17.5	17.5	26.3
700	16.6	16.6	24.9
750	14.8	14.8	22.2
800	12.0	12.0	18.0

TABLE 3.I.3 (c)
LEVEL D: STRESS INTENSITY

Code: **ASME NF**
Material: **SA516, Grade 70**
Service Conditions: **Level D**
Item: **Stress Intensity**

Temp. (Deg. F)	Classification and Value (ksi)		
	S_m	P_m	$P_m + P_b$
-20 to 100	23.3	45.6	68.4
200	23.1	41.5	62.3
300	22.5	40.4	60.6
400	21.7	39.1	58.7
500	20.5	36.8	55.3
600	18.7	33.7	50.6
650	18.4	33.1	49.7
700	18.3	32.9	49.3

TABLE 3.I.3 (d)

Code: ASME NB
Material: Alloy X
Service Conditions: Level D
Item: Stress Intensity

Temp. (Deg. F)	Classification and Value (ksi)		
	P_m	P_L	$P_L + P_b$
-20 to 100	48.0	72.0	72.0
200	48.0	72.0	72.0
300	46.2	69.3	69.3
400	44.9	67.4	67.4
500	42.0	63.0	63.0
600	39.4	59.1	59.1
650	38.4	57.6	57.6
700	37.4	56.1	56.1
750	36.5	54.8	54.8
800	35.8	53.7	53.7

TABLE 3.I.4
REFERENCE AND DERIVED PROPERTIES OF ISFSI REINFORCED CONCRETE, SUBGRADE, AND UNDERGRADE

Property	**Value**
Concrete Compressive Strength (psi)	4,500
Concrete Rupture Strength (psi)	335.4
Allowable Bearing Stress (psi)	4,972.5*
Mean Coefficient of Thermal Expansion (in/in-deg. F)	5.5E-06
Modulus of Elasticity (psi)	57,000 x (Concrete Compressive strength (in psi))$^{1/2}$
Subgrade Yield Stress (psi)	25[¥]
Subgrade Strain Compatible Modulus of Elasticity (ksi) (see Figure 2.I.5)	Space A: 18.8 Space B: 14.0 Spaces C and D: 17.7

* Per ACI-318 (2005), Sec. 10.17.1 and Sec. 9.3.2.4. Since the ISFSI concrete is always confined, the allowable value is doubled.

[¥] Only applied to Space A.

TABLE 3.I.5
SOIL PROPERTIES, COMPUTED SETTLEMENT, AND CORRESPONDING ELASTIC MODULII FOR THE SUBGRADE

Item		Value
1.	Characteristics for Subgrade Below SFP: Water Content 'w_n' Soil Parameter 'a' Soil Parameter 'b' Poisson's Ratio	 14% 0.18 0.13 0.45
2..	Derived Properties for the Subgrade Below SFP (Note 1): Computed Long-Term Settlement (in) (Note 2) Computed Elastic Modulus (psi)	 0.189 5,377
3.	Values used in the Structural Analyses Model for Subgrade Below SFP: Limiting Long-Term Settlement (in) Corresponding Elastic Modulus (psi)	 From Table 2.I.2 5,081
4.	Soil Characteristics for Subgrade Above SFP: Water Content 'w_n' Soil Parameter 'a' Soil Parameter 'b' Poisson's Ratio	 14% 0.09 0.13 0.45
5.	Derived Properties for the Subgrade Above SFP (Note 3): Computed Long-Term Settlement (in) (Note 2) Computed Elastic Modulus (psi)	 0.39 5,073
6.	Values used in the Structural Analyses Model for Subgrade Above SFP: Long-Term Settlement (in) Corresponding Elastic Modulus (psi)	 From Table 2.I.2 4,946

Note 1: The substrate characteristics are obtained using the density data from Table 2-3 and Table 5-1 of reference [2.I.7]. The soil compaction index 'Cc' is a direct function of soil parameters w_n, a, and b per [2.I.7]. The long-term settlement and the elastic modulus are derived using the relationships in [2.I.6].

Note 2: See Table 2.I.2 for the values of settlement (greater than those computed here for conservatism) used as the Design Basis data for qualification of the ISFSI structures.

Note 3: The Design Basis settlement has been set at a higher value than that computed for the TSP and SFP to allow for the variation in the soil parameters at a host site.

TABLE 3.I.6
MENU OF LS-DYNA RUNS (SSI ANALYSES)

No.	Case	Comment
1.	VVM array model (5x5 array) with 100% concrete modulus for the SFP	To obtain interface load for the ISFSI structures
2.	VVM array model (5x5 array) with 50% concrete modulus for the SFP	To obtain interface load for the ISFSI structures
3.	VVM array model (5x5 array) for the optional ISFSI design with retaining walls	To obtain interface load for the ISFSI structures
4.	Design Basis Single VVM seismic model	To qualify VVM components.

Note: The LS-DYNA models implemented in cases 1-3 have an unintended conservatism caused by modeling the MPC guide/divider plate junctions as hinged joints without rotational fixity; except for those joints on the symmetric plane of the model where rotational constraints are imposed by the symmetric boundary condition. This has the effect of eliminating MPC guide plates, except those on the symmetric plane of the model, during the seismic event which exacerbates the movement of the MPC and increases all associated impact loads. Despite this conservatism, the results show positive safety margins and are used for the ISFSI structure safety evaluation. The affected three simulations may be rerun in the future with the correct modeling assumption for the MPC guide/divider plate junctions and this may increase certain computed safety margins.

TABLE 3.I.7

ISFSI INTERFACE LOADS OBTAINED FROM LS-DYNA SSI SIMULATIONS

Interface Load	Case 1	Case 2	Case 3	Case 4
CEC to SFP Impact Load, lb	7.014×10^{5}	9.442×10^{5}	9.340×10^{5}	6.433×10^{5}
Transporter to TSP Contact Load per Track, lb	9.759×10^{5}	1.035×10^{6}	N/A	1.148×10^{6}
Soil Compressive Load on the Retaining Wall, lb	N/A	N/A	3.448×10^{6}	N/A
In-Plane Tensile Load on TSP from Retaining Wall, lb	N/A	N/A	7.605×10^{5}	N/A
In-Plane Tensile Load on SFP from Retaining Wall, lb	N/A	N/A	2.438×10^{6}	N/A

TABLE 3.I.8

LOADS APPLIED IN THE ISFSI STRUCTURAL EVALUTION†

Load on ISFSI	Loading Configurations I, II and III	Loading Configuration IV
Load on SFP at each VVM location ‡, lbf	950,000	650,000
Total Load on TSP due to Transporter ‡, lbf	$5.2 \times 400000 = 2.08 \times 10^6$	$5.75 \times 400,000 = 2.3 \times 10^6$
In-Plane Tensile Load on TSP Extreme Face, lbf	8×10^5	
In-Plane Tensile Load on SFP Extreme Face, lbf	2.6×10^6	

Notes:

† For conservatism, the loads used for ISFSI structural evaluation bound the peak loads obtained from SSI simulations (see Table 3.I.7)

‡ The listed load is a sum of dead and seismic components. These loads are appropriately divided as dead and seismic in ANSYS prior to applying the appropriate load factors and combinations per Table 2.I.11.

TABLE 3.I.9*

RESULTS FROM TORNADO MISSILE ANALYSIS (LOAD CASE 03 OF TABLE 2.I.5)			
Item	**Bounding Value, inch**	**Allowable Value, inch**	**Safety Factor**
Maximum Vertical Displacement of lid (inch) (inclined impact)	< 3	12**	> 4
Perforation of Inner Shield Dome Steel	Yes (see Fig. 3.I.7)	N/A	N/A
Maximum Peak Impact Force (kips)	< 1,000	1,849	>1

* Details of the calculations can be found in [3.I.27]

** This is the minimum distance between the Closure Lid bottom plate and the top lid of the MPC.

TABLE 3.I.10
MOMENT RESULTS AND CORRESPONDING MINIMUM SAFETY FACTORS FOR THE ISFSI STRUCTURES

Support Foundation Pad (SFP)‡			
ISFSI Load Configuration	Maximum Moment Induced (lbf-in/in)	Moment Capacity (lbf-in/in)	Minimum Safety Factor
Fully Loaded (Base Model)	86,094	210,270	2.44
Half Loaded (Configuration II)	133,840	222,130	1.66
Middle Row Loaded (Configuration III)	169,940	213,890	1.26
Single VVM Loaded (Configuration IV)	100,810	236,310	2.34
Top Surface Pad (TSP)‡			
Fully Loaded (Base Model)	223,870	254,660	1.138
Half Loaded (Configuration II)	146,370	229,210	1.57
Middle Row Loaded (Configuration III)	205,860	233,370	1.134
Single VVM Loaded (Configuration IV)	222,360	235,070	1.057
Retaining Wall †			
Fully Loaded (Case 3 of Table 3.I.6)	80,000	175,000	2.19

‡ The moment capacities for the SFP and TSP are calculated using axial-force-moment interaction diagram corresponding to the axial force and moment induced in the limiting element.

† The moment capacity for the Retaining Wall is based on the pure bending.

TABLE 3.I.11
PUNCHING SHEAR SAFETY FACTORS FOR ISFSI STRUCTURES

ISFSI Structure	Punching Safety Factor
SFP	2.4
TSP	1.5

TABLE 3.I.12
PRESUMPTIVE SOIL BEARING

Computed Bearing Stress (psi)	Allowable Bearing Stress (psi)	Safety Factor	Minimum Safety Factor Required per [2.I.8]
42.8	90	2.1	2.0

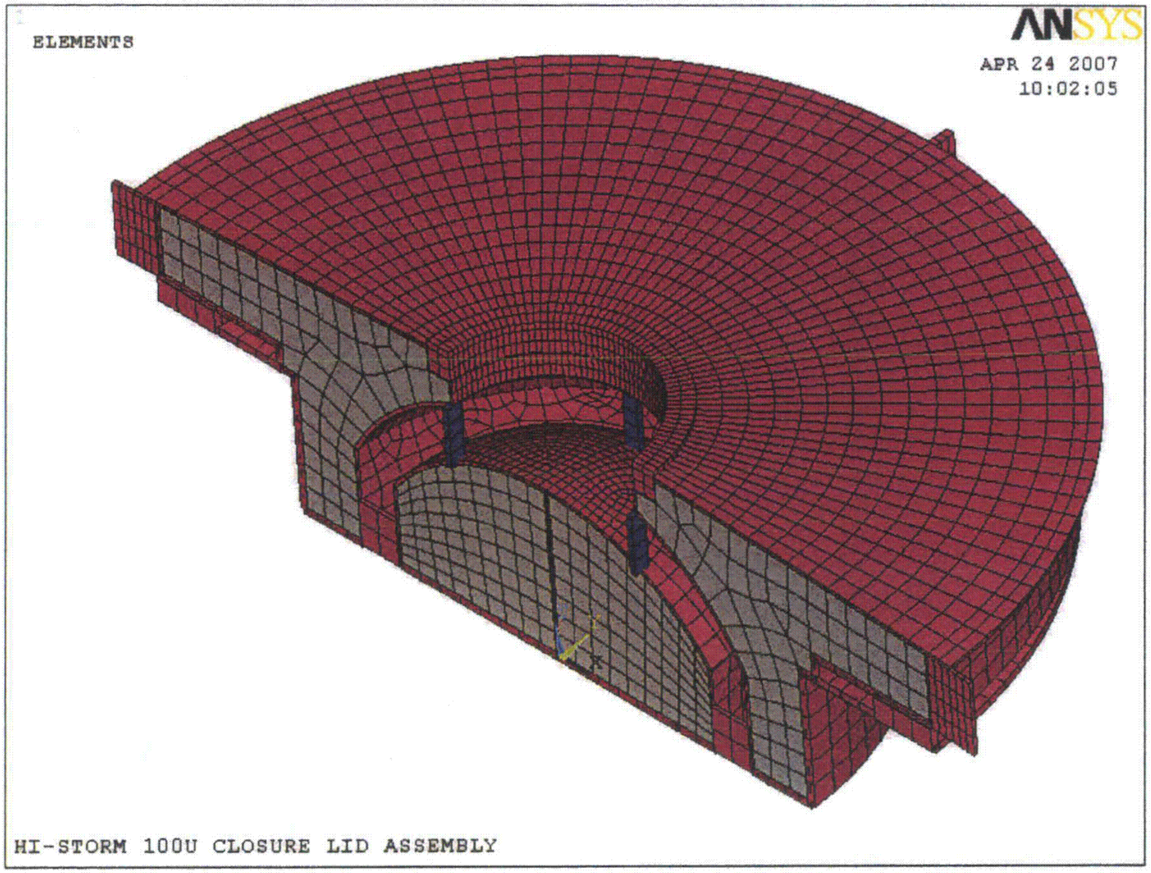


Figure 3.I.1; 3-D ANSYS/LSDYNA Finite Element Model of Closure Lid (Current Configuration)

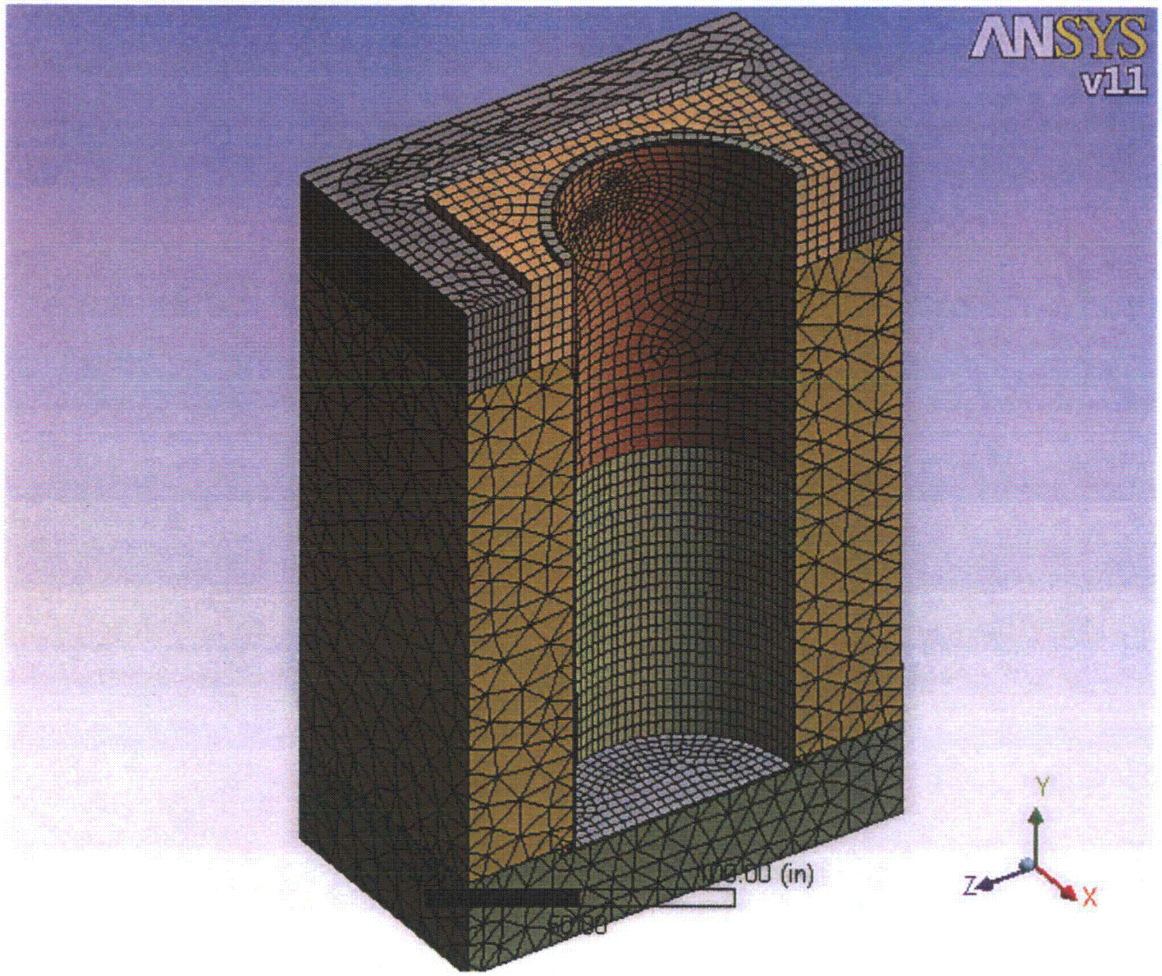


Figure 3.I.2; 3-D ANSYS Finite Element One-Half Model of Substrate Surrounding VVM, CEC Container Shell, TSP, and VIP

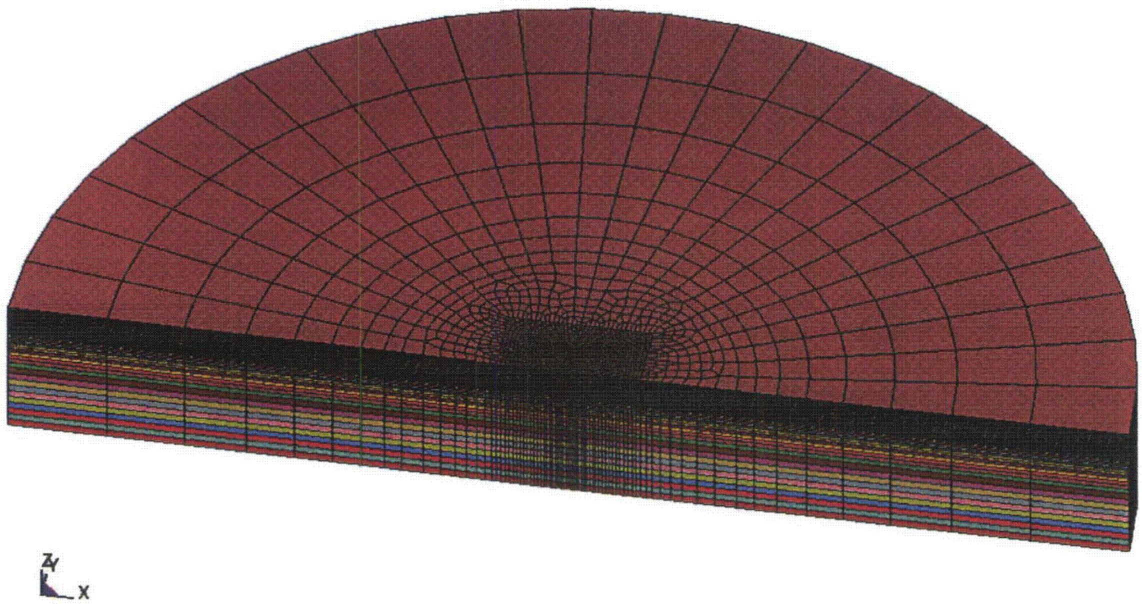


Figure 3.I.3-A; 3-D LSDYNA Soil Model for Design Basis Seismic Response Analysis

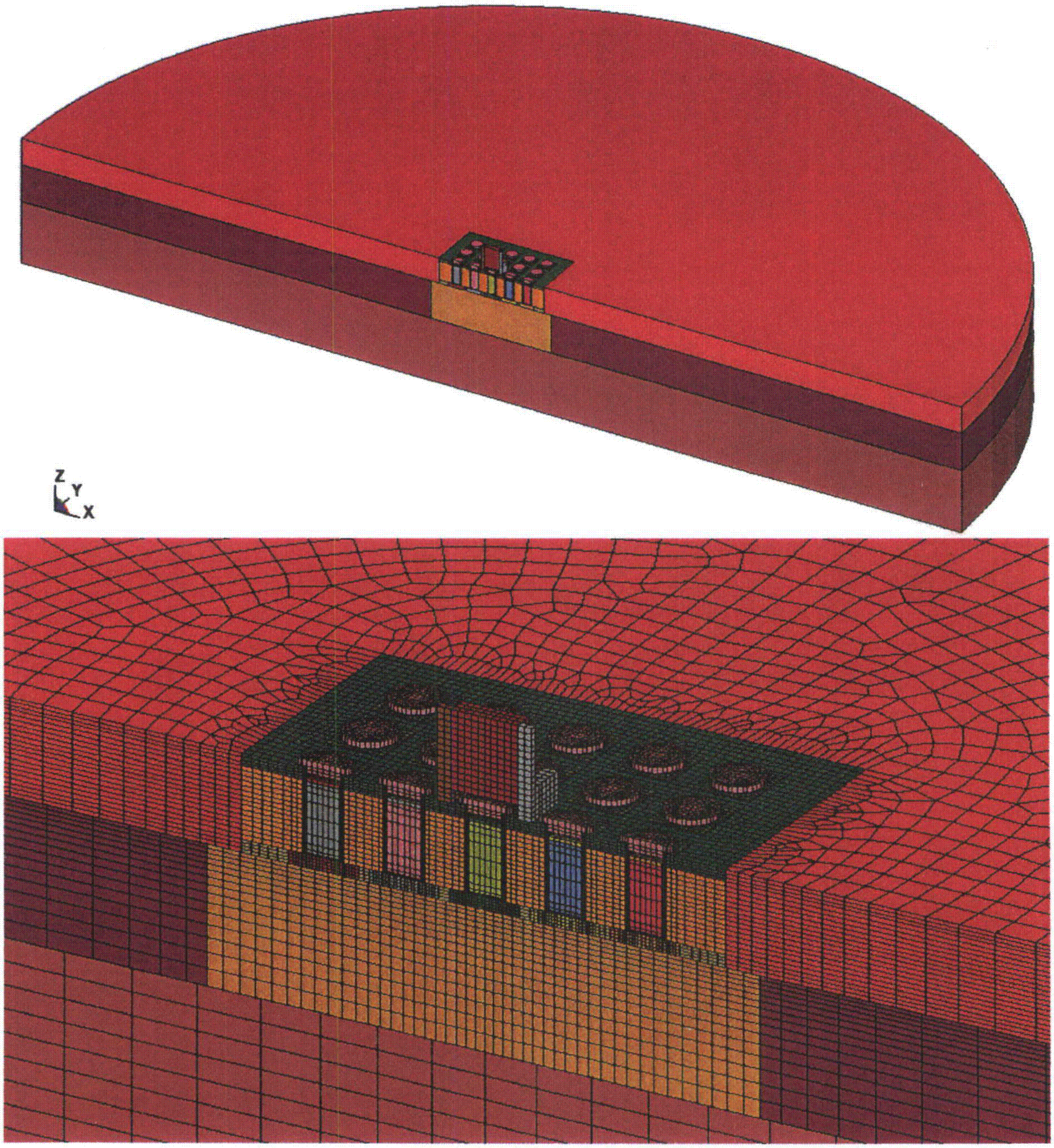


Figure 3.I.3-B; 3-D LSDYNA Model for Non-Linear SSI Analysis of 5x5 loaded VVMs on the Support Foundation

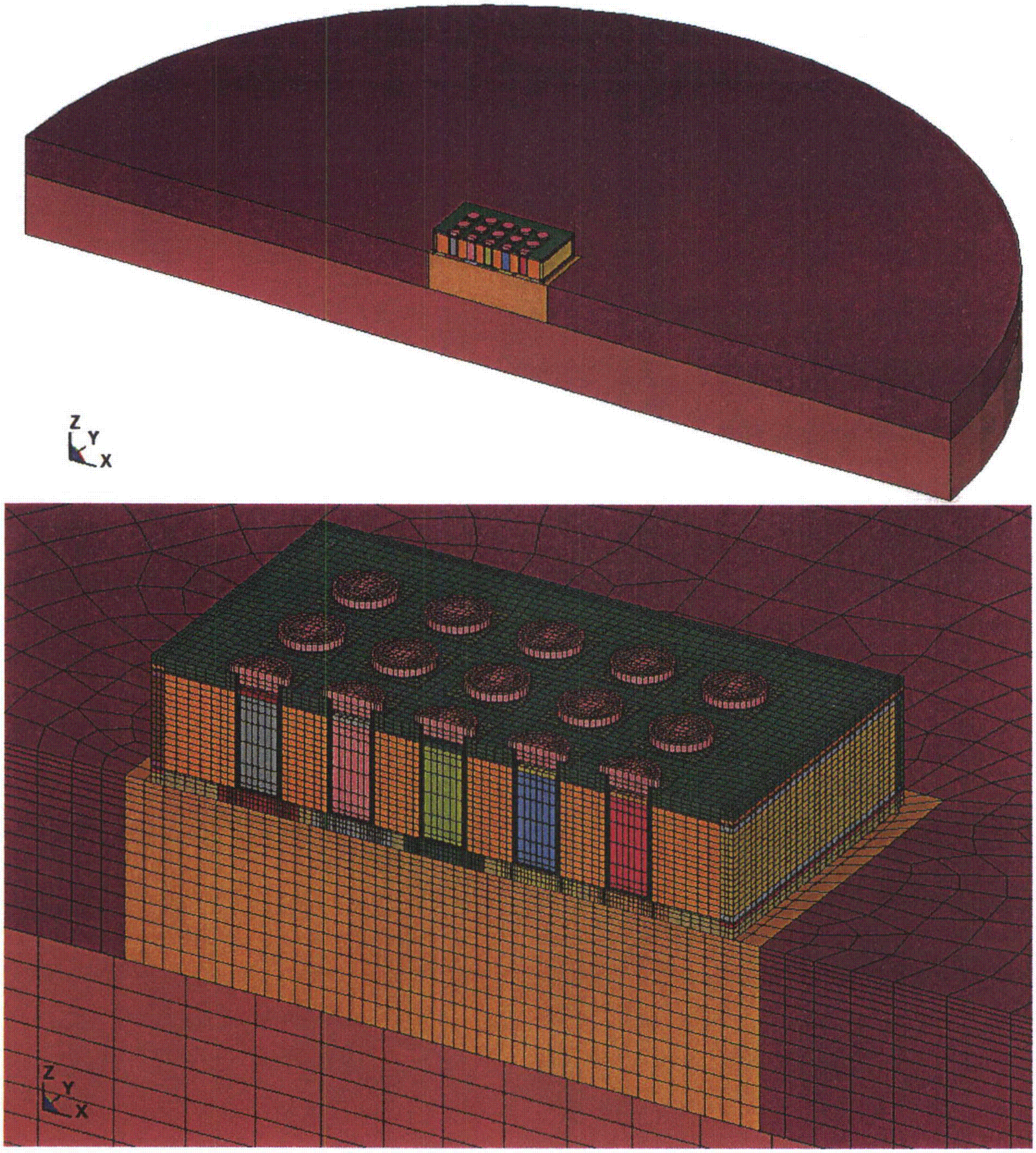


Figure 3.I.3-C; 3-D LSDYNA Model for Non-Linear SSI Analysis of 5x5 loaded VVMs on the Support Foundation with Retaining Walls

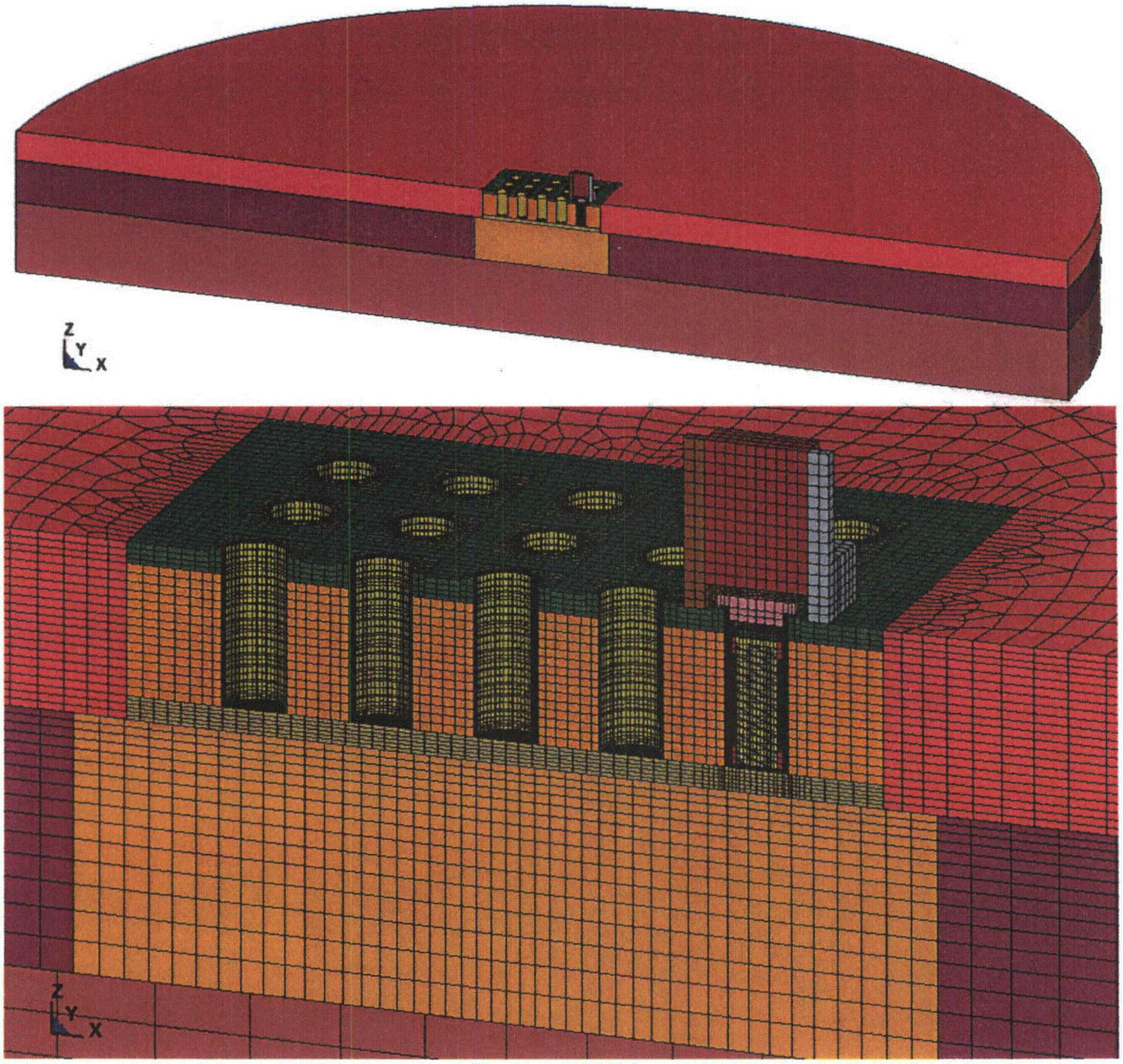


Figure 3.I.3-D; 3-D LSDYNA Model for Non-Linear SSI Analysis of a single VVM on Support Foundation

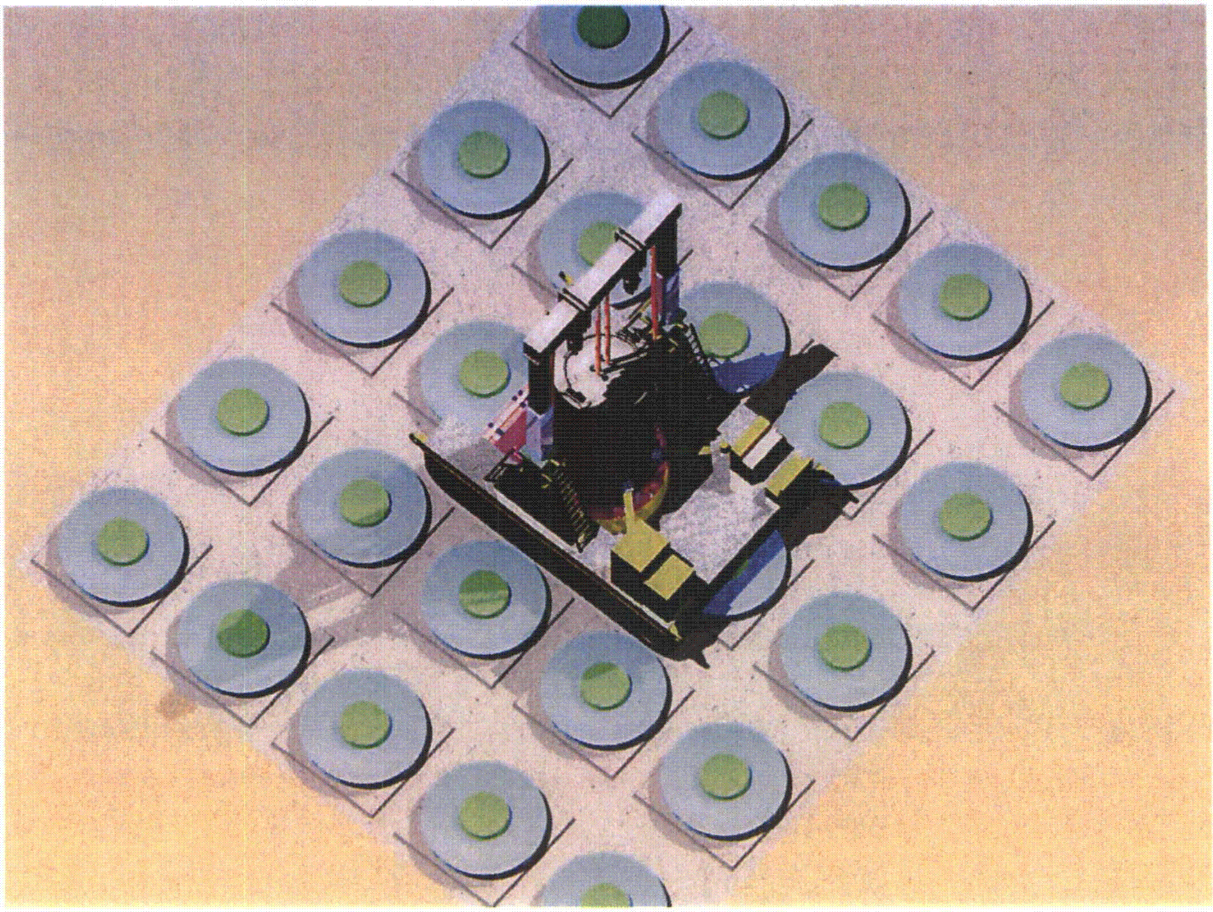


Figure 3.I.4; Cask Transporter on the ISFSI Positioned to Transfer MPC in the Central Cavity in the 5x5 VVM Array (illustrative analysis case)

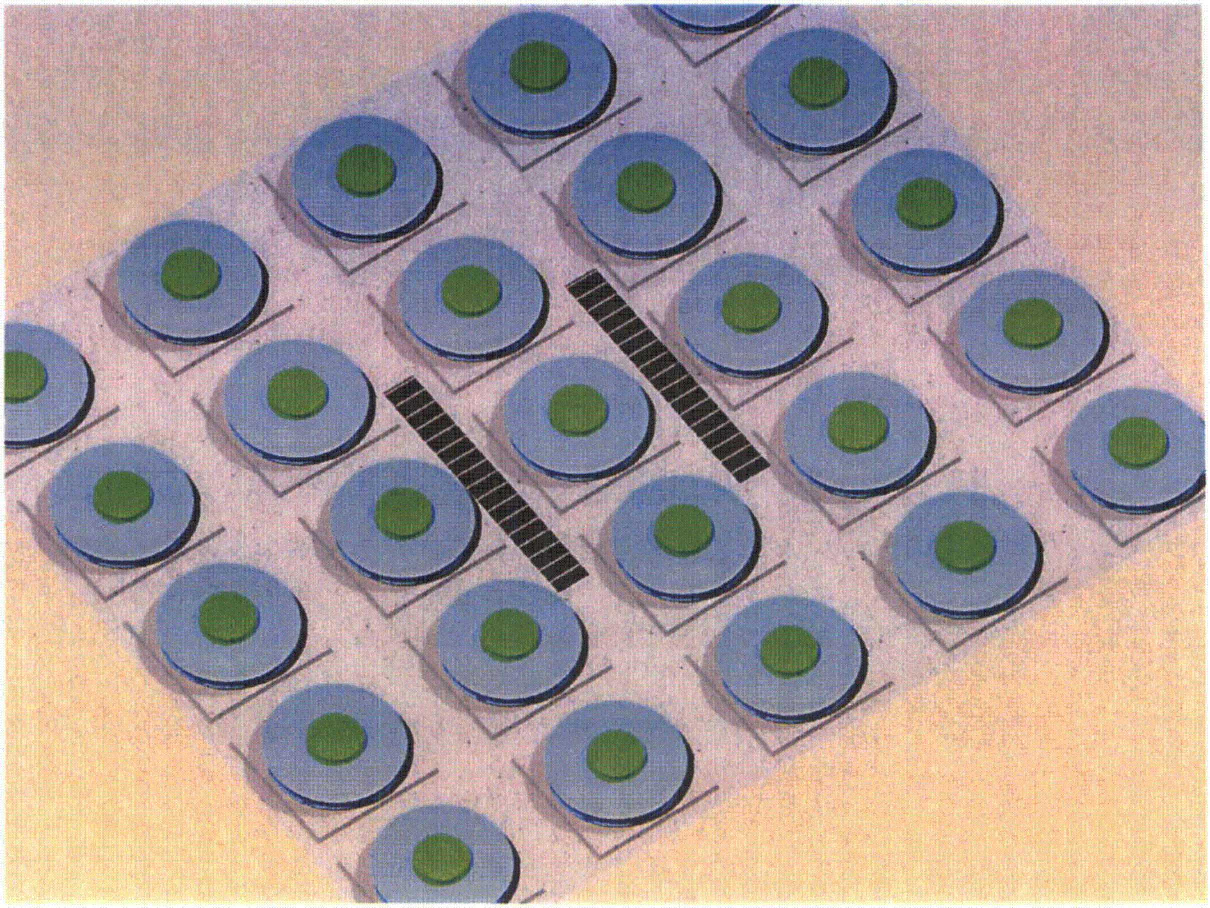


Figure 3.I.5; Load patch from the loaded Transporter in Figure 3.I.19
(Illustrative analysis case)

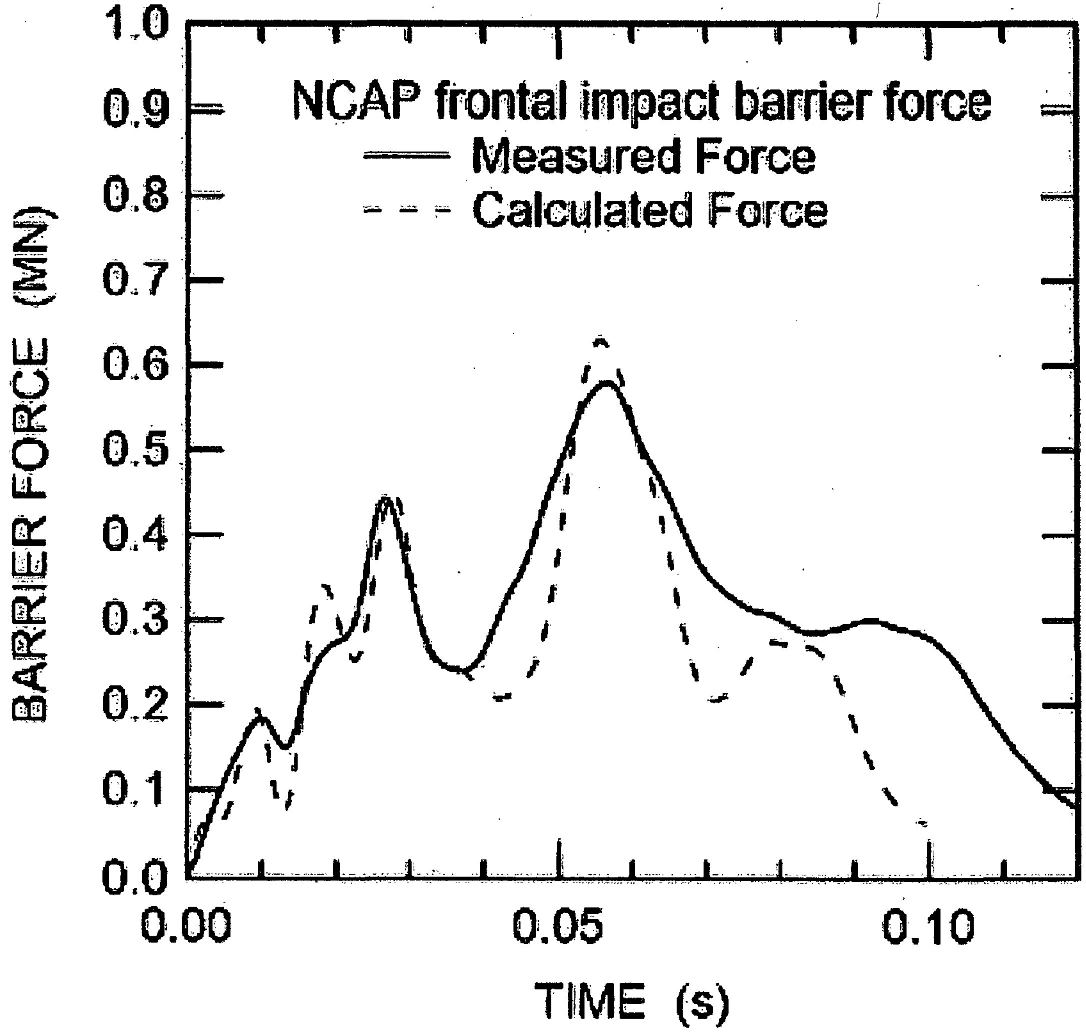


Figure 3.I.6; Test Results from 35mph Impact of a Ford (1705 Kg) Against a Rigid Wall

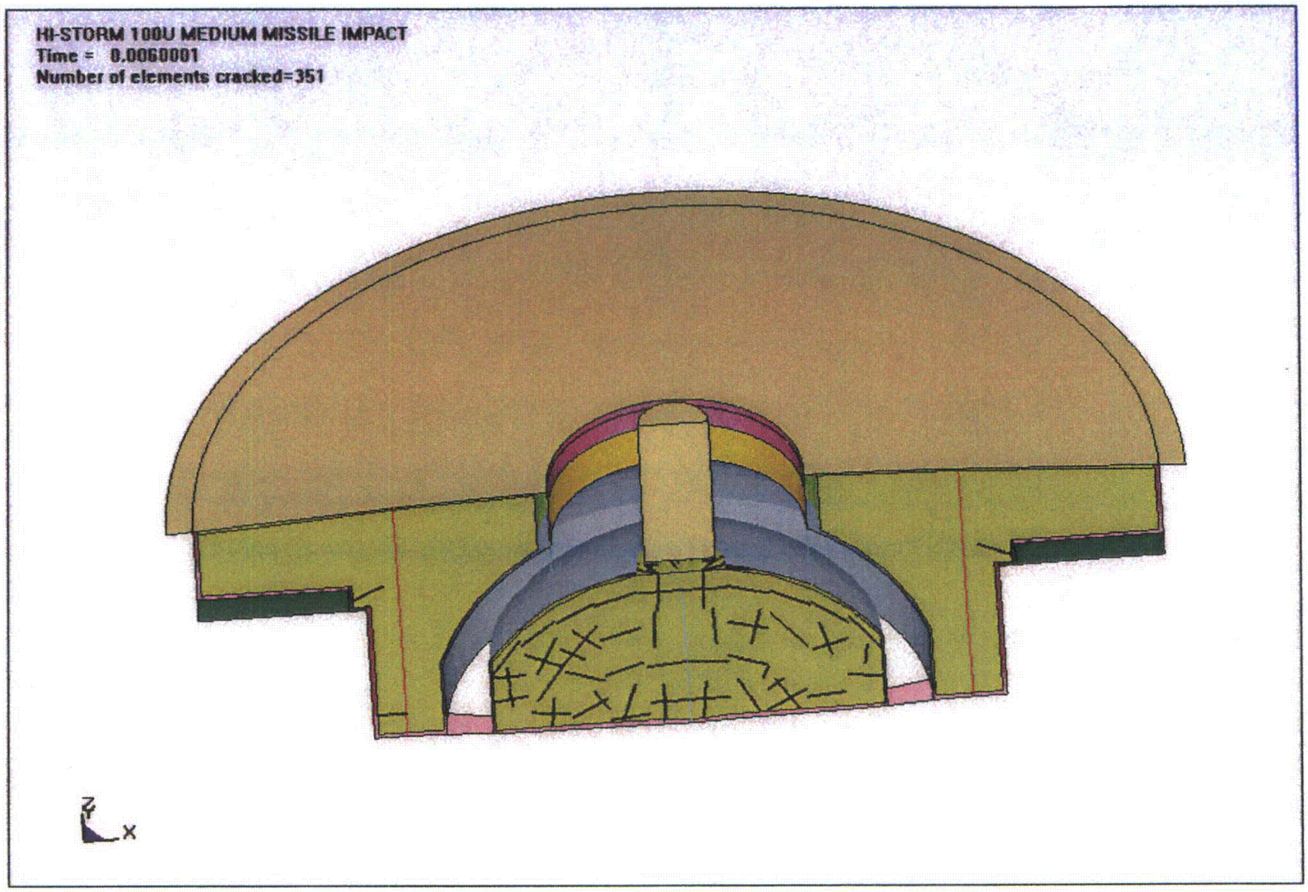


Figure 3.I.7; LSDYNA Model Section for Central Intermediate Missile Strike (subsequent to impact)

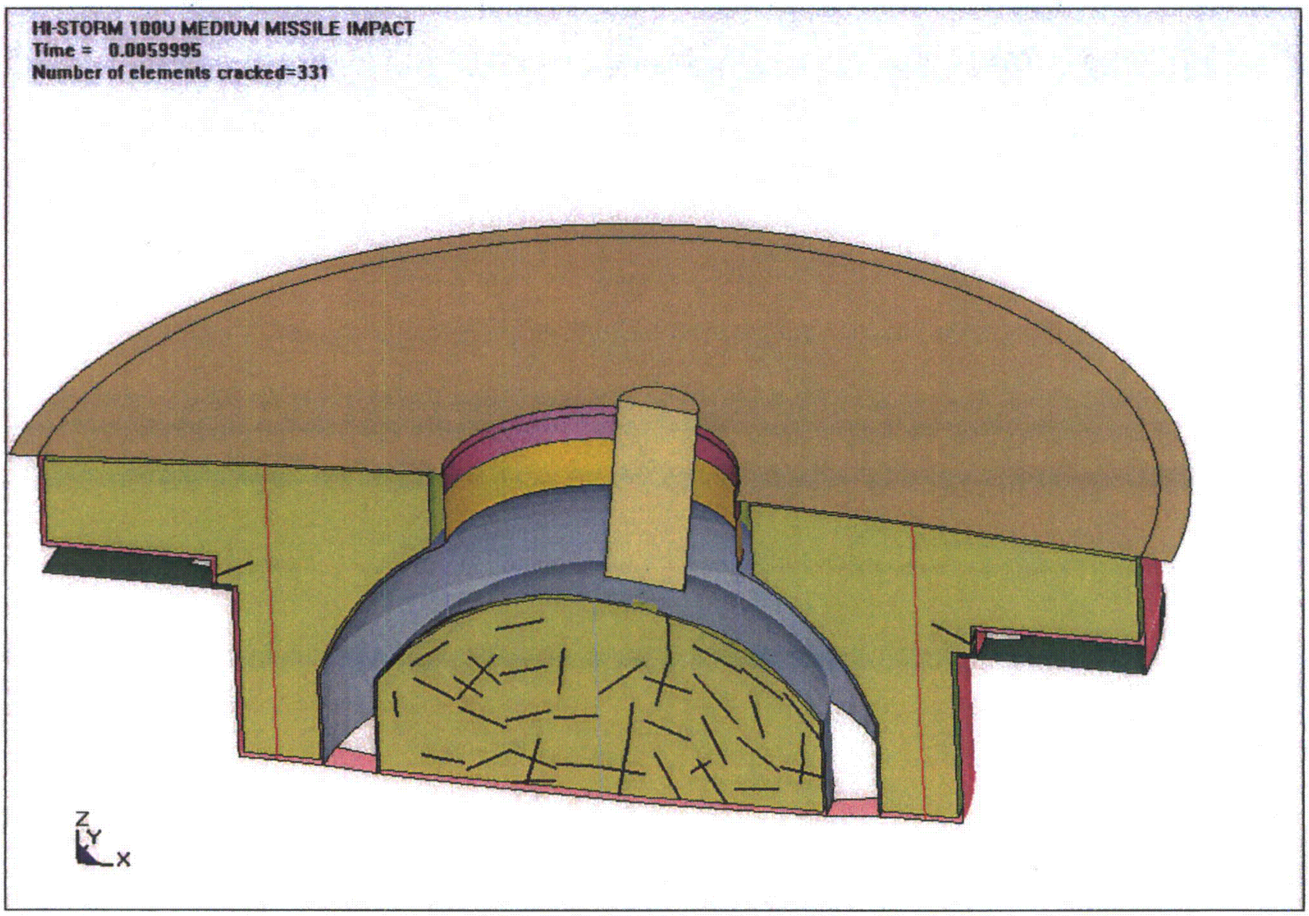


Figure 3.I.8; LSDYNA Model Section for Inclined Intermediate Missile Strike (subsequent to impact)

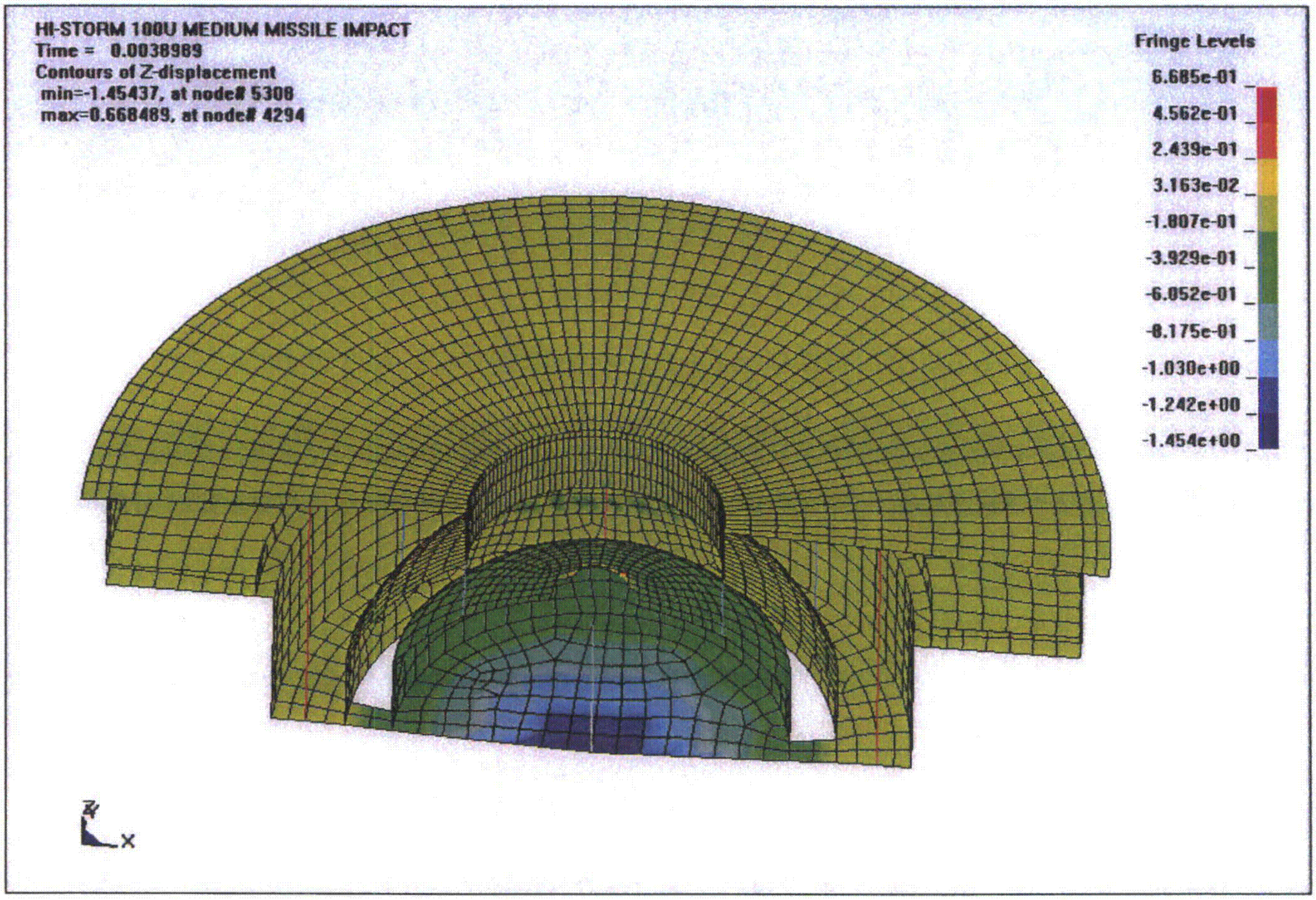


Figure 3.I.9; Deformation Profile at Time of Maximum Deformation – Central Strike

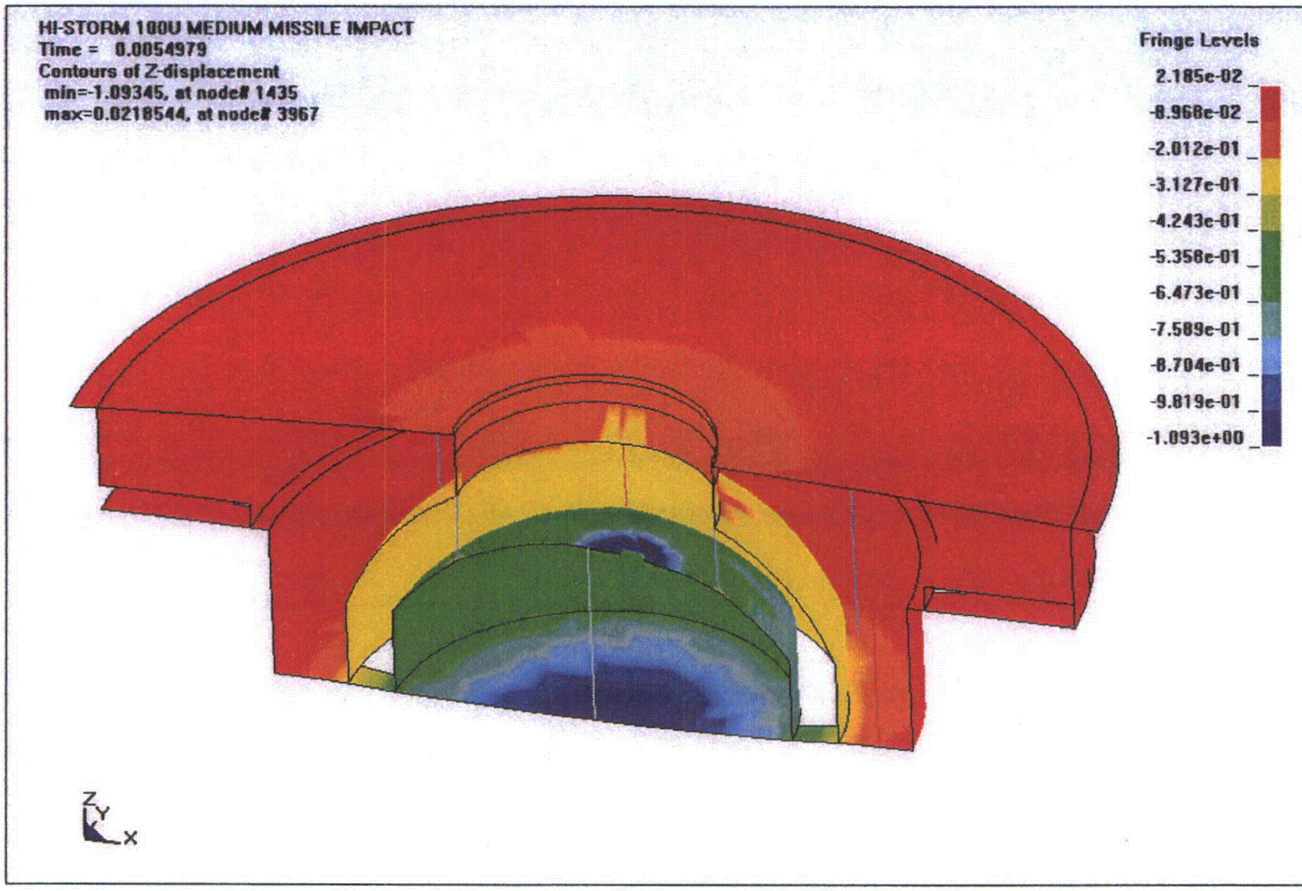


Figure 3.I.10; Deformation Profile at Time of Maximum Deformation – Inclined Strike

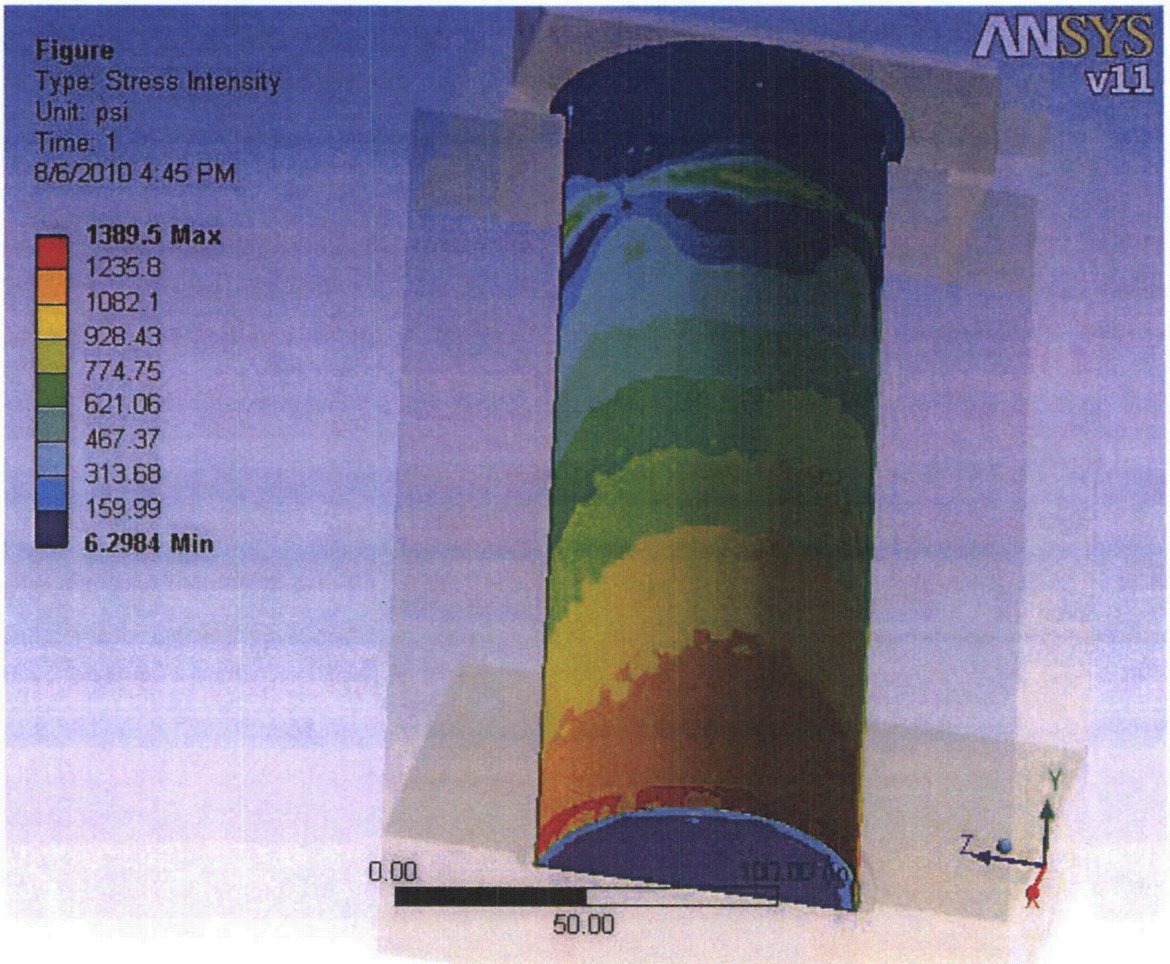


Figure 3.I.11; Stress Distribution in CEC Shell from Transporter and Substrate (Load Case 07)

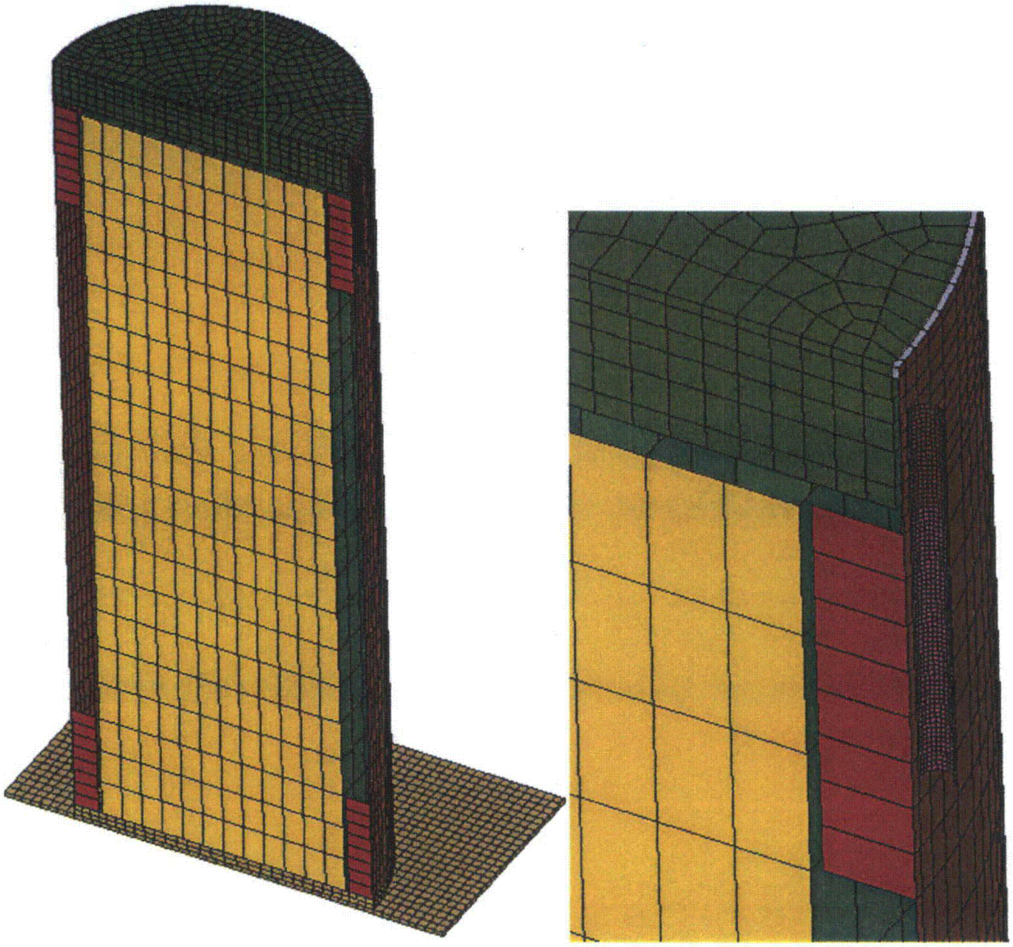


Figure 3.I.12; MPC Guide/MPC Impact LS-DYNA Model

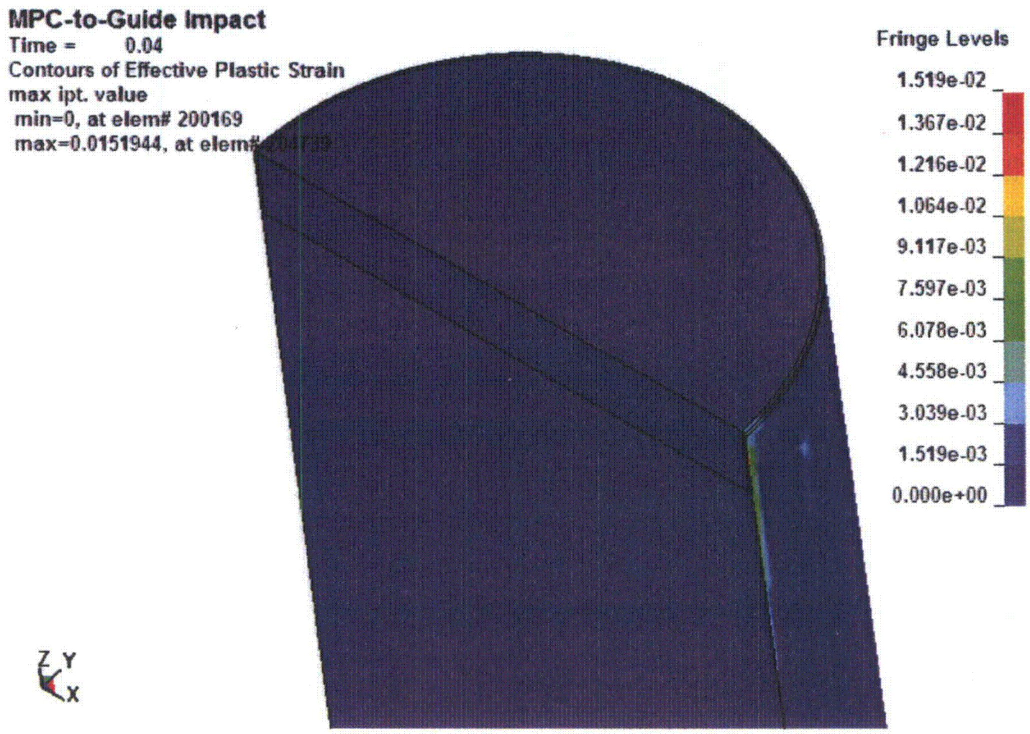


Figure 3.I.13; Maximum Plastic Strain of the MPC Enclosure Vessel in the Impact Region

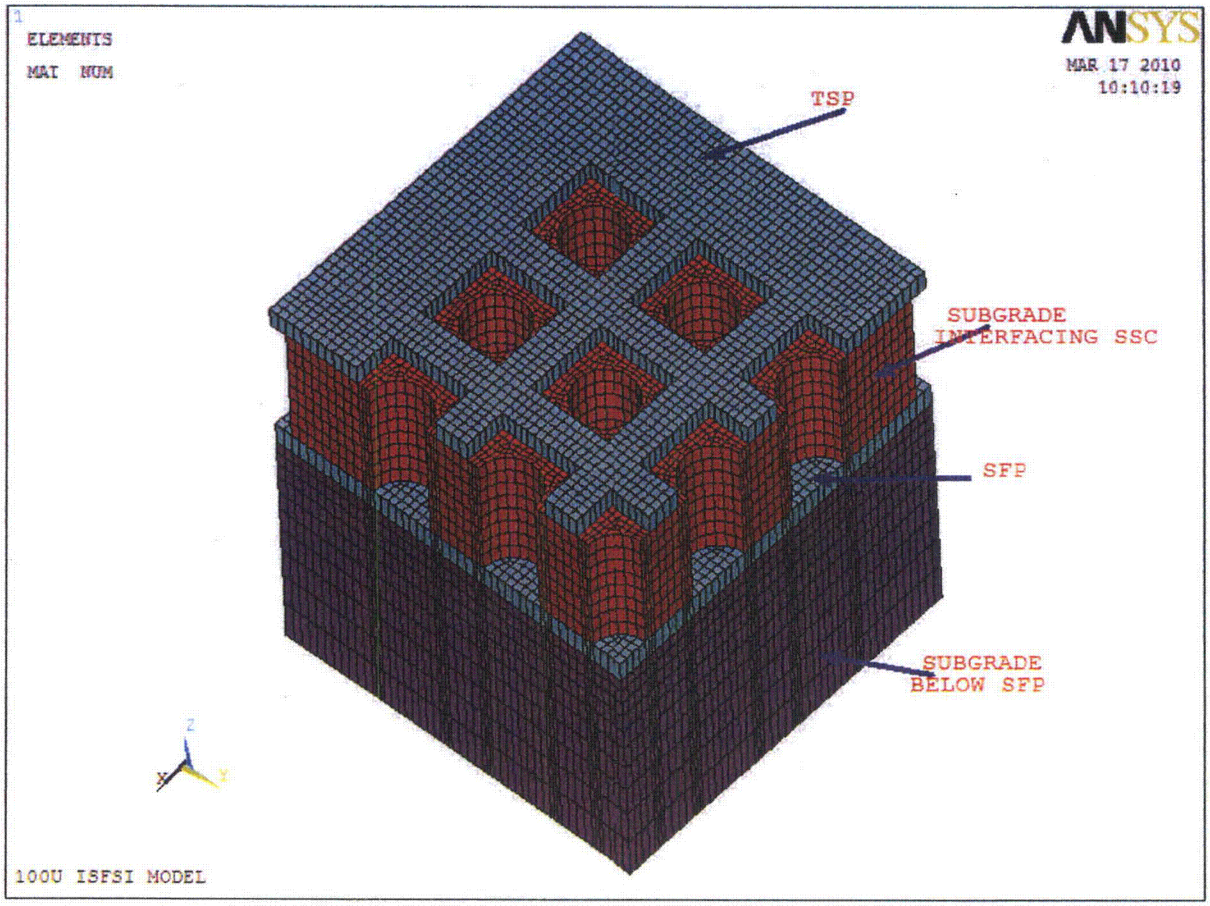
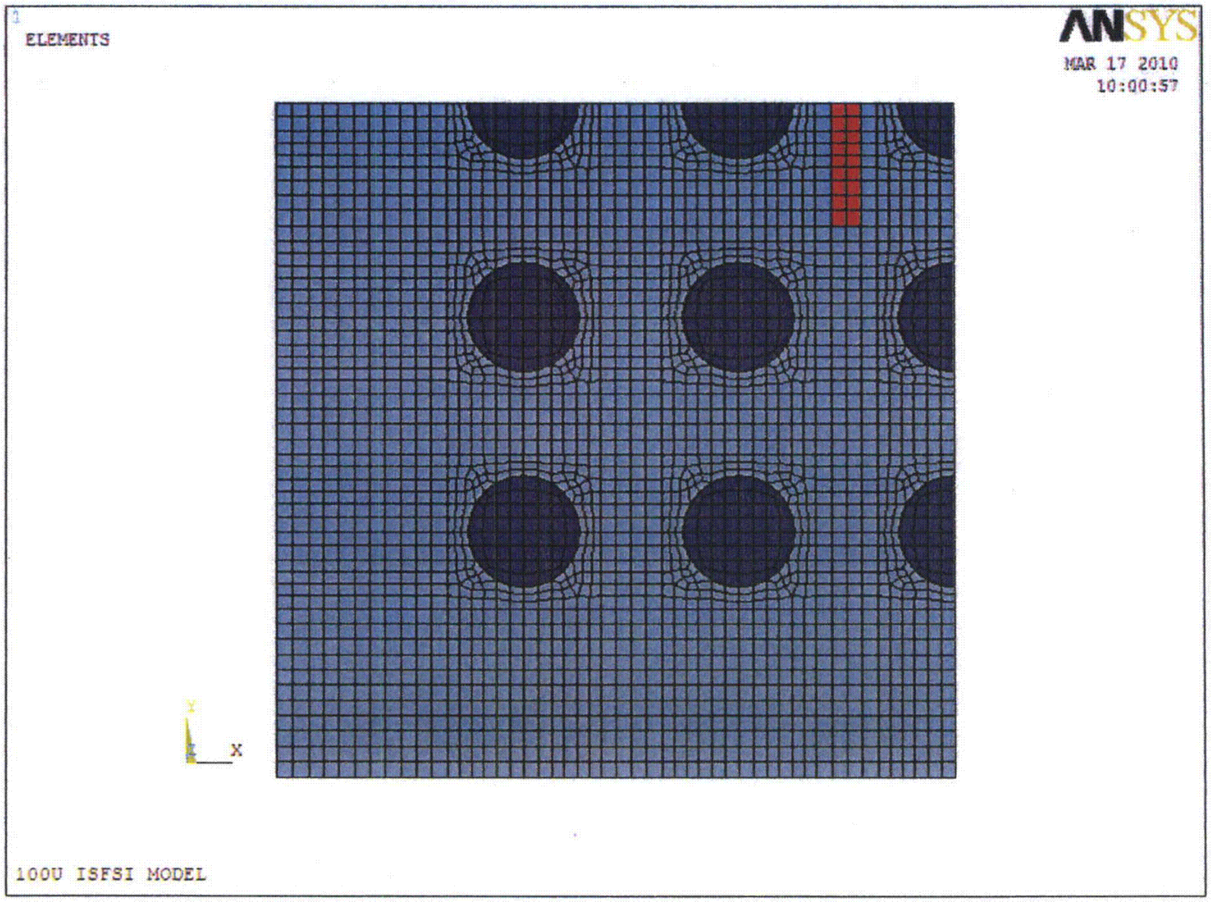


Figure 3.I.14; Finite Element Model of the ISFSI Reinforced Concrete Structures



Note: The blue footprint shows the loaded VVM locations on the SFP and the red footprint represents the loaded TSP area with the cask transporter.

Figure 3.I.15; ANSYS Finite Element Model of ISFSI Showing the Fully Loaded Configuration (Base Model)

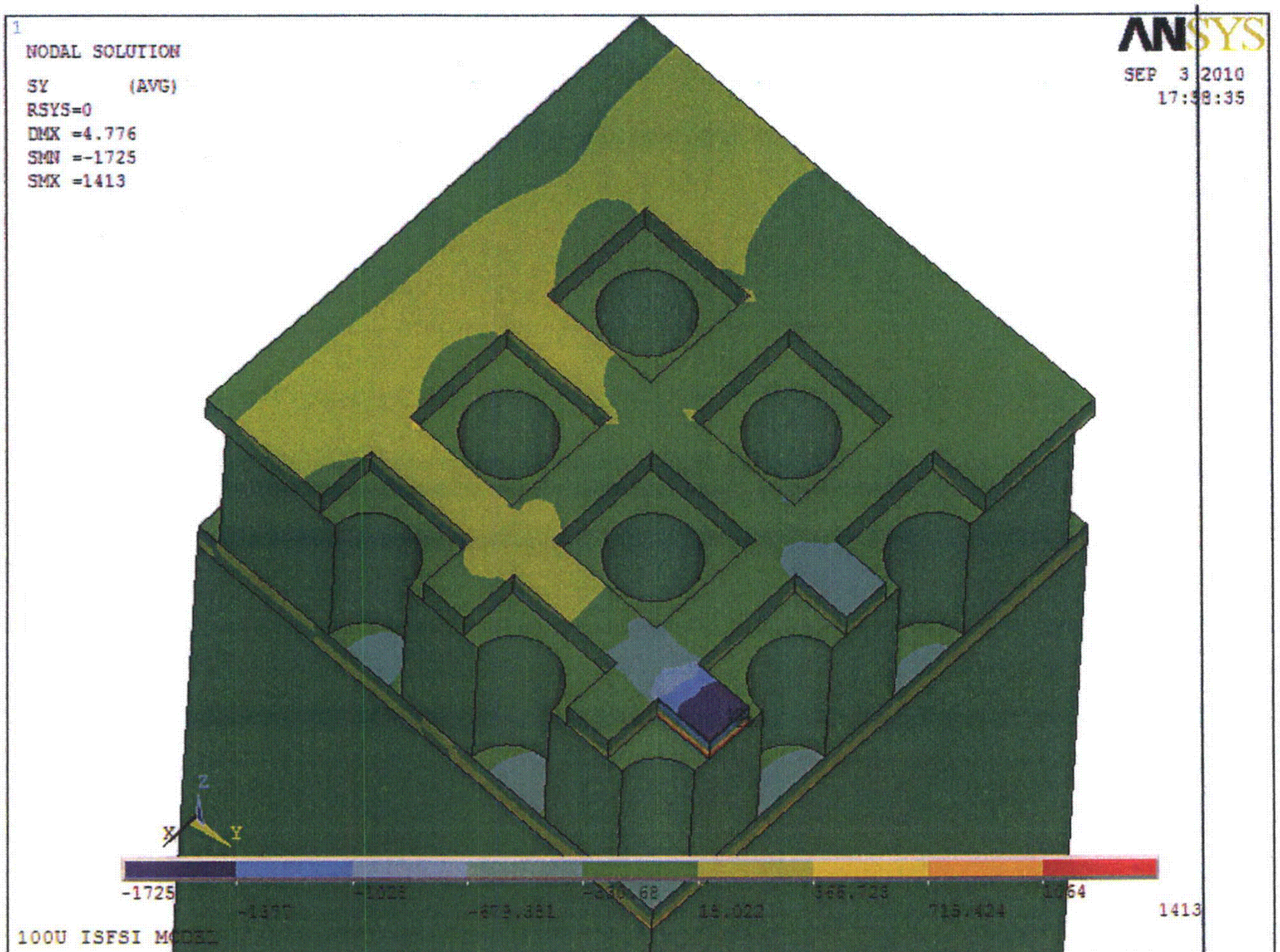


Figure 3.I.16; Normal Stress in the ISFSI in the Direction of the Transporter Path for Base Configuration – Load Combination LC-3 from Table 2.I.11

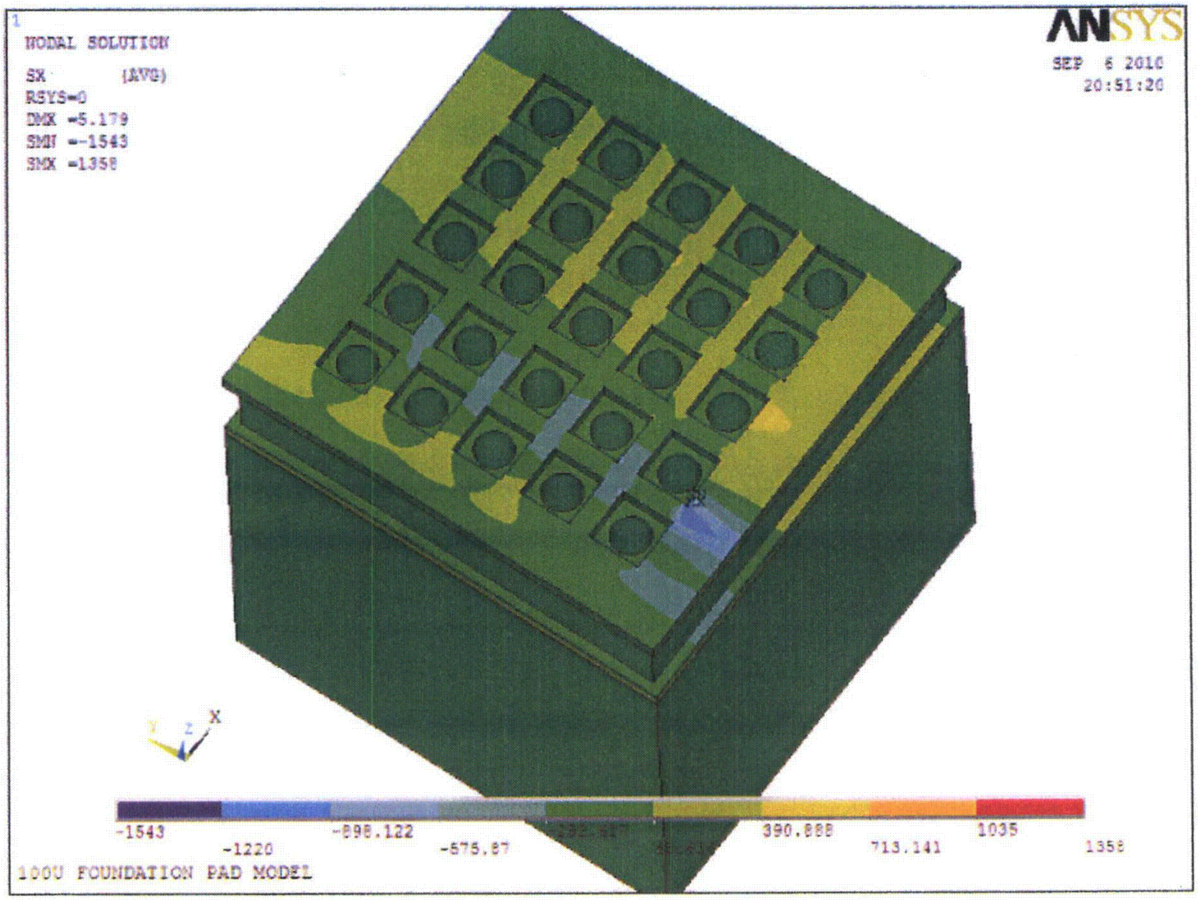


Figure 3.I.17; Normal Stress in the ISFSI in the Direction of the Transporter Path for Configuration II – Load Combination LC-3 from Table 2.I.11

Figure 3.I.18; Normal Stress in the ISFSI in the Direction of the Transporter Path for Configuration III – Load Combination LC-3 from Table 2.I.11

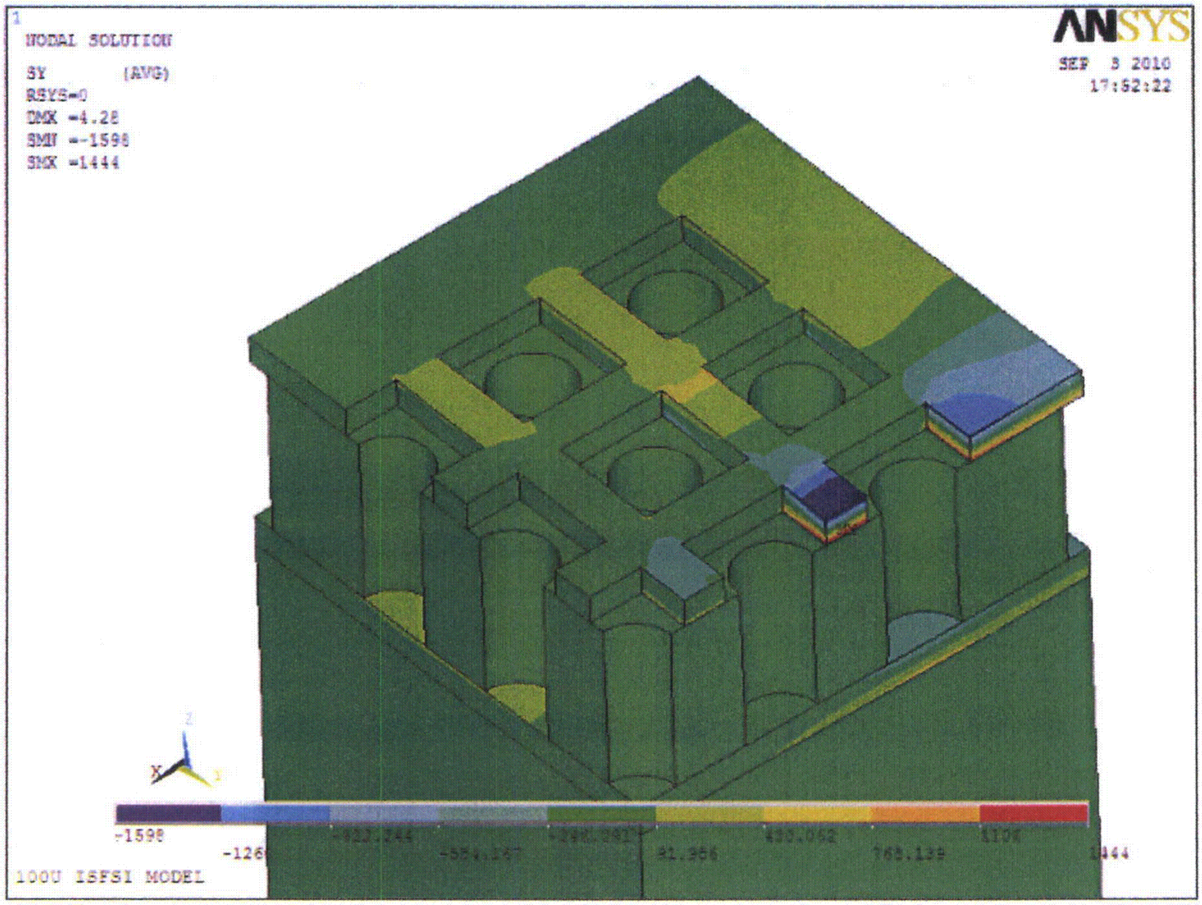
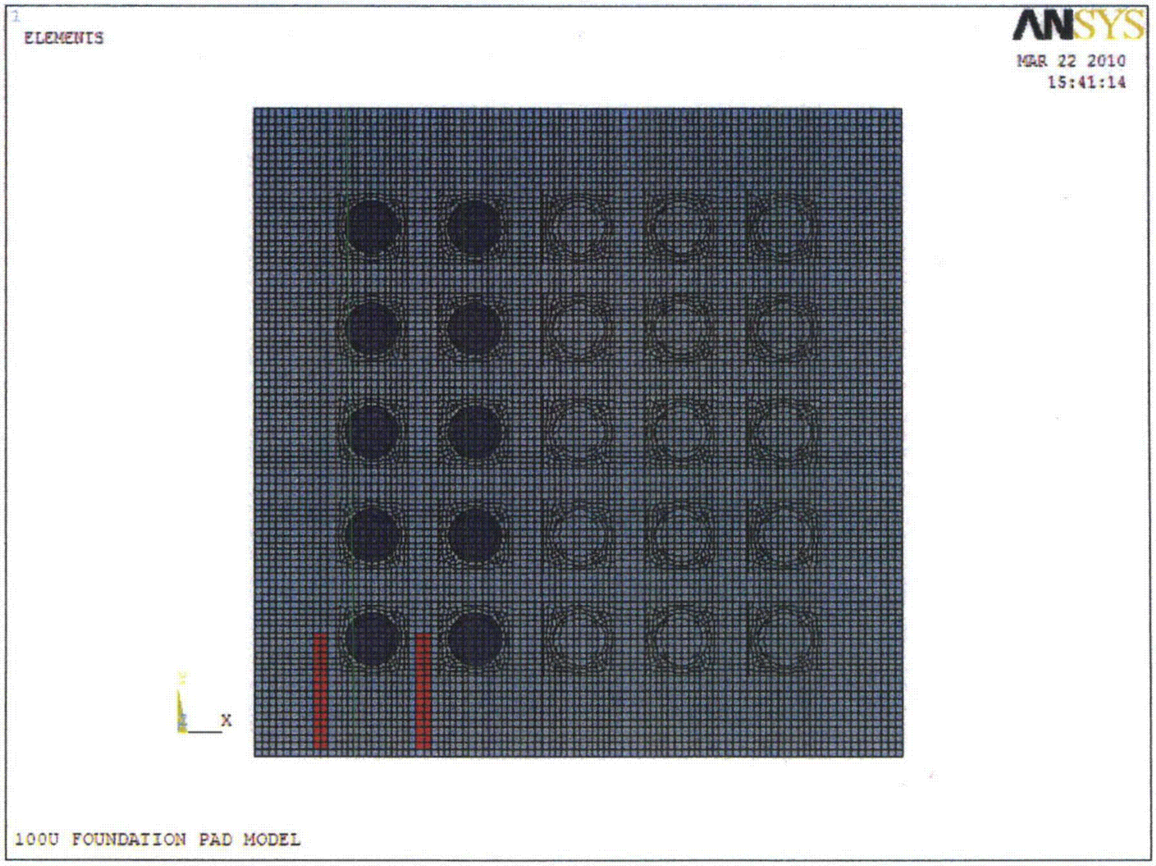
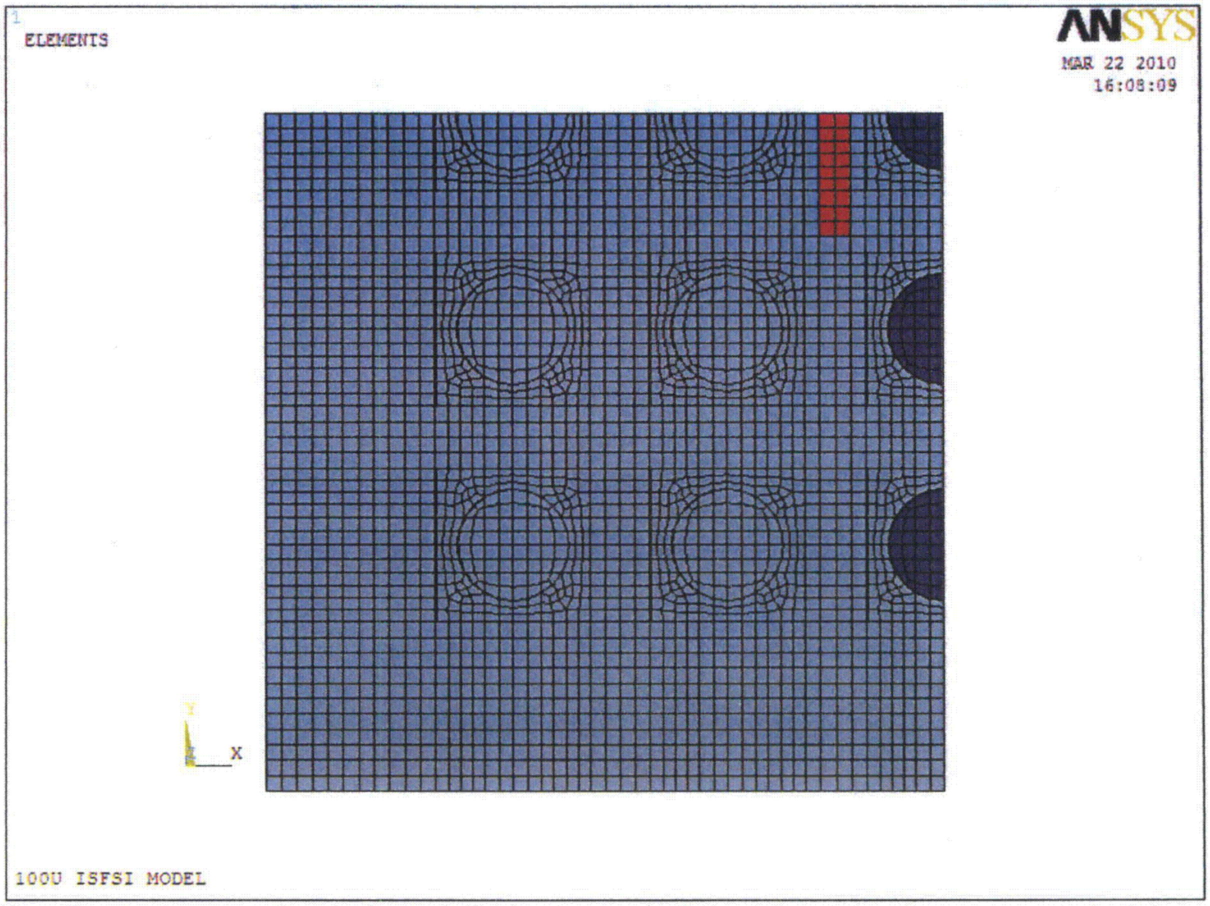


Figure 3.I.19; Normal Stress in the ISFSI in the Direction of the Transporter Path for Configuration IV – Load Combination LC-3 from Table 2.I.11



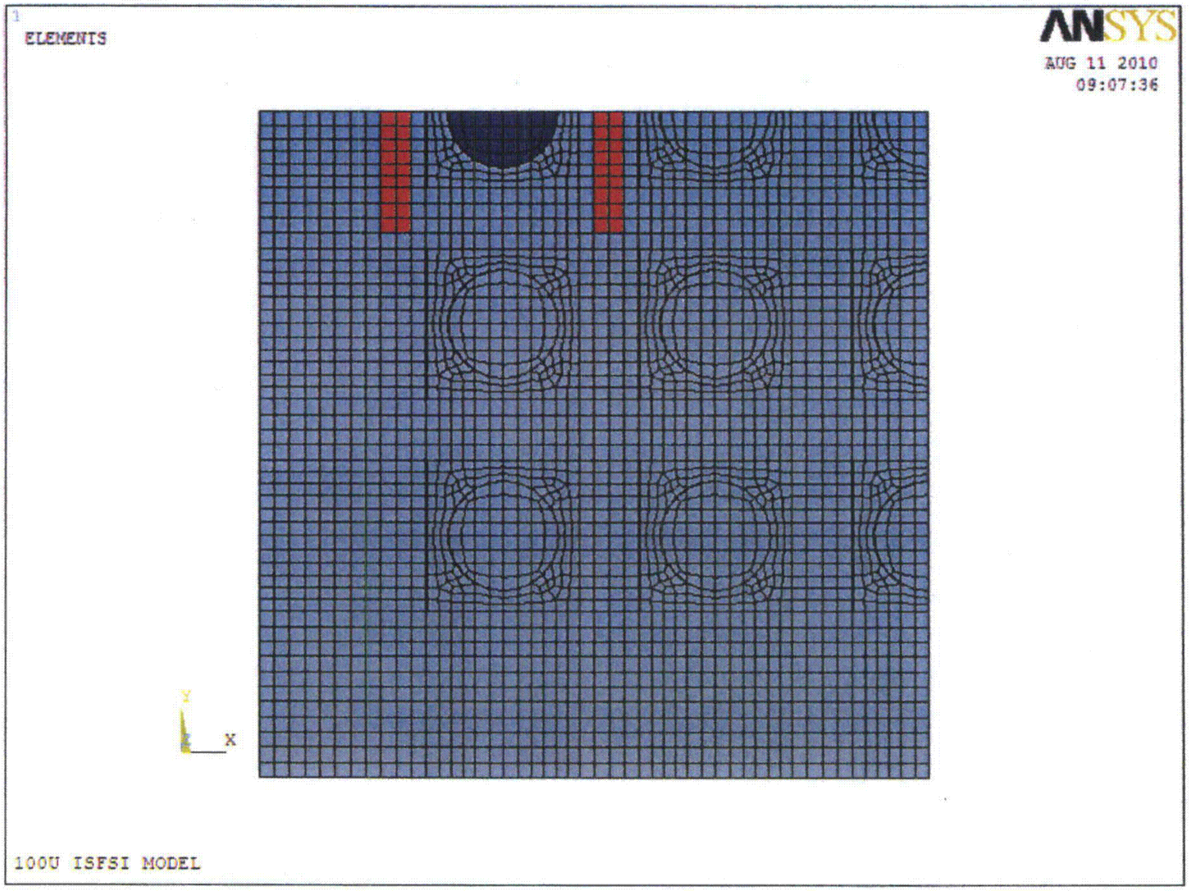
Note: The blue footprints show the loaded VVM locations on the SFP and the red footprint represents the loaded TSP area with the transporter.

Figure 3.I.20; ANSYS Finite Element of ISFSI Showing the Partially Loaded Configuration (Configuration II)



Note: The blue footprints show the loaded VVM locations on the SFP and the red footprint represents the loaded TSP area with the transporter.

Figure 3.I.21; ANSYS Finite Element of ISFSI Showing the Center Row Loading (Configuration III)



Note: The blue footprints show the loaded VVM locations on the SFP and the red footprint represents the loaded TSP area with the transporter.

Figure 3.I.22; ANSYS Finite Element of ISFSI Showing the Single VVM Loaded (Configuration IV)

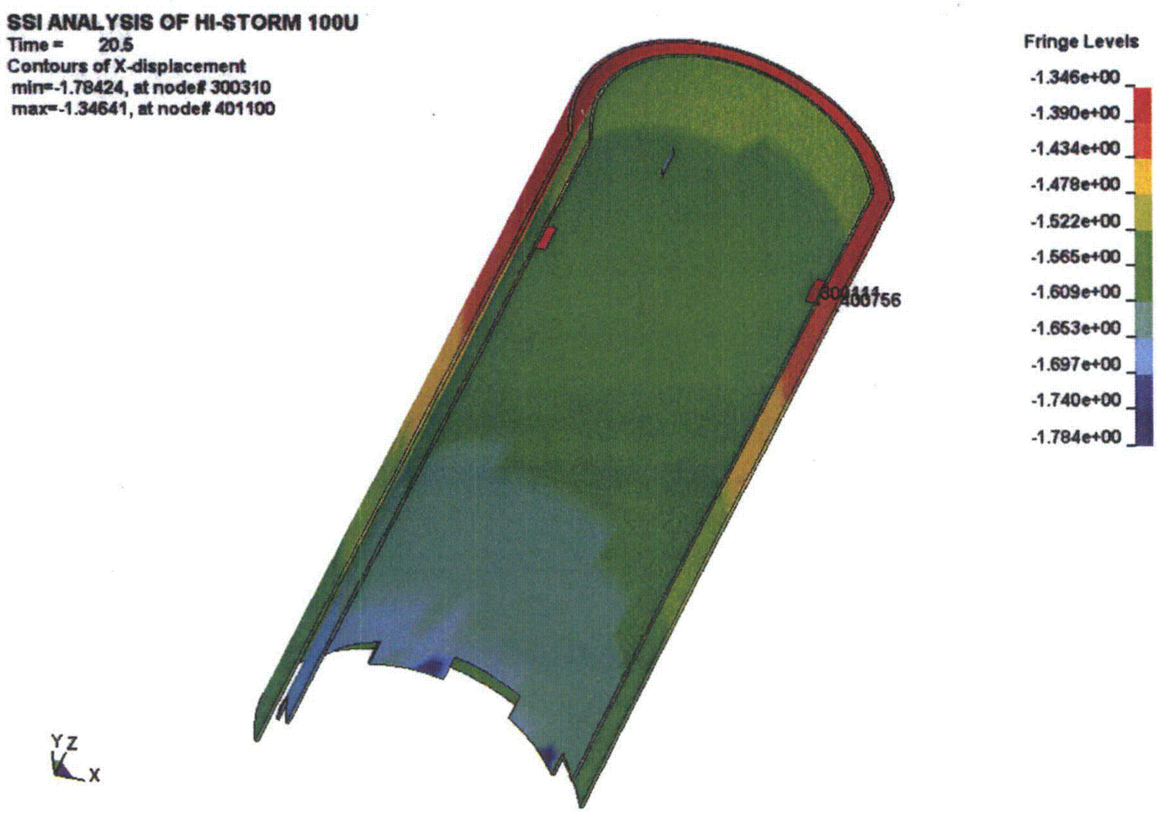


Figure 3.I.23-A; Divider and CEC Shell Displacement Distribution at the End of the Earthquake

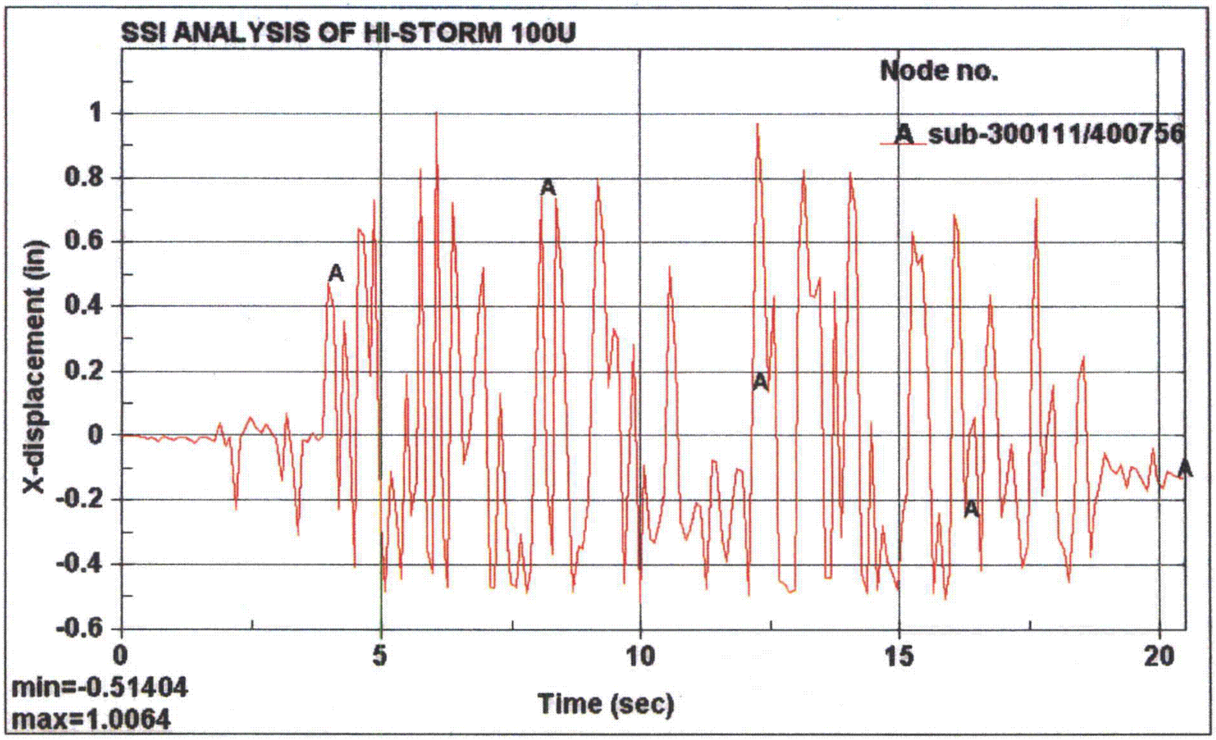


Figure 3.I.23-B; Changes of the Radial Gap between CEC Shell and Divider Shell Measured at the Top Guide Elevation
(Radial gap change at the end of earthquake = 0.1325 inches)

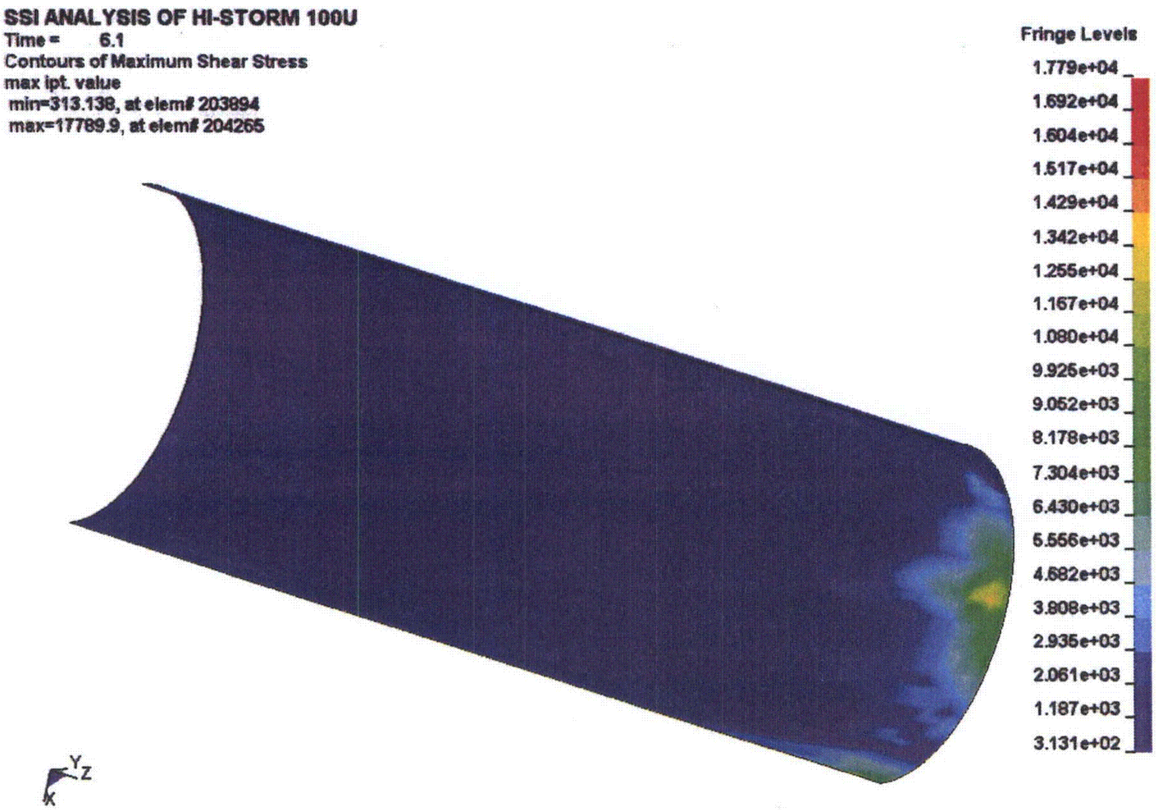


Figure 3.I.24; Maximum Shear Stress of the MPC Shell
(Maximum Primary Stress Intensity = 2×6,430 psi = 12,860 psi)

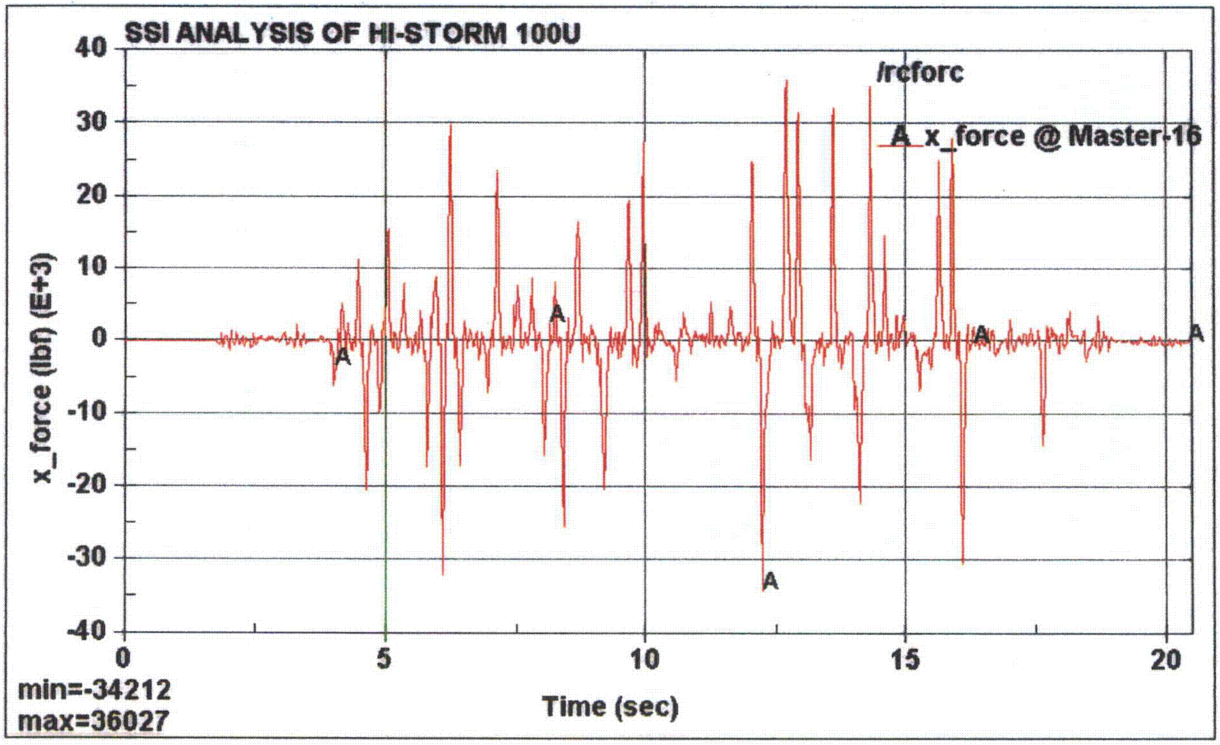


Figure 3.I.25-A; Impact Force between the MPC and MPC Top Guides
(Maximum Impact Force = 2×36,027 lb = 72,054 lb to account for half-symmetric model)

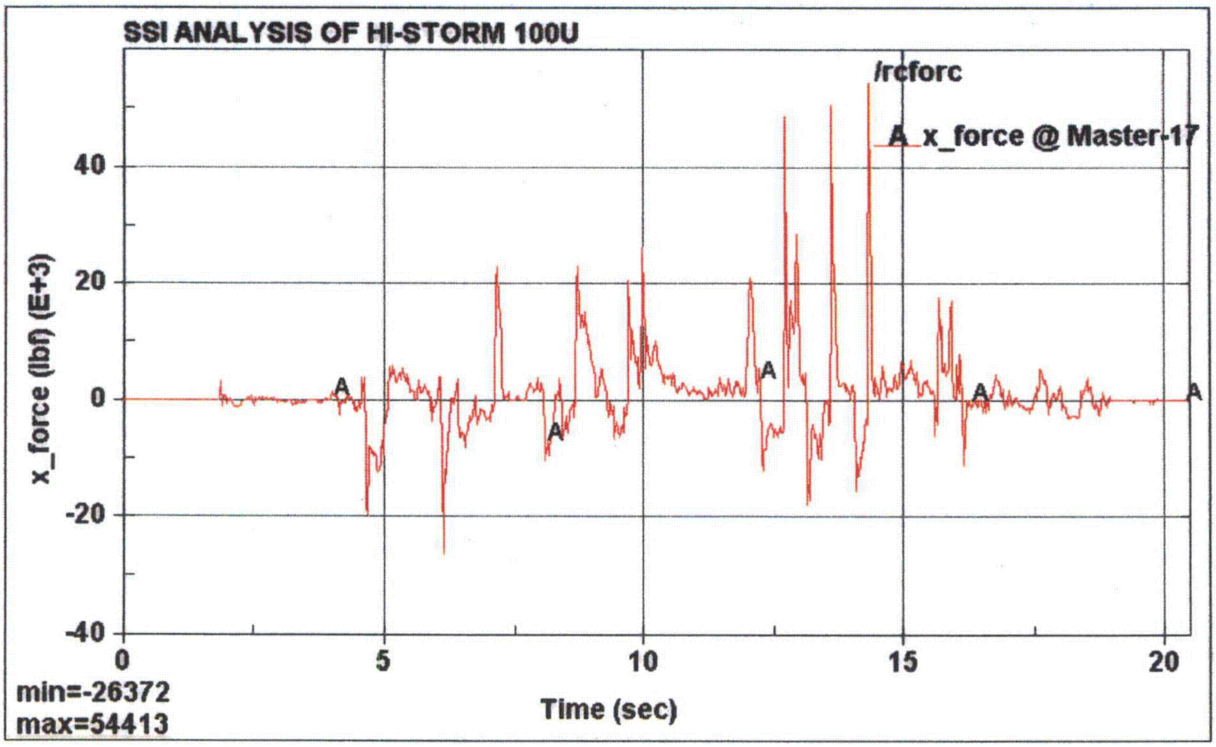


Figure 3.I.25-B; Impact Force between the MPC and MPC Bottom Guides
(Maximum Impact Force = 2×54,413 lb = 108,826 lb to account for half-symmetric model)

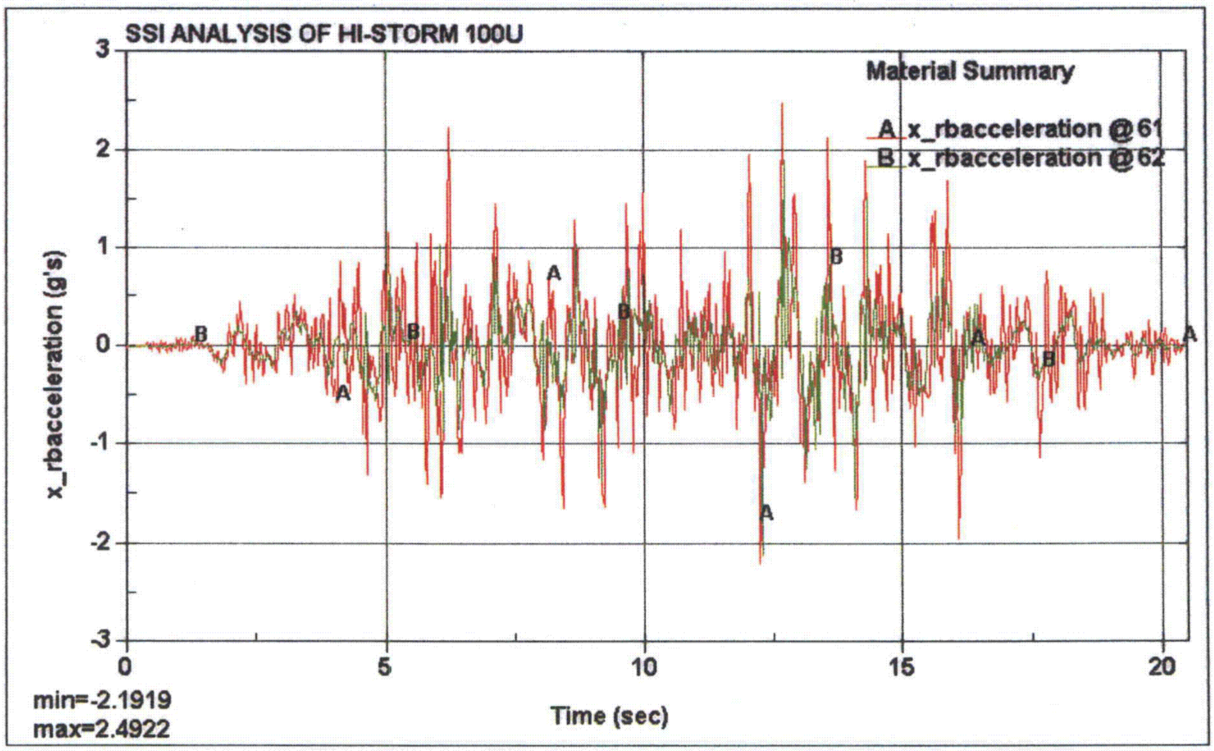


Figure 3.I.26; MPC Lid and Baseplate Lateral Acceleration Time Histories
(A - MPC Lid; B - MPC Baseplate)

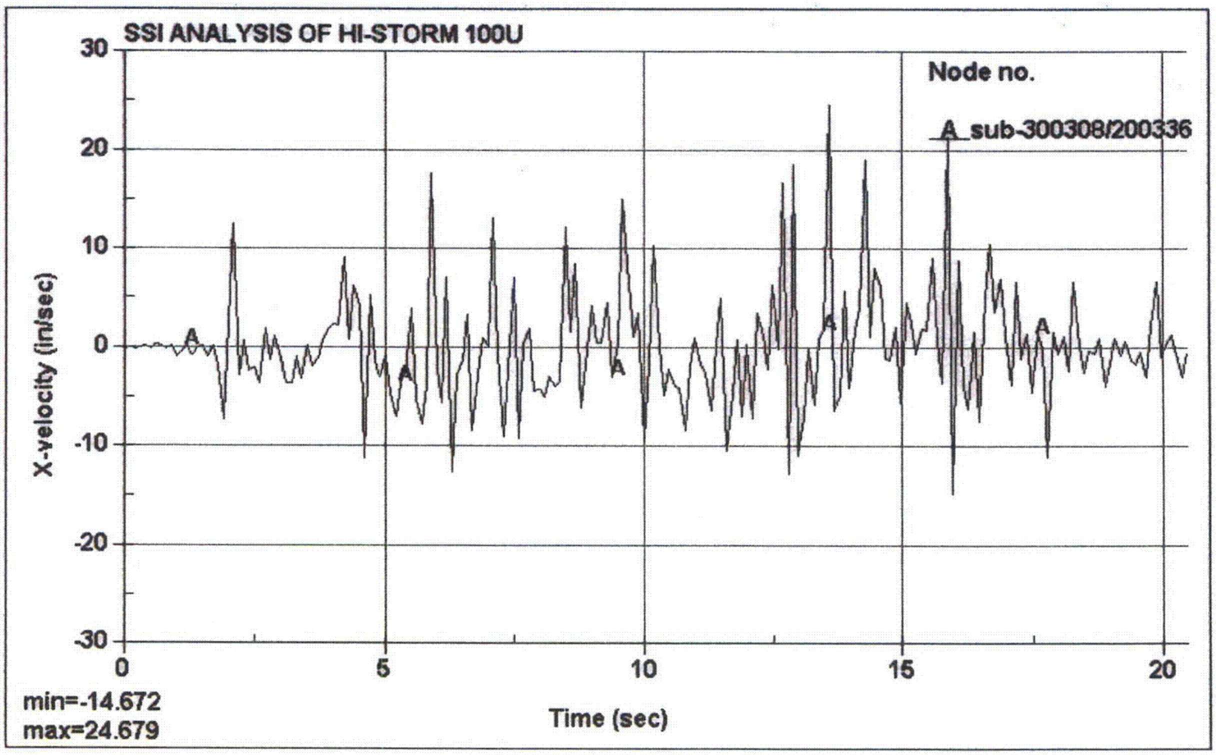


Figure 3.I.27; MPC Lid to MPC Top Guide Approaching Velocity Time History

4.5 THERMAL EVALUATION OF SHORT TERM OPERATIONS

Prior to placement in a HI-STORM overpack, an MPC must be loaded with fuel, sealed, drained, dried, backfilled with helium and transferred to the HI-STORM overpack. These steps must be performed in reverse when unloading the HI-STORM. The MPC can also be transferred between HI-STORM overpacks, if necessary, or to a HI-STAR transport overpack for transport off-site. All of the above operations are referred to as short term operations. These are short duration events that would likely happen at most twice for an individual MPC.

Short term operations occur when the loaded MPC is in the HI-TRAC transfer cask. The following discrete thermal scenarios, for short term events involving the HI-TRAC transfer cask, are analyzed in this section.

- (i) Post-Loading Wet Transfer Operations
- (ii) MPC Cavity Vacuum Drying
- (iii) Normal Onsite Transport in a Vertical Orientation
- (iv) MPC Cooldown and Reflood for Unloading Operations
- (v) HI-TRAC Fire Accident
- (vi) HI-TRAC Jacket Water Loss Accident

In this section scenarios (i) thru (iv) are addressed. Scenarios (v) and (vi) are addressed in subsection 4.6.2. Chapter 8 provides a description of the typical loading steps involved in moving nuclear fuel from the spent fuel pool to dry storage in the HI-STORM overpack. The transition from a wet to a dry environment must occur without exceeding the short-term operation temperature limits per ISG-11 Rev. 3 (see Table 4.3.1).

Movement of the MPC while in the HI-TRAC generally occurs in the vertical orientation, which preserves the thermosiphon action within the MPC. To avoid excessive temperatures, movement of the MPC with the HI-TRAC in the horizontal orientation is generally not permitted. However, it is recognized that an occasional downending of a HI-TRAC may become necessary to clear an obstruction such as a low fuel handling building door opening. In such a case the operational imperative for HI-TRAC downending must be ascertained and the permissible duration of horizontal configuration must be established on a site-specific basis and compliance with the thermal limits of ISG-11 [4.1.4] must be demonstrated as a part of the site-specific safety evaluation under 10CFR 72.212.

4.5.1 HI-TRAC Thermal Model

The HI-TRAC transfer cask is used to load and unload the HI-STORM concrete storage overpack, and may include onsite transport of the MPC from the loading facility to a cask transfer facility (CTF). Licensing drawings of the HI-TRAC are in Chapter 1. Within a loaded HI-TRAC, heat generated in the MPC is transported from the contained fuel assemblies to the MPC shell in the manner described in Section 4.4. From the outer surface of the MPC to the ambient air, heat is transported through the HI-TRAC overpack by a combination of conduction, thermal radiation and natural convection. For evaluation of the thermal state of a loaded canister during all short-term operations the three dimensional (3D) thermal model of the MPC described in Section 4.4 is utilized.

All FLUENT thermal analyses to establish margins of safety are carried out for the case of maximum Design Basis heat load and the MPC model that yields the highest peak cladding temperature under the long term storage condition. The above criterion identifies MPC-32 under regionalized fuel loading with X = 0.5 as the governing case.

Two HI-TRAC transfer cask designs, namely, the 125-ton and the 100-ton versions, are developed for onsite handling and transport, as discussed in Chapter 1. The two designs are principally different in terms of lead thickness and the thickness and number of the heat dissipating ribs (radial connectors) in the water jacket region. The aggregate heat dissipation by the ribs is defined by the product of the number of radial ribs, N and thickness, t_r. The analytical model developed for HI-TRAC thermal characterization conservatively accounts for these differences by applying the higher lead thickness and constructing the water jacket region having the lowest product of N and t_r. In this manner, the HI-TRAC thru-wall resistance to heat transfer is overestimated, yielding higher MPC internal and fuel cladding temperatures.

Transport of heat within HI-TRAC occurs through multiple concentric layers of air, steel and shielding materials. A small gap exists between the outer surface of the MPC and the inner surface of the HI-TRAC overpack. Heat is transported across this gap by the parallel mechanisms of conduction and thermal radiation. Assuming that the MPC is centered and does not contact the transfer cask walls conservatively minimizes heat transport across this gap. Heat is transported through the cylindrical wall of the HI-TRAC transfer cask by conduction through successive layers of steel, lead, and steel. A water jacket, which provides neutron shielding for the HI-TRAC transfer cask, surrounds the cylindrical steel wall. The water jacket is essentially an array of carbon steel radial ribs with welded, connecting enclosure plates. Heat is dissipated by conduction and natural convection in the water cavities and by conduction in the radial ribs. Heat is passively rejected to the ambient from the outer surface of the HI-TRAC transfer cask by natural convection and thermal radiation.

The HI-TRAC transfer cask thermal analysis is based on a 3D FLUENT model that incorporates several conservative features, namely:

i. A constant solar flux is assumed with maximum permissible heat load and asymptotic steady state conditions to yield the most adverse temperature field in the cask. A theoretically bounding solar absorbtivity of 1.0 is applied to all exposed surfaces.

ii. Air motion in the HI-TRAC annulus is conservatively neglected. The MPC is assumed to be concentrically aligned with the cask cavity and the annulus is filled with air. This scenario maximizes thermal resistance.

iii. Although the HI-TRAC transfer cask baseplate is in contact with supporting surfaces, for conservatism, an insulated boundary condition is applied to the HI-TRAC baseplate.

iv. The HI-TRAC transfer cask fluid columns in the water jacket and the open air volume above the MPC are conservatively assumed to remain in the laminar flow regime.

v. The HI-TRAC transfer cask/ MPC annular gap shrinks under heat up to operating temperatures. A conservatively postulated gap reduction is applied to the thermal model.

vi. Buoyancy driven motion of air above the MPC is included in the thermal model.

vii. Radiation heat transfer is simulated by the more robust Discrete Ordinates (DO) model deployed in the HI-STAR 180 (Docket 71-9325) and HI-STORM FW (72-1032) in lieu of the DTRM model.

The computational fluid dynamics model of the HI-TRAC transfer cask captures all essential details of the cask body including the radial ribs, lead, steel shells and the water jacket. Figures 4.5.1 show the discretization of the cask and its enclosed MPC for FLUENT implementation.

4.5.2 Time-to-Boil for a Water-Filled MPC

Fuel loading operations are conducted with the HI-TRAC transfer cask and its contents submerged in pool water. Under these conditions, the HI-TRAC transfer cask is essentially at the pool water temperature. When the HI-TRAC transfer cask and the loaded MPC under water-flooded conditions is removed from the pool and staged in an ambient air environment, the water, MPC, and HI-TRAC transfer cask metal absorb the decay heat emitted by the fuel assemblies. This results in a slow temperature rise of the HI-TRAC transfer cask with time, starting from an initial pool water temperature. The rate of temperature rise is limited by the thermal inertia of the HI-TRAC transfer cask.

The available time before the water in the MPC would reach boiling is computed under a conservative set of assumptions summarized below:

i. Heat loss by natural convection and radiation from the exposed HI-TRAC surfaces to ambient air is neglected (i.e., an adiabatic heat-up calculation is performed).

ii. The smaller of the two (i.e., 100-ton and 125-ton) HI-TRAC transfer cask metal mass is credited in the analysis. The 100-ton design has a significantly smaller quantity of metal mass, which will result in a higher rate of temperature rise.

iii. The water mass in the MPC cavity is understated.

Table 4.5.2 summarizes the lower bound weights and thermal inertias of the constituent components in the loaded HI-TRAC transfer cask. The rate of temperature rise of the HI-TRAC transfer cask and contents during an adiabatic heat-up is given by the ratio Q/C where:

Q = Coincident fuel decay heat in the canister
C = Thermal inertia of a loaded HI-TRAC (Btu/°F) (See Table 4.5.2)

Therefore, the time-to-boil, τ is given by the simple algebraic formula $\tau = C(212-T)/Q$ where 212°F has been set as the boiling temperature and T represents the temperature of the pool water under fuel loading operations. The time-to-boil clock starts when the HI-TRAC is no longer submerged in the pool water. Table 4.5.3 provides a summary of τ at several representative heat loads and initial pool water temperatures. The calculation of time-to-boil for a loaded canister shall be made using the above formula.

As set forth in the HI-STORM operating procedures, in the unlikely event that the maximum allowable time provided in Table 4.5.3 is found to be insufficient to complete wet transfer operations, a forced water circulation shall be initiated and maintained to remove the decay heat from the MPC cavity. In this case, relatively cooler water will enter via the MPC lid drain port connection and heated water will exit from the vent port. The minimum water flow rate required to maintain the MPC cavity water temperature below boiling with an adequate subcooling margin is determined as follows:

$$M_W = \frac{Q}{C_{pW}\,(T_{max} - T_{in})}$$

where:

M_W = minimum water flow rate (lb/hr)
C_{pw} = water heat capacity (Btu/lb-°F)
T_{max} = maximum MPC cavity water mass temperature (must be less than 212°F)
T_{in} = MPC water inlet temperature

For example, the MPC cavity water temperature limited to 150°F, MPC water inlet temperature at 125°F and design basis maximum heat load (36.9 kW), the water flow rate computes as 5038 lb/hr (10.1 gpm).

4.5.3 MPC Temperatures During Moisture Removal Operations

4.5.3.1 Vacuum Drying Operation

The initial loading of SNF in the MPC requires that the water within the MPC be drained, fuel dried and the water replaced with helium. Vacuum drying of fuel is conducted by evacuating the MPC after completion of MPC draining operation. For MPCs containing Moderate Burnup Fuel (MBF) assemblies only, this operation may be carried out using the vacuum drying method up to the threshold heat loads defined in Table 4.5.1. In this Table threshold heat loads Q1 and Q2 are defined wherein Q1 is the threshold heat load for vacuum drying operations without time limits and Q2 is the threshold heat load for time-limited vacuum drying.

Vacuum drying of MPCs containing High Burnup Fuel (HBF) is not permitted. High burnup fuel drying must be conducted by using a forced helium drying (FHD) process as discussed in Section 4.5.3.2. To minimize fuel temperatures during vacuum drying operations the HI-TRAC annulus must be water filled.

A 3-D FLUENT thermal model of the MPC is constructed in the same manner as described in Section 4.4. The principal input to this model is the effective conductivity of fuel under vacuum drying operations. To reasonably bound vacuum drying operations the effective conductivity of fuel is computed assuming the MPC is filled with water vapor at a very low pressure (1 torr) for the entire duration of vacuum drying[1]. The methodology for computing the effective conductivity is given in Section 4.4.1. To ensure a conservative evaluation the thermal model is incorporated with the following assumptions:

i. Threshold heat load Q1, defined in Table 4.5.1, is assumed and steady-state condition reached under Q1 results in vacuum drying without time limits.
ii. Threshold heat load Q2, defined in Table 4.5.1, is assumed and a transient calculation is performed to determine the permissible vacuum drying time under Q2. The transient calculation is started assuming the MPC has reached 212°F boiling temperature in the operational step preceding vacuum drying (i.e. water blow down operations). The vacuum drying clock starts when the MPC is drained.
iii. The external surface of the MPC shell is postulated to vary linearly from 100°C (212°F) normal boiling temperature of water at the top to 111°C (231°F) elevated pressure boiling temperature at the bottom to account for the hydrostatic head.
iv. The bottom surface of the MPC is insulated.
v. MPC internal convection heat transfer is suppressed.

1 This is very conservative as the MPC pressure is progressively lowered below ambient pressure to facilitate moisture removal. Near the end of the vacuum drying operation the pressure is substantially lowered to approximately 1 torr to facilitate the 30-minute 3-torr vacuum rebound test followed by backfilling of the MPC with helium.

vi. Top surface of the MPC is in communicative contact with air. Natural convection and radiation cooling from the MPC top is included in the thermal model.

The principle objective of the vacuum drying analysis is to ensure that fuel temperatures are below ISG-11, Rev. 3 temperature limits (See Table 4.3.1). Under threshold heat load Q1 the results and margins are tabulated in Table 4.5.5. Under the time limited threshold heat load Q2 the peak cladding temperature plot is shown in Figure 4.5.2. The results under the scenarios Q1 and Q2 (with appropriate time limit) show that ISG-11, Rev. 3 limits are met with ample margins.

4.5.3.2 Forced Helium Dehydration (FHD)

A forced helium dehydration (FHD) system, which is a closed loop dehumidification system consisting of a condenser, a demoisturizer, a compressor, and a pre-heater is utilized to extract moisture from the MPC cavity through repeated displacement of its contained helium, accompanied by vigorous turbulent flow. A vapor pressure of 3 torr or less is assured by verifying that the helium temperature exiting the demoisturizer is maintained at or below the threshold of 21°F for a minimum of 30 minutes. See Appendix 2.B for detailed discussion of the design criteria and operation of an FHD system.

The FHD system provides concurrent fuel cooling during the moisture removal process through forced convective heat transfer. The attendant forced convection-aided heat transfer occurring during operation of the FHD system ensures that the fuel cladding temperature will remain below the applicable peak cladding temperature limit for normal conditions of storage, which is well below the high burnup cladding temperature limit 752°F (400°C) for all combinations of SNF type, burnup, decay heat, and cooling time. Because the FHD operation induces a state of forced convection heat transfer in the MPC, (in contrast to the quiescent mode of natural convection in long term storage), it is readily concluded that the peak fuel cladding temperature under the latter condition will be greater than that during the FHD operation phase. In the event that the FHD system malfunctions, the forced convection state will transition to natural convection, which corresponds to the conditions of normal onsite transport. As a result, the peak fuel cladding temperatures will approximate the values reached during normal onsite transport as described in subsection 4.5.4.

4.5.4 Maximum Temperatures Under Onsite Transport Conditions

A 3-D FLUENT thermal model of an MPC inside a HI-TRAC transfer cask was constructed as described in Subsection 4.5.1 to evaluate temperature distributions under onsite transport. In the onsite transportmode the annular region between the canister and the cask has air and the cask is subject to heat input from insolation. The heat generation rate in the MPC is assumed to be at its maximum permissible under regionalized storage (Q = 36.9 kW, X = 0.5, MPC-32) and the ambient temperature is assumed to correspond to the maximum ambient temperature specified in Table 2.2.2 under short term operations. Even though the duration of onsite transport is typically short enough to preclude the MPC and HI-TRAC from reaching steady-state, a steady-state thermal analysis is conservatively performed. The results summarized herein are when steady state conditions have been reached.

The safety analysis of the onsite transport scenario requires the computation of the margins of safety with respect to the peak fuel cladding temperature of moderate and high burnup fuel[2], MPC internal pressure, fuel basket metal temperature, hydraulic pressure in the water jacket and the temperature of the HI-TRAC body parts.

The water in the water jacket surrounding the HI-TRAC transfer cask body provides necessary neutron shielding. During normal handling and onsite transport operations this shielding water is contained within the water jacket at an elevated pressure. The water jacket is equipped with two pressure relief devices to prevent overpressure. The computed fuel temperatures in this scenario remain below the respective cladding temperature limits of moderate and high burnup fuel (Table 4.3.1). As these are bounding steady state temperatures, the results support onsite transport of fuel in the HI-TRAC without the aid of any supplemental cooling for all combinations of fuel burnup and cooling times up to the maximum design heat load of the HI-STORM System. The MPC internal pressure, fuel basket and the HI-TRAC parts temperatures presented in Table 4.5.4 and their corresponding allowable limits show positive margins of safety.

4.5.5 Cask Cooldown and Reflood Analysis During Fuel Unloading Operation

NUREG-1536 requires an evaluation of cask cooldown and reflood procedures to support fuel unloading from a dry condition. Past industry experience generally supports cooldown of cask internals and fuel from hot storage conditions by direct water quenching. Direct MPC cooldown is effectuated by introducing water through the lid drain line. From the drain line, water enters the MPC cavity near the MPC baseplate. Steam produced during the direct quenching process will be vented from the MPC cavity through the lid vent port. To maximize venting capacity, both vent port RVOA connections must remain open for the duration of the fuel unloading operations. As direct water quenching of hot fuel results in steam generation, it is necessary to limit the rate of water addition to avoid MPC overpressurization. For example, steam flow calculations using bounding assumptions (100% steam production and MPC at design pressure) show that the MPC is adequately protected under a reflood rate of 3715 lb/hr; limiting the water reflood rate to this amount or less would prevent exceeding the MPC design pressure.

During direct reflood operations the fuel cladding is subject to high temperature gradients and concomitant thermal stresses. The integrity of fuel under direct quenching is evaluated in a generic manner in the HI-STORM FW SAR (Docket No. 72-1032, Ref. [4.5.2]). To define a bounding scenario at time t = 0 sec, a uniformly bounding temperature throughout the entire fuel rod is set at 752°F (400°C), which is the temperature limit of fuel cladding. At time t = 0.1 sec, a reasonably bounding 80°F quench water temperature is assigned to the lower half of the fuel rod to simulate a thermal shock with a large step change in the cladding temperature. The resulting transient stress and

2 The cladding temperature limit for the high burn up fuel is more restrictive (See Table 4.3.1).

strain distributions in the fuel rod are evaluated with finite element ANSYS models. The results show that the maximum stress and strain values remain within the elastic range and remain well within failure strain limit (a factor of 6 against failure strain). This safety analysis documented in the HI-STORM FW FSAR provides the assurance that the MPC reflood event will not cause a breach of fuel cladding.

4.5.6 Maximum Internal Pressure

After fuel loading and vacuum drying, but prior to installing the MPC closure ring, the MPC is initially filled with helium. During handling and on-site transport operations in the HI-TRAC transfer cask, the gas temperature within the MPC rises to its maximum operating temperature as determined by on the thermal analysis methodology described previously. In Table 4.5.4, the MPC internal pressure co-incident with the MPC temperature is reported and compared with the short term (off-normal) pressure limit specified in Table 2.2.1 to show compliance with design limit.

4.5.7 Safety Evaluation of HI-TRAC Under Short-Term Operations

Analyses reported in the preceding subsections show that the peak fuel cladding temperature of moderate and high burnup fuel during short-term operations meet the ISG-11 Rev. 3 limits (see Table 4.3.1). The coincident MPC internal pressure is also computed and reported in Table 4.5.4.which shows that the computed pressure is below the MPC short-term condition design pressure (Table 2.2.1).

Further, under normal handling and onsite transport operations, the bulk temperature inside the water jacket reported in Table 4.5.4 is less than the coincident saturation temperature of the jacket water at the set pressure of the pressure relief devices (307°F), so the shielding water in the water jacket will not boil.

During vacuum drying operations (see paragraph 4.5.3.1), the annular gap between the MPC and the HI-TRAC is required to be filled with water. The boiling temperature of annulus water bounds the maximum temperatures of all HI-TRAC components, which are located radially outside the water-filled annulus. The maximum annulus water temperature remains well below the saturation temperature of jacket water (307°F). In accordance with the limits placed in paragraph 4.5.3.1 vacuum drying of high burnup fuel is not permitted. Vacuum drying of moderate burn-up fuel is evaluated in Table 4.5.5. The results show that under vacuum drying operations the fuel temperatures remain within ISG-11, Rev. 3 limits. In closing, the analyses and evaluations in Section 4.5 show that HI-TRAC transfer cask thermal design is adequate to satisfy all safety limits under short-term operations.

Table 4.5.1

THRESHOLD HEAT LOADS FOR MOISTURE REMOVAL OPERATIONS

Drying Method	Fuel Burnup	Threshold Heat Load[Note 1]	Time Limits
Vacuum Drying	MBF	Q1	None
Vacuum Drying	MBF	MPC Heat Load > Q1 and ≤ Q2	Yes (40 hrs)
FHD	MBF and/or HBF	36.9 kW	None
Note 1: Threshold heat loads are defined below: Q1 = 26 kW Q2 = 30 kW			

Table 4.5.2

HI-TRAC TRANSFER CASK WEIGHTS AND THERMAL INERTIA DATA

Component	Weight (lbs)	Heat Capacity (Btu/lb-°F)	Thermal Inertia (Btu/°F)
Water Jacket	7,000	1.0	7,000
Lead	52,000	0.031	1,612
Carbon Steel	40,000	0.1	4,000
Alloy-X MPC (empty)	39,000	0.12	4,680
Fuel	40,000	0.056	2,240
MPC Cavity Water*	6,500	1.0	6,500
			26,032 (Total)
* Water mass conservatively understated.			

Table 4.5.3

TIME-TO-BOIL FOR WATER IN THE MPC CAVITY

Initial Temperature (°F)	Time (hrs) @ Q = 36.9 kw	Time (hrs) @ Q = 30 kw	Time (hrs) @ Q = 25 kw	Time (hrs) @ Q = 20 kw
80	27.3	33.6	40.3	50.4
90	25.2	31.0	37.2	46.5
100	23.2	28.5	34.2	42.7
110	21.1	25.9	31.1	38.9
120	19.0	23.4	28.1	35.1
125	18.0	22.1	26.5	33.2

Table 4.5.4

HI-TRAC ONSITE TRANSFER- TEMPERATURE AND PRESSURE MARGINS

	Maximum Temperatures (°F)		
Component	Computed	Permissible Limit[Note 1]	Margin
Fuel Cladding	711	752	41
MPC Basket	707	950	243
Basket Peripheral Panels	595	950	355
MPC Shell	468	775	307
HI-TRAC Inner Shell	336	800	464
Radial Lead	279	600	321
HI-TRAC Water Jacket Shell	253	800	547
Water Jacket Bulk Water	248	307	59
Axial Neutron Shield[Note2]	291	350	59
Pressure (psi)			
MPC[Note 3]	101.7	110	8.3

Note 1: Temperatures and Pressure limits under HI-TRAC short-term operation are specified in Tables 2.2.1 and 2.2.3.
Note 2: Maximum section average temperature.
Note 3: The MPC pressure is computed under the maximum backfill pressure specified in Table 4.4.12.

Table 4.5.5

MAXIMUM FUEL TEMPERATURES UNDER VACUUM DRYING OPERATIONS

Threshold Heat Load[Note 1]	Time Limit	Temperature (°F)	Temperature Limit[Note 2]	Margin (°F)
Q1	None	1025	1058	33
Q2	40 hrs	1020	1058	38

Notes:
1) Threshold heat loads defined in Table 4.5.1.
2) Temperature limit of moderate burnup fuel shown. Vacuum drying of high burn-up fuel is not permitted (See Subsection 4.5.3).

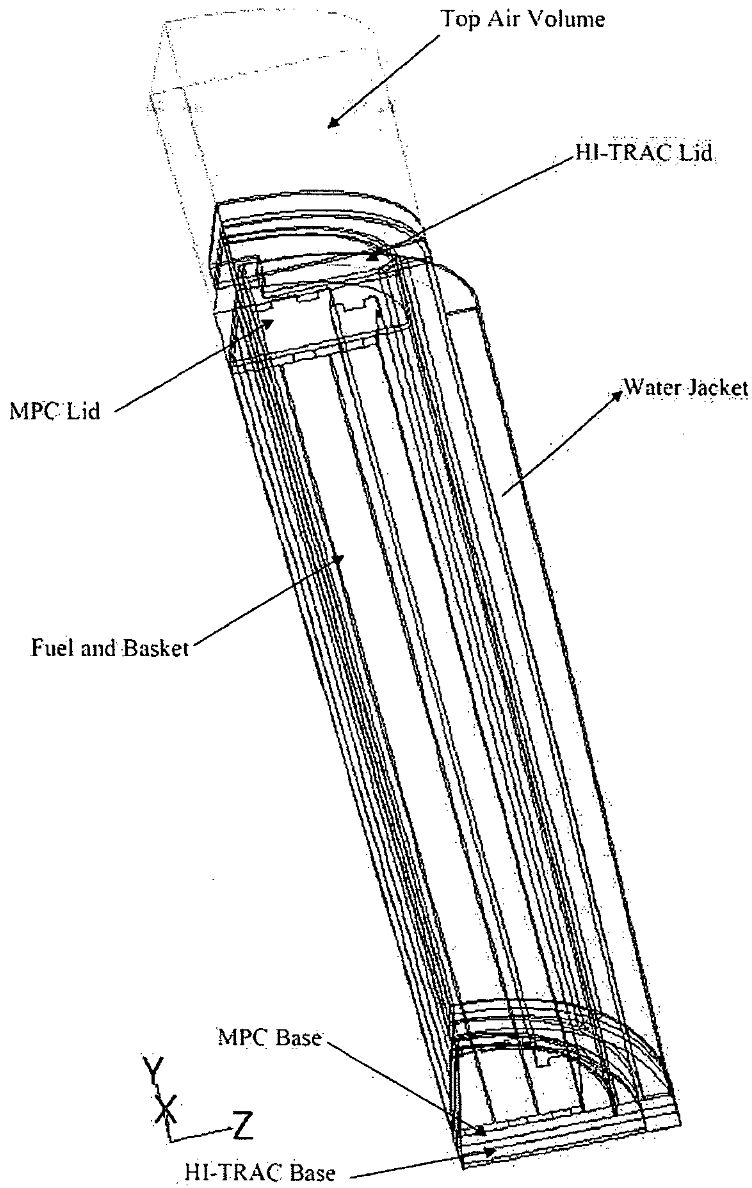


Figure 4.5.1: 3D QUARTER SYMMETRIC THERMAL MODEL OF THE HI-TRAC TRANSFER CASK

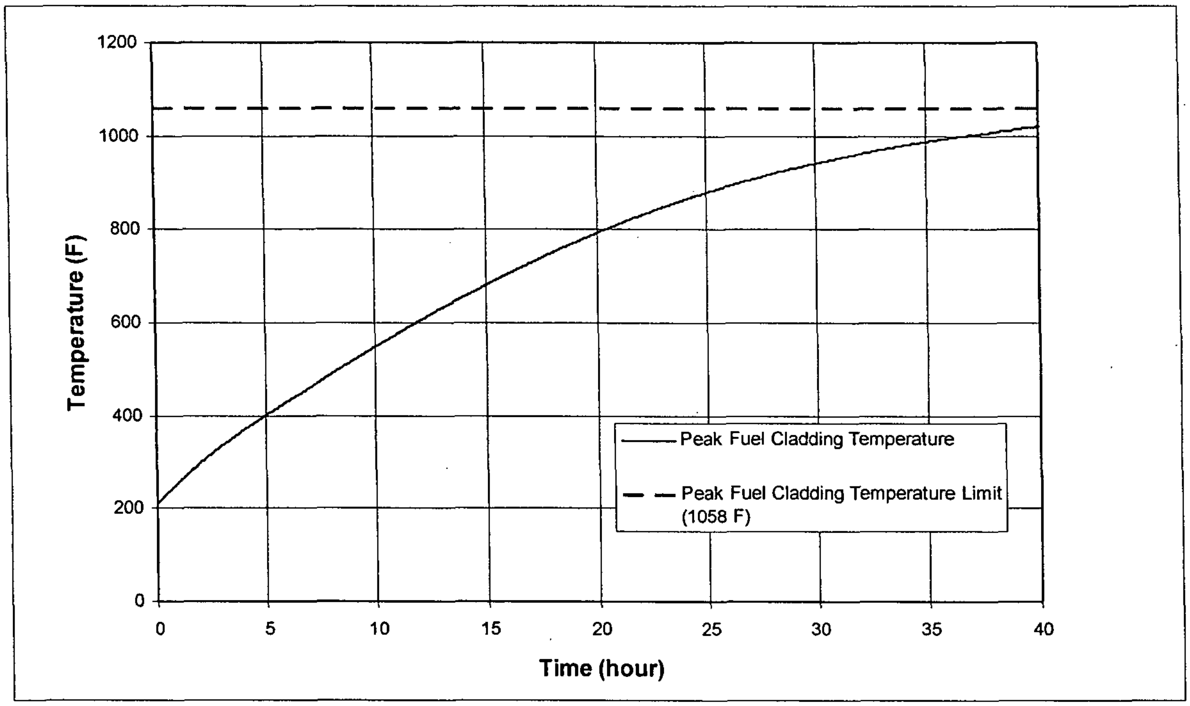


Figure 5.4.2: PEAK CLADDING TEMPERATURE CURVE UNDER VACUUM DRYING OPERATIONS AT THRESHOLD HEAT LOAD Q2

4.6 OFF-NORMAL AND ACCIDENT EVENTS[1]

In accordance with NUREG 1536 the HI-STORM 100 System is evaluated for the effects of off-normal and accident events. The design basis off-normal and accident events are defined in Chapter 2. For each event, the cause of the event, means of detection, consequences, and corrective actions are discussed and evaluated in Chapter 11. To support the Chapter 11 evaluations, thermal analyses of limiting off-normal and accident events are provided in the following.

To ensure a bounding evaluation for the array of fuel storage configurations permitted in Section 2.1, a limiting storage condition is evaluated in this section. The limiting storage condition is previously determined in the Section 4.5 and adopted herein for all off-normal and accident evaluations.

4.6.1 Off-Normal Events

4.6.1.1 Off-Normal Pressure

This event is defined as a combination of (a) maximum helium backfill pressure (Table 4.4.12), (b) 10% fuel rods rupture, and (c) limiting fuel storage configuration. The principal objective of the analysis is to demonstrate that the MPC off-normal design pressure (Table 2.2.1) is not exceeded. The MPC off-normal pressures are reported in Table 4.4.9. The result[2] is confirmed to be below the off-normal design pressure (Table 2.2.1).

4.6.1.2 Off-Normal Environmental Temperature

This event is defined by a time averaged ambient temperature of 100°F for a 3-day period (Table 2.2.2). The results of this event (maximum temperatures and pressures) are provided in Table 4.6.1 and 4.6.2. The results are below the off-normal condition temperature and pressure limits (Tables 2.2.1 and 2.2.3).

4.6.1.3 Partial Blockage of Air Inlets

The HI-STORM 100 System is designed with debris screens installed on the inlet and outlet openings. These screens ensure the air passages are protected from entry and blockage by foreign objects. As required by the design criteria presented in Chapter 2, it is postulated that the HI-STORM air inlet vents are 50% blocked . The resulting decrease in flow area increases the flow resistance of the inlet ducts. The effect of the increased flow resistance on fuel temperature is analyzed for the normal ambient temperature (Table 2.2.2) and a limiting fuel storage configuration. The computed temperatures are reported in Table 4.6.1 and the corresponding MPC internal pressure in Table 4.6.2. The results are confirmed to be below the temperature limits (Table 2.2.3) and pressure limit (Table 2.2.1) for off-normal conditions.

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1 A new standalone Section 4.6 is added in CoC Amendment 3 to address thermal analysis of off-normal and accident events. The results are evaluated in Chapter 11.

2 Pressures relative to 1 atm absolute pressure (i.e. gauge pressures) are reported throughout this section.

4.6.2 Accident Events

4.6.2.1 Fire Accidents

Although the probability of a fire accident affecting a HI-STORM 100 System during storage operations is low due to the lack of combustible materials at an ISFSI, a conservative fire event has been assumed and analyzed. The only credible concern is a fire from an on-site transport vehicle fuel tank. Under a postulated fuel tank fire, the outer layers of HI-TRAC or HI-STORM overpacks are heated for the duration of fire by the incident thermal radiation and forced convection heat fluxes. The amount of fuel in the on-site transporter is limited to a volume of 50 gallons.

(a) HI-STORM Fire

The fuel tank fire is conservatively assumed to surround the HI-STORM Overpack. Accordingly, all exposed overpack surfaces are heated by radiation and convection heat transfer from the fire. Based on NUREG-1536 and 10 CFR 71 guidelines [4.6.1], the following fire parameters are assumed:

1. The average emissivity coefficient must be at least 0.9. During the entire duration of the fire, the painted outer surfaces of the overpack are assumed to remain intact, with an emissivity of 0.85. It is conservative to assume that the flame emissivity is 1.0, the limiting maximum value corresponding to a perfect blackbody emitter. With a flame emissivity conservatively assumed to be 1.0 and a painted surface emissivity of 0.85, the effective emissivity coefficient is 0.85. Because the minimum required value of 0.9 is greater than the actual value of 0.85, use of an average emissivity coefficient of 0.9 is conservative.

2. The average flame temperature must be at least 1475°F (800°C). Open pool fires typically involve the entrainment of large amounts of air, resulting in lower average flame temperatures. Additionally, the same temperature is applied to all exposed cask surfaces, which is very conservative considering the size of the HI-STORM cask. It is therefore conservative to use the 1475°F (800°C) temperature.

3. The fuel source must extend horizontally at least 1 m (40 in), but may not extend more than 3 m (10 ft), beyond the external surface of the cask. Use of the minimum ring width of 1 meter yields a deeper pool for a fixed quantity of combustible fuel, thereby conservatively maximizing the fire duration.

4. The convection coefficient must be that value which may be demonstrated to exist if the cask were exposed to the fire specified. Based upon results of large pool fire thermal measurements [4.6.2], a conservative forced convection heat transfer coefficient of 4.5 Btu/(hr×ft^2×°F) is applied to exposed overpack surfaces during the short-duration fire.

Based on the 50 gallon fuel volume, the overpack outer diameter and the 1 m fuel ring width [4.6.1], the fuel ring surrounding the overpack covers 147.6 ft^2 and has a depth of 0.54 in. From this depth and a constant fuel consumption rate of 0.15 in/min, the fire duration is calculated to be 3.62 minutes. The fuel consumption rate of 0.15 in/min is a lowerbound value from a Sandia National Laboratories report [4.6.2]. Use of a lowerbound fuel consumption rate conservatively maximizes the duration of the fire.

To evaluate the impact of fire heating of the HI-STORM overpack, a thermal model of the overpack cylinder was constructed using the ANSYS computer code. The initial temperature of the overpack was conservatively assumed to be the maximum temperature field during storage (Table 4.4.7).. In this model the outer surface and top surface of the overpack were subjected for the duration of fire (3.62 minutes) to the fire conditions defined in this subsection. In the post-fire phase, the ambient conditions preceding the fire were restored. The transient study was conducted for a period of 5 hours, which is sufficient to allow temperatures in the overpack to reach their maximum values and begin to recede.

Due to the severity of the fire condition radiative heat flux, heat flux from incident solar radiation is negligible and is not included. Furthermore, the smoke plume from the fire would block most of the solar radiation. It is recognized that the ventilation air in contact with the inner surface of the HI-STORM Overpack with design-basis decay heat and normal ambient temperature conditions varies between 80°F at the bottom and 220°F at the top of the overpack. It is further recognized that the inlet and outlet ducts occupy a miniscule fraction of area of the cylindrical surface of the massive HI-STORM Overpack. Due to the short duration of the fire event and the relative isolation of the ventilation passages from the outside environment, the ventilation air is expected to experience little intrusion of the fire combustion products. As a result of these considerations, it is conservative to assume that the air in the HI-STORM Overpack ventilation passages is held constant at a substantially elevated temperature (300°F) during the entire duration of the fire event.

The thermal transient response of the storage overpack is determined using the ANSYS finite element program. Time-histories for points in the storage overpack are monitored for the duration of the fire and the subsequent post-fire equilibrium phase.

Heat input to the HI-STORM Overpack while it is subjected to the fire is from a combination of an incident radiation and convective heat fluxes to all external surfaces. This can be expressed by the following equation:

$$q_F = h_{fc}(T_A - T_S) + \sigma\varepsilon[(T_A + C)^4 - (T_S + C)^4]$$

where:

q_F =Surface Heat Input Flux (Btu/ft^2-hr)
h_{fc} = Forced Convection Heat Transfer Coefficient (4.5 Btu/ft^2-hr-°F)
σ = Stefan-Boltzmann Constant
T_A = Fire Temperature (1475°F)
C= Conversion Constant (460 (°F to °R))
T_S = Surface Temperature (°F)

ε = Average Emissivity (0.90 per 10 CFR 71.73)

The forced convection heat transfer coefficient is based on the results of large pool fire thermal measurements [4.6.2].

After the fire event, the ambient temperature is restored and the storage overpack cools down (post-fire temperature relaxation). Heat loss from the outer surfaces of the storage overpack is determined by the following equation:

$$q_S = h_S (T_S - T_A) + \sigma\varepsilon [(T_S + C)^4 - (T_A + C)^4]$$

where:

q_S =Surface Heat Loss Flux (W/m^2 (Btu/ft^2-hr))
h_S = Natural Convection Heat Transfer Coefficient (Btu/ft^2-hr-^{o}F)
T_S = Surface Temperature (^{o}F))
T_A = Ambient Temperature (^{o}F)
σ = Stefan-Boltzmann Constant
ε = Surface Emissivity
C= Conversion Constant (460 (^{o}F to ^{o}R))

In the post-fire temperature relaxation phase, h_s is obtained using literature correlations for natural convection heat transfer from heated surfaces [4.2.9].

During the fire the overpack external shell temperatures are substantially elevated (~550^{o}F) and an outer layer of concrete approximately 1 inch thick reaches temperatures in excess of short term temperature limit. This condition is addressed specifically in NUREG-1536 (4.0,V,5.b), which states that:

> "The NRC accepts that concrete temperatures may exceed the temperature criteria of ACI 349 for accidents if the temperatures result from a fire."

These results demonstrate that the fire accident event analyzed in a most conservative manner is determined to have a minor affect on the HI-STORM Overpack. Localized regions of concrete are exposed to temperatures in excess of accident temperature limit. The bulk of concrete remains below the short term temperature limit. The temperatures of steel structures are within the allowable temperature limits.

Having evaluated the effects of the fire on the overpack, we now evaluate the effects on the MPC and contained fuel assemblies. Guidance for the evaluation of the MPC and its internals during a fire event is provided by NUREG-1536 (4.0,V,5.b), which states:

> "For a fire of very short duration (i.e., less than 10 percent of the thermal time constant of the cask body), the NRC finds it acceptable to calculate the fuel temperature increase by assuming that the cask inner wall is adiabatic. The fuel

temperature increase should then be determined by dividing the decay energy released during the fire by the thermal capacity of the basket-fuel assembly combination."

The time constant of the cask body (i.e., the overpack) can be determined using the formula:

$$\tau = \frac{c_p \times \rho \times L_c^2}{k}$$

where:

c_p = Overpack Specific Heat Capacity (Btu/lb-°F)
ρ = Overpack Density (lb/ft^3)
L_c = Overpack Characteristic Length (ft)
k = Overpack Thermal Conductivity (Btu/ft-hr-°F)

The concrete contributes the majority of the overpack mass and volume, so we will use the specific heat capacity (0.156 Btu/lb-°F), density (142 lb/ft^3) and thermal conductivity (1.05 Btu/ft-hr-°F) of concrete for the time constant calculation. The characteristic length of a hollow cylinder is its wall thickness. The characteristic length for the HI-STORM Overpack is therefore 29.5 in, or approximately 2.46 ft. Substituting into the equation, the overpack time constant is determined as:

$$\tau = \frac{0.156 \times 142 \times 2.46^2}{1.05} = 128\, hrs$$

One-tenth of this time constant is approximately 12.8 hours (768 minutes), substantially longer than the fire duration of 3.62 minutes, so the MPC is evaluated by considering the MPC canister as an adiabatic boundary. The fuel temperature rise is computed next.

Table 4.5.2 lists lower-bound thermal inertia values for the MPC and the contained fuel assemblies. Applying a conservative upperbound decay heat load (38 kW (1.3x10^5 Btu/hr)) and adiabatic heating for the 3.62 minutes fire, the fuel temperature rise computes as:

$$\Delta T_{fuel} = \frac{\text{Decay heat} \times \text{Time duration}}{\text{(MPC + Fuel) heat capacities}} = \frac{1.3 \times 10^5 \text{ Btu/hr} \times (3.62/60) hr}{(2240 + 4680) \text{ Btu/}^\circ F} = 1.1^\circ F$$

This is a very small increase in fuel temperature. Consequently, the impact on the MPC internal helium pressure will be quite small. Based on a conservative analysis of the HI-STORM 100 System response to a hypothetical fire event, it is concluded that the fire event does not adversely affect the temperature of the MPC or contained fuel. We conclude that the ability of the HI-STORM 100 System to cool the spent nuclear fuel within design temperature limits during and after fire is not compromised.

(b) HI-TRAC Fire

During the handling of the HI-TRAC transfer cask, the transporter fuel tank capacity must be limited to a 50 gallons. The duration of the 50-gallon fire under the conservatively postulated spill defined in the HI-STORM fire evaluation computes as 4.775 minutes. To demonstrate the fuel cladding and MPC pressure boundary integrity under exposure to this fire duration event during a fire accident analysis of the loaded 100-ton HI-TRAC is performed. In this analysis, the contents of the HI-TRAC are conservatively postulated to undergo a transient heat-up as a lumped mass from the decay heat input and heat input from the short duration fire. This analysis, because of the lower mass of the 100-ton HI-TRAC, bounds the effects for the 125-ton HI-TRAC. Using understated thermal inertia of the HI-TRAC and design maximum heat load (36.9 kW) the temperature rise rate computes as 5.553°F/min. Therefore, the temperature rise computed as the product of this rate and the fire duration reported above is 26.5°F. In this manner the maximum cladding temperature obtained by adding the temperature rise to the initial condition (See Table 4.5.4) computes as 737°F. The maximum fire temperature computed in the conservative manner above remains below the 1058°F accident temperature limit (Table 4.3.1) by substantial margins.

The elevated temperatures as a result of the fire accident will cause the pressure in the water jacket to increase and the overpressure relief valves to vent steam to the atmosphere. Based on the fire heat input to the water jacket, 11% of the water in the water jacket is boiled off. However, it is conservatively assumed, for dose calculations, that all the water in the water jacket is lost. In the 125-ton HI-TRAC, which uses Holtite in the lids for neutron shielding, the elevated fire temperatures would cause the Holtite to exceed its design accident temperature limits. This condition is conservatively addressed by ignoring neutron shield in the accident dose calculations.

Due to the increased temperatures of the MPC during fire accident the internal MPC pressure increases. The fire accident pressure is computed assuming the MPC cavity temperature rises by the fire accident temperature rise computed in this section. The result is tabulated in Table 4.6.2. The fire accident MPC pressure is substantially below the accident pressure limit (Table 2.2.1).

4.6.2.2 Jacket Water Loss

In this subsection, the fuel cladding and MPC boundary integrity is evaluated for a postulated loss of water from the HI-TRAC water jacket. The HI-TRAC is equipped with an array of water compartments filled with water. For a bounding analysis, all water compartments are assumed to lose their water and be replaced with air. Heat dissipation by natural convection and radiation in the air space is included in the thermal model. The HI-TRAC is assumed to have the maximum thermal payload (design heat load) and assumed to have reached steady state (maximum) temperatures. Under these assumed set of adverse conditions, the maximum temperatures are computed using the 3D HI-TRAC thermal model constructed in Section 4.5 with the water in water jacket spaces replaced with air. The computed results are tabulated in Table 4.6.3. The results of jacket water loss evaluation confirm that the cladding, MPC and HI-TRAC component temperatures are below the limits prescribed in Chapter 2 (Table 2.2.3). The co-incident MPC pressure is also computed and compared with the MPC accident design pressure (Table 2.2.1). The result (Table 4.6.2) is confirmed to be below the limit.

4.6.2.3 Extreme Environmental Temperatures

To evaluate the effect of extreme weather conditions, an extreme ambient temperature (Table 2.2.2) is postulated to persist for a 3-day period. For a conservatively bounding evaluation the extreme temperature is assumed to last for a sufficient duration to allow the HI-STORM 100 System to reach steady state conditions. Because of the large mass of the HI-STORM 100 System, with its corresponding large thermal inertia and the limited duration for the extreme temperature, this assumption is conservative. Starting from a baseline condition evaluated in Section 4.4 (normal ambient temperature and limiting fuel storage configuration) the temperatures of the HI-STORM 100 System are conservatively assumed to rise by the difference between the extreme and normal ambient temperatures (45°F). The HI-STORM extreme ambient temperatures computed in this manner are reported in Table 4.6.4. The co-incident MPC pressure is also computed (Table 4.6.2) and compared with the accident design pressure (Table 2.2.1). The result is confirmed to be below the accident limit.

4.6.2.4 100% Blockage of Air Inlets

This event is defined as a complete blockage of all four bottom inlets. The immediate consequence of a complete blockage of the air inlets is that the normal circulation of air for cooling the MPC is stopped. An amount of heat will continue to be removed by localized air circulation patterns in the overpack annulus and outlet ducts, and the MPC will continue to radiate heat to the relatively cooler storage overpack. As the temperatures of the MPC and its contents rise, the rate of heat rejection will increase correspondingly. Under this condition, the temperatures of the overpack, the MPC and the stored fuel assemblies will rise as a function of time.

As a result of the considerable inertia of the storage overpack, a significant temperature rise is possible if the inlets are substantially blocked for extended durations. This accident condition is, however, a short duration event that is identified and corrected through scheduled periodic surveillance. Nevertheless, this event is conservatively analyzed assuming a substantial duration of blockage. The event is analyzed using the FLUENT CFD code. The HI-STORM thermal model is the same 3-Dimensional model constructed for normal storage conditions (see Section 4.4) except for the bottom inlet ducts, which are assumed to be impervious to air. Using this model, a transient thermal solution of the HI-STORM 100 System starting from normal storage conditions is obtained. The results of the blocked ducts transient analysis are presented in Table 4.6.5 and confirmed to be below the accident temperature limits (Table 2.2.3). The co-incident MPC pressure is also computed and compared with the accident design pressure (Table 2.2.1). The result (Table 4.6.2) is confirmed to be below the limit.

4.6.2.5 Burial Under Debris

Burial of the HI-STORM 100 System under debris is not a credible accident. During storage at the ISFSI there are no structures over the casks. Minimum regulatory distances from the ISFSI to the nearest ISFSI security fence precludes the close proximity of substantial amount of vegetation. There is no credible mechanism for the HI-STORM 100 System to become completely buried under debris. However, for conservatism, complete burial under debris is considered.

To demonstrate the inherent safety of the HI-STORM 100 System, a bounding analysis that considers the debris to act as a perfect insulator is considered. Under this scenario, the contents of the HI-STORM 100 System will undergo a transient heat up under adiabatic conditions. The minimum available time ($\Delta\tau$) for the fuel cladding to reach the accident limit depends on the following: (i) thermal inertia of the cask, (ii) the cask initial conditions, (iii) the spent nuclear fuel decay heat generation and (iv) the margin between the initial cladding temperature and the accident temperature limit. To obtain a lowerbound on $\Delta\tau$, the HI-STORM 100 Overpack thermal inertia (item i) is understated, the cask initial temperature (item ii) is maximized, decay heat overstated (item iii) and the cladding temperature margin (item iv) is understated. A set of conservatively postulated input parameters for items (i) through (iv) are summarized in Table 4.6.6. Using these parameters $\Delta\tau$ is computed as follows:

$$\Delta\tau = \frac{m \times c_p \times \Delta T}{Q}$$

where:

$\Delta\tau$ = Allowable burial time (hr)
m = Mass of HI-STORM System (lb)
c_p = Specific heat capacity (Btu/lb-°F)
ΔT = Permissible temperature rise (°F)
Q = Decay heat load (Btu/hr)

Substituting the parameters in Table 4.6.6, a substantial burial time (34.6 hrs) is obtained. The co-incident MPC pressure is also computed and compared with the accident design pressure (Table 2.2.1). The result (Table 4.6.2) is confirmed to be below the limit.

Table 4.6.1
OFF-NORMAL CONDITION MAXIMUM
HI-STORM TEMPERATURES[3]

Location[4]	**Off-Normal Ambient Temperature[5] (°F)**	**Partial Inlet Ducts Blockage (°F)**
Fuel Cladding	731	725
MPC Basket	728	721
MPC Shell	489	478
Overpack Inner Shell	342	339
Lid Concrete Bottom Plate	322	321
Lid Concrete Section Temperature	266	260

Table 4.6.2
OFF-NORMAL AND ACCIDENT CONDITION MAXIMUM MPC PRESSURES

Condition	**Pressure (psig)**
Off-Normal Conditions	
Off-Normal Ambient	101.4
Partial Blockage of Inlet Ducts	100.4
Accident Conditions	
Extreme Ambient Temperature	104.4
100% Blockage of Air Inlets	118.1
Burial Under Debris	134.8
HI-TRAC Jacket Water Loss	107.7
HI-TRAC Fire Accident	104.9

[3] The temperatures reported in this table are below the off-normal temperature limits specified in Chapter 2, Table 2.2.3.
[4] Temperatures of limiting components reported.
[5] Obtained by adding the off-normal-to-normal ambient temperature difference of 20°F (11.1°C) to normal condition HI-STORM temperatures reported in Section 4.4.

Table 4.6.3
HI-TRAC JACKET WATER LOSS ACCIDENT MAXIMUM TEMPERATURES

Component	Temperature (°F)
Fuel Cladding	781
MPC Basket	777
MPC Shell	513
HI-TRAC Inner Shell	406
HI-TRAC Water Jacket Shell	293

Table 4.6.4
EXTREME ENVIRONMENTAL CONDITION MAXIMUM HI-STORM TEMPERATURES

Component	Temperature[6] (°F)
Fuel Cladding	756
MPC Basket	753
MPC Shell	514
Overpack Inner Shell	367
Lid Concrete Bottom Plate	347
Lid Concrete Section Temperature	291

6 Obtained by adding the extreme ambient to normal temperature difference (45°F) to normal condition temperatures reported in Section 4.4.

Table 4.6.5

32-HOURS BLOCKED INLET
DUCTS MAXIMUM HI-STORM TEMPERATURES

Component	Temperatures@32 hrs (°F)
Fuel Cladding	890
MPC Basket	884
MPC Shell	583
Overpack Inner Shell	480
Lid Concrete Bottom Plate	433
Lid Concrete Section Temperature	328

Table 4.6.6

SUMMARY OF INPUTS FOR BURIAL UNDER DEBRIS ANALYSIS

Thermal Inertia Inputs:	
M (Lowerbound HI-STORM 100 Weight)	150000 lb
Cp (Carbon steel heat capacity)[7]	0.1 Btu/lb-°F
Cask initial temperature[8]	728°F
Q (Decay heat)	1.3×10^5 Btu/hr
ΔT (clad temperature margin)[9]	300°F

[7] Carbon steel has the lowest heat capacity among the principal materials employed in MPC and overpack construction (carbon steel, stainless steel and concrete).

[8] Conservatively overstated.

[9] The clad temperature margin is conservatively understated in this table.

Table 4.6.7

[Intentionally Deleted]

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SUPPLEMENT 10.I

RADIATION PROTECTION

The HI-STORM 100U is a modular, underground vertical ventilated module (VVM) designed to accept all MPC models for storage at an ISFSI in lieu of above ground overpacks, like the HI-STORM 100 and HI-STORM 100S. As such, the radiological dose to plant personnel as well as members of the general public is well below those of the HI-STORM 100 and HI-STORM 100S when the MPC is in the overpack. Since the determination of off-site doses is necessarily site-specific, dose assessments similar to those described in Chapter 10 are to be prepared by the licensee as part of implementing the HI-STORM 100U System in accordance with 10CFR72.212 [10.0.1].

HI-STORM 100U Loading and Unloading Operations

The operations associated with the use of the HI-STORM 100U, described in Supplements 1.I and 8.I, are quite similar to the operations for all other variations of the HI-STORM 100 system. In both the aboveground and underground overpack, the MPC is transferred between the HI-TRAC and the overpack and in both cases the lid of the overpack is placed atop the overpack once the HI-TRAC is removed from the overpack. The only significant difference between the aboveground and underground overpack is the position of the HI-TRAC relative to ground level. For the aboveground overpack, the bottom of the HI-TRAC is approximately 18 feet above the ground and for the underground overpack, the bottom of the HI-TRAC is essentially at ground level. From an operations perspective, it will be easier to access the mating device and the pool lid bolts when the HI-TRAC is positioned atop the underground overpack rather than the aboveground overpack. In both cases, the same bolting and unbolting operations around the base of the HI-TRAC must be performed. Therefore, the estimated occupational dose for these scenarios is the same. The fact that the body of the HI-TRAC is closer to the ground when the underground overpack is being loaded will not affect the occupational dose rate since it is assumed that the workers not performing a task are positioned far enough away as to receive minimal dose.

Once the MPC transfer is complete and the HI-TRAC has been removed, the lid is placed on the overpack. For the underground overpack, this is a relatively simple operation of lifting the lid and placing it in the correct location. Unlike the aboveground overpack, the lid is not bolted to the body of the overpack. However, the outlet vent cover is installed on the overpack lid after the lid is placed upon the HI-STORM 100U, which installation requires bolting. Installation of the outlet vent cover places workers over the lid and adds some time to the operation. The duration of this operation can be estimated based on information provided in the tables in Section 10.3. Installation of the vent cover would be similar to the installation and alignment of the closure ring on top of the MPC. This activity is listed with an estimated duration of 5 min, for a single operator, in the tables in Section 10.3. Since the outlet vent cover is closer to the center of the lid than the closure ring, it is assumed here that two operators are required. There are four bolts, and bolt installation is typically listed in Section 10.3 to be performed at 2 bolts per minute, resulting in a duration of 2 minutes. Again, due to the location of those bolts, it is assumed that two operators are necessary to perform this activity. In total, it is then conservatively estimated that it will take 10 minutes for two operators to perform the installation. The dose rate on top of the overpack lid is 31.53 mrem/hr (see Table 5.1.1), which translates to a dose to the individual of 5.26 mrem and a total dose of 10.51 person-mrem. This is a small increase (about 1 %) in the total dose when considering the entire MPC transfer into the HI-STORM system. However, it is recommended that the operators do not spend any unnecessary time on top of the lid to ensure/meet the ALARA principle. It should also be mentioned that actual occupational dose during loading vary widely depending on site specific conditions. Experience has shown that the dose rates are in general significantly lower than those estimated in Chapter 10 of this FSAR.

In conclusion, the operator dose rates will be similar to those described in Chapter 10 for the aboveground overpack. Therefore, occupational exposure estimates for typical canister loading, closure, transfer operations, and ISFSI inspections may be calculated using the information presented in the tables of Chapter 10 for the site-specific application of the HI-STORM 100U system. For the fuel loading/unloading, transportation, and storage operations utilizing the HI-STORM 100U, the dose information provided in Chapter 10 may be considered bounding.

Excavation Activities

In the event it is desired to expand a loaded ISFSI utilizing the HI-STORM 100U design, excavation of material (i.e., soil) in the vicinity of the ISFSI is required. Radiation protection during excavation activities is achieved by prescribing a minimum proximity of any excavation activity to an existing operating HI-STORM 100U array. As described in 3.I.4.4 (iv), two scenarios may exist:

(i) No Retaining Wall Installed: In this case, a minimum distance from the loaded ISFSI, called the Excavation Exclusion Zone (EEZ) is established based on the site specific subgrade and earthquake data using the methodology described in subsection 3.I.4.7. The EEZ ensures that the subgrade around the operating ISFSI will remain unaffected by the excavation during an earthquake. The required distance from the ISFSI for the EEZ is influenced by the properties of the subgrade and the strength of the DBE for the site. The EEZ must lie outside the Radiation Protection Space (RPS) defined as the spatial region around the ISFSI specified to provide radiation protection and safety from tornado missiles, shown on the licensing drawing.

(ii) Retaining Wall installed: If a retaining wall is installed at or beyond the Radiation Protection Space (RPS) per the licensing drawing and Table 2.I.2 then the EEZ boundary is at the retaining wall. A retaining wall may be installed on any or all sides of the ISFSI. Site specific radiation protection measures for excavation activities need to include confirmation of the minimum soil properties along with the minimum distances between the excavation area and the loaded VVMs, as well as radiological monitoring of the excavation area.

Site specific evaluations also need to be performed to ensure that the radiation protection space boundary is maintained. Site specific accident scenarios (e.g., seismic conditions) will need to be accounted for in these evaluations. A general accident scenario evaluation, however, has been performed for the HI-STORM 100U design.

The impact of a tornado missile penetrating the soil creating a horizontal hole extending from the metal surface of the VVM to the outer surface of the soil was also considered. This evaluation, presented in Supplement 5.I, demonstrates that the dose at the site boundary is below the limit specified in 10 CFR 72.

Normal Operation of Storage

During normal operation of storage, radiation will predominantly emanate from the inlet and outlet vents and the top of the lid. However, there are also some additional radiation streaming paths and scenarios that may have to be considered in the radiation protection program. The following two scenarios have been evaluated for the HI-STORM 100U design.

The first scenario evaluated address radiation streaming from a loaded VVM through an adjacent empty VVM. An empty VVM adjacent to a loaded VVM could potentially constitute a radiation streaming path since the soil providing shielding is limited between adjacent VVMs. Therefore, radiation passing through the soil to the unloaded VVM will have a path of less shielding and could contribute to occupational dose. This evaluation is presented in detail in Supplement 5.I, and concluded that there are no concerns about the dose rates contributing to occupational dose across the top of the empty VVM due to radiation streaming from the loaded neighboring VVM.

The second scenario concerns the soil access tube, or test station, that is part of the ICCPS design (see Figure 2.I.1) and could represent a potential streaming path. Therefore, radiation passing through the soil access tube could contribute to occupational dose. This evaluation is presented in detail in Supplement 5.I, and assumes a tube located about 5.5 feet from the center of the VVM with a diameter of 4 inches, that reaches down to the support foundation. With these dimensions, it is shown that there are no concerns about the dose rates contributing to occupational dose on the top of the soil access tube due to radiation streaming from a loaded VVM. However, if the tube is larger or located closer to the VVM, then the actual dimensions should be considered in the site specific dose rate calculations, and the result of the calculations should be considered in the site specific radiation protection program.

SUPPLEMENT 11.I

ACCIDENT EVALUATION FOR THE HI-STORM 100U SYSTEM

11.I.0 INTRODUCTION

This supplement is focused on the off-normal and accident condition evaluations of the HI-STORM 100U vertical ventilated module (VVM). Only those events that are actually affected by the design of the overpack are discussed in detail herein. The reader is referred to the main body of Chapter 11 for discussions of any off-normal or accident conditions that are not dependent on the design of the storage overpack (i.e., MPC-only or HI-TRAC events).

The evaluations described herein parallel those of the HI-STORM 100 overpack contained in the main body of Chapter 11 of this FSAR. To ensure readability, the sections in this supplement are numbered to be directly analogous to the sections in the main body of the chapter. For example, the fire accident evaluation presented in Supplement Subsection 11.I.2.4 for the HI-STORM 100U is analogous to the evaluation presented in Subsection 11.2.4 of the main body of Chapter 11 for the HI-STORM 100. Tables and figures (if any) in this supplement, however, are labeled sequentially by section. If there is an analogous table or figure in the main body of Chapter 11, an appropriate notation is made in the supplement table or figure.

11.I.1 OFF-NORMAL EVENTS

A general discussion of off-normal events is presented in Section 11.1 of the main body of Chapter 11. The following off-normal events are discussed in this supplement:

Off-Normal Pressure
Off-Normal Environmental Temperature
Leakage of One MPC Seal Weld
Partial Blockage of Air Inlets
Off-Normal Handling of HI-TRAC Transfer Cask
Malfunction of FHD System

Off-Normal Wind

The results of the evaluations presented herein demonstrate that the HI-STORM 100U System can withstand the effects of off-normal events without affecting its ability to perform its intended function, and is in compliance with the applicable acceptance criteria.

11.I.1.1 Off-Normal Pressure

A discussion of this off-normal condition is presented in Subsection 11.1.1 of the main body of Chapter 11. A description of the cause of, detection of, corrective actions for and radiological impact of this event is presented therein.

Structural

The structural evaluation of the MPC enclosure vessel for off-normal internal pressure conditions is discussed in Section 3.4. The applicable pressure boundary stress limits are confirmed to bound the stresses resulting from the off-normal pressure.

Thermal

In 4.6.1 the MPC internal pressure under the conditions of 10% fuel rods ruptured, insolation and a limiting fuel storage configuration in an aboveground overpack is evaluated. This evaluation is bounding as the MPC temperatures in the 100U overpack are bounded by the aboveground overpack.

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event. As discussed in the structural evaluation mentioned above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the off-normal pressure does not affect the safe operation of the HI-STORM 100U System.

11.I.1.2 Off-Normal Environmental Temperatures

A discussion of this off-normal condition is presented in Subsection 11.1.2 of the main body of Chapter 11. A description of the cause of, detection of, corrective actions for and radiological impact of this event is presented therein.

Structural

The effect on the MPC for the upper off-normal thermal conditions (i.e., 100°F) is an increase in the internal pressure. However, as shown previously the resultant pressure is below the off-normal design pressure (Table 2.2.1). The effect of the lower off-normal thermal conditions (i.e., -40°F) requires an evaluation of the potential for brittle fracture. Such an evaluation is presented in Subsections 3.1.2 and 3.I.1.

Thermal

Supplement 4.I calculates bounding temperatures and pressures for the HI-STORM 100U under the elevated temperature condition. The calculated temperatures and pressures are reported in Table 4.I.5 and are below the off-normal limits (Tables 2.2.3, 2.I.8 and 2.2.1).

The off-normal event considering an environmental temperature of -40°F and no solar insolation for a duration sufficient to reach thermal equilibrium is evaluated with respect to material design temperatures of the HI-STORM 100U overpack. The HI-STORM 100U overpack is conservatively assumed to reach -40°F throughout the structure. Chapter 3, Subsection 3.1.2 details the structural analysis and testing performed to assure prevention of brittle fracture failure of the HI-STORM 100U System.

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the specified off-normal environmental temperatures do not affect the safe operation of the HI-STORM 100U System.

11.I.1.3 Leakage of One MPC Seal Weld

A discussion of this off-normal condition is presented in Subsection 11.1.3 of the main body of Chapter 11. The discussion presented therein is applicable in its entirety to an MPC in a HI-STORM 100U VVM as well.

11.I.1.4 Partial Blockage of Air Inlets

A discussion of this off-normal condition is presented in Subsection 11.1.4 of the main body of Chapter 11. A description of the cause of, detection of, corrective actions for and radiological impact of this event is presented therein.

Structural

There are no structural consequences as a result of this off-normal event.

Thermal

Supplement 4.I calculates bounding temperatures for 50% blockage of the air inlets. The calculated bounding temperatures are reported in Table 4.I.6 and are below the MPC and VVM off-normal design temperatures (Tables 2.2.3 and 2.I.8). Additionally, the increased temperatures generate an elevated MPC internal pressure, also reported in Table 4.I.6, which is less than the off-normal design pressure (Table 2.2.1).

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the specified off-normal partial blockage of air inlet ducts event does not affect the safe operation of the HI-STORM 100U System.

11.I.1.5 Off-Normal Handling of HI-TRAC

A discussion of this off-normal condition is presented in Subsection 11.1.5 of the main body of Chapter 11. The discussion presented therein remains completely applicable, as the design and method of operation of the HI-TRAC is the same as with the HI-STORM 100U.

11.I.1.6 Failure of FHD System

A discussion of this off-normal condition is presented in Subsection 11.1.6 of the main body of Chapter 11. The discussion presented therein remains completely applicable for all MPCs.

11.I.1.7 Deleted

11.I.1.8 Off-Normal Wind

The HI-STORM 100U is designed for use at any site in the United States. Supplement 4.I evaluates the effects of off-normal wind (>0 and up to 15 MPH). The off-normal wind is postulated as a constant horizontal wind caused by extreme weather conditions (see Table 2.I.1). To determine the effects of the off-normal wind, it is conservatively assumed that these winds persist for a sufficient duration to allow the HI-STORM 100U System to reach thermal equilibrium. Because of the large mass of the HI-STORM 100U System with its corresponding large thermal inertia and the unlikely condition of a unidirectional wind for a long period of time, this assumption is conservative. The analyses presented in Supplement 4.I shows that the peak fuel cladding and material temperatures remains below the off-normal limits (Tables 2.2.3 and 2.I.8). Because the HI-STORM 100U System is designed to withstand the off-normal wind without any effect on its ability to maintain safe storage conditions, there is no requirement for detection of the off-normal wind.

Structural

There are no structural consequences as a result of this off-normal event.

Thermal

Supplement 4.I calculates peak fuel cladding temperatures for horizontal wind speeds of up to 15 miles per hour. The calculated temperatures (reported in Table 4.I.7) are below the off-normal limits (Table 2.2.3).

Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this off-normal event.

Based on this evaluation, it is concluded that the specified off-normal wind event does not affect the safe operation of the HI-STORM 100U System. The HI-STORM 100U System is designed to withstand the off-normal wind without any effect on its ability to maintain safe storage conditions. There are no corrective actions required for the off-normal wind. The off-normal wind has no radiological impact, and the confinement barrier and shielding integrity are not affected.

11.I.2 ACCIDENT EVENTS

A general discussion of accident events is presented in Section 11.1 of the main body of Chapter 11. The following accident events are discussed in this supplement section:

HI-TRAC Transfer Cask Handling Accident
HI-STORM 100U Overpack Handling Accident
Tip-Over
Fire Accident
Partial Blockage of MPC Basket Vent Holes
Tornado
Flood
Earthquake
100% Fuel Rod Rupture
Confinement Boundary Leakage
Explosion
Lightning
100% Blockage of Air Inlets
Burial Under Debris
Extreme Environmental Temperature

The results of the evaluations performed herein demonstrate that the HI-STORM 100U System can withstand the effects of all credible and hypothetical accident conditions and natural phenomena without affecting safety function, and is in compliance with the applicable acceptance criteria.

In addition to the above accidents events, identification of additional hazards during construction proximate to an operating ISFSI is treated in 11.I.2.17.

11.I.2.1 HI-TRAC Transfer Cask Handling Accident

A discussion of this accident condition is presented in Subsection 11.2.1 of the main body of Chapter 11. The discussion presented therein is applicable in its entirety, as the design and method of operation of the HI-TRAC is the same for the HI-STORM 100U.

11.I.2.2 HI-STORM Overpack Handling Accident

This accident event is not applicable to the HI-STORM 100U as this is an underground overpack surrounded by soil.

11.I.2.3 Tip-Over

This accident event is not applicable to the HI-STORM 100U. Due to the subterranean installation of the VVM with a surrounding subgrade for lateral support, tip-over is precluded.

11.I.2.4 Fire Accident

A discussion of this accident condition is presented in Subsection 11.2.4 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein. In addition, the discussion of the fire analysis for the HI-TRAC transfer cask presented therein remains completely applicable, as the design and method of operation of the HI-TRAC do not need to be changed for use with the HI-STORM 100U.

Structural

There are no structural consequences as a result of the fire accident condition.

Thermal

Supplement 4.I discusses the impact of a fire on the HI-STORM 100U System. As justified therein, the evaluation for the fire effects on an aboveground cask presented in Section 11.2 bound the effects on the HI-STORM 100U System. As described in Section 11.2, the effects of the fire do not cause any system component or the contained fuel to exceed any design limit. As such, the results are bounding for the HI-STORM 100U System.

Shielding

With respect to concrete damage from a fire, NUREG-1536 (4.0,V,5.b) states: "the loss of a small amount of shielding material is not expected to cause a storage system to exceed the regulatory requirements in 10 CFR 72.106 and, therefore, need not be estimated or evaluated in the SAR."

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event.

Radiation Protection

Since there is a very localized reduction in shielding and no effect on the confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the overpack fire accident does not affect the safe operation of the HI-STORM 100U System.

11.I.2.5 Partial Blockage of MPC Basket Vent Holes

A discussion of this accident condition is presented in Subsection 11.2.5 of the main body of Chapter 11. The discussion presented therein is applicable in its entirety to an MPC in a HI-STORM 100U VVM.

11.I.2.6 Tornado

A discussion of this accident condition is presented in Subsection 11.2.6 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Because of its underground construction, the HI-STORM 100U is not affected by the tornado wind. The effect of tornado missiles propelled by high velocity winds that attempt to penetrate the exposed portions of the HI-STORM 100U must, however, be considered.

Structural

Analyses presented in Supplement 3.I show that the impact of an intermediate tornado missile on the HI-STORM 100U closure lid does not result in the perforation of the lid or result in a structural collapse. The result of the tornado missile impact on the VVM is limited to localized damage of the shielding.

Thermal

There are no thermal consequences as a result of the tornado beyond those discussed for the wind herein.

Shielding

A tornado missile may cause localized damage to the HI-STORM 100U closure lid. As the HI-STORM 100U top is heavily shielded (a thick MPC lid backed up by a steel-concrete-steel top) the overall damage consequences (site boundary dose) are insignificant.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event.

Radiation Protection

There is no degradation in confinement capabilities of the MPC, since the tornado missiles do not impact the MPC, as discussed above. A tornado missile may cause localized damage in the HI-STORM 100U closure lid. However, the damage will have a negligible effect on the site boundary dose.

Based on this evaluation, it is concluded that the tornado accident does not affect the safe operation of the HI-STORM 100U System.

11.I.2.7 Flood

A discussion of this accident condition is presented in Subsection 11.2.7 of the main body of Chapter 11. A description of the cause of this event is presented therein.

Structural

The structural evaluation of the MPC for the accident condition external pressure (Table 2.2.1) is presented in Section 3.4 and the resulting stresses from this event are shown to be well within the allowable values.

Thermal

The thermal consequences of flood are bounded by the 100% air inlets blockage accident (see Subsection 4.I.6.2).

Shielding

There is no effect on the shielding performance of the system as a result of this accident event. The floodwater provides additional shielding which reduces radiation dose.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event. The criticality analysis is unaffected because under the flooding condition water does not enter the MPC cavity and therefore the reactivity would be less than the loading condition in the spent fuel pool, which is presented in Section 6.1.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the flood accident does not affect the safe operation of the HI-STORM 100U System.

Flood Accident Corrective Action

The configuration of the VVM makes it uniquely suited to withstand a flooding event. Indeed, introducing water in the CEC is an effective method to lower the MPC contents' temperature. However, solid debris packed around the Divider Shell is an undesirable condition. Thus, while the thermal evaluations discussed in Supplement 4.I demonstrate that the HI-STORM 100U System will safely withstand a flood, corrective actions after such an event may be necessary. Periodic VVM air temperature monitoring, required for the HI-STORM 100U System, will identify any blockage of the cooling passages that results in a non-normal thermal condition, including blockages due to a flood borne debris.

If the measured temperature rise exceeds the allowable value, then corrective actions to alleviate the condition will be required. To restore the system to a normal configuration, all flood water and any debris deposited by the receding water must be removed. The specific methods to be used are appropriately site specific and shall be addressed in the site emergence action plan. Examples of acceptable cleaning approaches include:

1. The MPC is removed from the VVM using the HI-TRAC transfer cask, allowing direct access to the interior of the VVM through both the inlet vents and the top of the module cavity. Water sprays and vacuuming is used to directly clean the VVM passages and surfaces.

2. Appropriate vacuuming equipment is inserted through the inlet ducts and down to the bottom plenum. Water is sprayed in through the outlet vents. Remote cameras are used to inspect the VVM cooling passages to identify debris and remove debris.

The adequacy of the cooling passages clearance operation is verified by visual inspection or, if the optional air temperature monitoring is used, the return of the air outlet temperatures to within allowable limits.

11.I.2.8 Earthquake

A discussion of this accident condition is presented in Subsection 11.2.8 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Structural

Because of its underground construction, the HI-STORM 100U VVM is inherently safe under seismic events. Analyses presented in Supplement 3.I show that the VVM will continue to render its intended function under a seismic event whose ZPAs are bounded by the values set forth in Supplement 2.I.

Thermal

There is no effect on the thermal performance of the system as a result of this accident event.

Shielding

There is no effect on the shielding performance of the system as a result of this accident event.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the earthquake does not affect the safe operation of the HI-STORM 100U System.

11.I.2.9 100% Fuel Rod Rupture

A discussion of this accident condition is presented in Subsection 11.2.9 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Structural

The structural evaluation of the MPC for the accident condition internal pressure presented in Section 3.4 demonstrates that the MPC stresses are well within the allowable values.

Thermal

A bounding MPC internal pressure for the 100% fuel rod rupture condition is presented in Table 4.4.9. The design basis accident condition MPC internal pressure (Table 2.2.1) used in the structural evaluation bounds the calculated value.

Shielding

There is no effect on the shielding performance of the system as a result of this accident event.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the non-mechanistic 100% fuel rod rupture accident does not affect the safe operation of the HI-STORM 100U System.

11.I.2.10 Confinement Boundary Leakage

A discussion of this accident condition is presented in Subsection 11.2.10 of the main body of Chapter 11. The discussion presented therein remains completely applicable to an MPC in a HI-STORM 100U VVM as well.

11.I.2.11 Explosion

A discussion of this accident condition is presented in Subsection 11.2.11 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Structural

Because of its underground construction, the HI-STORM 100U and the MPC contained within are essentially shielded by the surrounding earth. Thus, no evaluation of the VVM or the contained MPC is required. The HI-STORM 100U closure lid is, however, aboveground and exposed to the explosion-induced pressure wave. Supplement 3.I includes an evaluation of the effect of the design-basis 10 psi pressure wave applied as a static pressure on the closure lid. This evaluation shows that the overpressure wave does not result in lid separation, and that all lid stresses are a fraction of the allowable limits.

Thermal

There is no effect on the thermal performance of the system as a result of this accident event.

Shielding

There is no effect on the shielding performance of the system as a result of this accident event.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. As discussed in the structural evaluation above, all stresses remain well within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the explosion accident does not affect the safe operation of the HI-STORM 100U System.

11.I.2.12 Lightning

A discussion of this accident condition is presented in Subsection 11.2.12 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Because of its underground construction, the subterranean portion of the HI-STORM 100U would not be subjected to a direct lightning strike. The HI-STORM 100U closure lid is, however, aboveground and could be subjected to a direct strike. The closure lid is, however, a steel encased concrete structure just like on the aboveground casks. Thus, the discussion presented in Subsection 11.2.12 remains completely applicable to the exposed portions of the HI-STORM 100U System. Therefore, it is concluded that a lightning event will not prevent the VVM from rendering its intended function.

11.I.2.13 100% Blockage of Air Inlets

A discussion of this accident condition is presented in Subsection 11.2.13 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Structural

There are no structural consequences as a result of this accident event.

Thermal

Supplement 4.I calculates bounding temperatures for the 100% blockage of the air inlets. The calculated bounding temperatures after 24 hours of 100% blockage are reported in Table 4.I.9. The results are below the MPC and VVM accident temperature limits (Tables 2.2.3 and 2.I.8). Additionally, the increased temperatures generate an elevated MPC internal pressure, also reported in Table 4.I.9, which is less than the design basis accident pressure listed in Table 2.2.1.

Shielding

There is no effect on the shielding performance of the system as a result of this accident event, since the concrete temperatures do not exceed the accident temperature limit.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the 100% blockage of air inlets accident does not affect the safe operation of the HI-STORM 100 System, if the blockage is removed in the specified time period.

11.I.2.14 Burial Under Debris

A discussion of this accident condition is presented in Subsection 11.2.14 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Structural

The structural evaluation of the MPC enclosure vessel for accident internal pressure conditions bounds the pressure calculated herein. Therefore, the resulting stresses from this event are well within the allowable values, as demonstrated in Section 3.4.

Thermal

Supplement 4.I discusses the impact of burial under debris on the HI-STORM 100U System. As explained therein, the evaluation for the effects of such an event on an aboveground cask presented in Section 11.2 bound the HI-STORM 100U.

Shielding

There is no adverse effect on the shielding performance of the system as a result of this accident event.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the burial under debris accident does not affect the safe operation of the HI-STORM 100U System, if the debris is removed within the specified time period.

11.I.2.15 Extreme Environmental Temperature

A discussion of this accident condition is presented in Subsection 11.2.15 of the main body of Chapter 11. A description of the cause of and corrective actions for this event is presented therein.

Structural

The structural evaluation of the MPC enclosure vessel for accident condition internal pressure bounds the pressure resulting from this event. Therefore, the resulting stresses from this event are bounded by the design-basis internal pressure and are well within the allowable values, as discussed in Section 3.4.

Thermal

Supplement 4.I calculates bounding temperatures for the HI-STORM 100U under the extreme environmental temperature condition. The calculated bounding temperatures and pressures are reported in Table 4.I.8 and are below the MPC and VVM accident temperature and pressure limits (Tables 2.2.3, 2.I.8 and 2.2.1).

Shielding

There is no effect on the shielding performance of the system as a result of this accident event, since the concrete temperature does not exceed the short-term temperature limit specified in Table 2.2.3.

Criticality

There is no effect on the criticality control features of the system as a result of this accident event.

Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. As discussed in the structural evaluation above, all stresses remain within allowable values, assuring confinement boundary integrity.

Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no effect on occupational or public exposures as a result of this accident event.

Based on this evaluation, it is concluded that the extreme environment temperature accident does not affect the safe operation of the HI-STORM 100U System.

11.I.2.16 Deleted

11.I.2.17 Additional Hazards during Construction Proximate to the ISFSI

To protect an installed ISFSI from any site construction activity in its proximity, a certain minimum ground buffer distance beyond the edge of the perimeter of the VVM arrays shall be established. This distance, referred to as the Excavation Exclusion Zone (EEZ), is the minimum distance from the ISFSI where excavation can occur if a retaining wall was not installed at the ISFSI per the licensing drawing and Table 2.I.2. This distance is established based on soil conditions and the strength of the DBE as discussed in Section 3.I. If the user installs a retaining wall at or beyond the Radiation Protection Space (RPS) then the EEZ boundary is the retaining wall. If a retaining wall is not installed, the EEZ boundary for a site is established using the methodology described in Section 3.I.4.

As is required for deploying casks certified under 10CFR72, Subpart L, every site modification that may potentially impact the continued operability of the ISFSI must be evaluated for acceptability under 10CFR72.212. A generic evaluation of the shielding consequences of digging a cavity adjacent to the RPS has been considered in Supplement 5.I of this FSAR. The analyses show that the dose at the edge of the cavity is below 0.2 mrem/hr, which is well below the customary limit that requires radiation posting at nuclear power plants.

Subsection 2.I.6 considers loadings from extreme environmental phenomena assuming that a deep cavity at the edge of the RPS perimeter with a retaining wall has been created as a part of site construction work and an accidental mechanical loading event across such cavity is credible.

Analyses summarized in Subsection 3.I.4 show that the design basis projectiles (large, medium, or small), specified in Chapter 2 of this FSAR, applied in the most vulnerable location of the construction cavity, will fail to reach the CEC.

In addition to the generic analyses documented in this FSAR to validate the sufficiency of the RPS boundary, analyses of the consequences of any credible site specific loads or events during site construction work shall be performed with due consideration of the duration and nature of the site construction activity. The user's §72.212 evaluation program, used in considering ISFSI-proximate activities at aboveground ISFSIs, shall apply to the HI-STORM 100U installation as well without limitation.

To summarize, as discussed in Supplement 2.I and documented in the licensing drawing package in Section 1.5, and the technical specifications; a RPS has been established per supplement 5.I with sufficient margin (ground buffer) against design basis projectiles analyzed in supplement 3.I. An EEZ shall be established within which excavation activities cannot be performed. If the retaining wall is present at or beyond the RPS the EEZ boundary is the located at the retaining wall. The RPS boundary and EEZ shall not be encroached upon during any site construction activity (this includes excavation). In addition to the generic analyses documented in this FSAR, site specific evaluation pursuant to §72.212 shall be performed for all other credible hazards that can be postulated during site construction. Administrative controls to guard against accidental human error in excavations (such as encroachment of the RPS) shall be addressed through written procedures consistent with the required controls needed for a safety significant activity within a Part 50 controlled area.

Subsection 2.I.2(iv) also requires the ISFSI owner to perform a seismic analysis of the ISFSI for the instance when the maximum amount of excavation of the area adjacent to the EEZ will exist to show that the RPS will not be encroached upon if a retaining wall is not used or be limited to excavation at a distance ten times the planned excavation depth from the ISFSI. The site's Design Basis Earthquake (DBE) will be used. PRA considerations shall not be used to diminish the strength of the seismic input. The Design Basis Seismic Model, described in 3.I.4, shall be used with appropriate representation of the construction cavity.

Because the actual projectiles for a specific ISFSI site are often different from the tornado borne missiles analyzed in Supplement 3.I herein, a site specific analysis of the effect of all credible missiles shall be performed assuming that the largest construction cavity adjacent to the ISFSI exists. PRA considerations shall not be used to rule out any missile that has been determined to be credible in the plant's FSAR.

Furthermore, the ISFSI owner shall implement ameliorative measures to prevent unacceptable damage to the ISFSI from any other credible adverse scenarios unique to a site that has not been considered in this FSAR. An example of such a measure is the installation of a berm to protect against environmental events such as soil erosion and mud slides. Such site specific design initiatives at any "100U" ISFSI, like its aboveground counterpart, are within the purview of the plant's §72.212 process.

LICENSING DRAWING PACKAGE COVER SHEET

CLIENT GENERAL	
PROJECT NO. 1024	P.O. NO. N/A
DRAWING PACKAGE I.D. 4501	TOTAL SHEETS △5 7

LICENSING DRAWING PACKAGE CONTENTS:

	SHEET	DESCRIPTION
	1	COVER SHEET
	2	VVM AND LAYOUT
	3	VVM IN CROSS SECTION
	4	CAVITY ENCLOSURE CONTAINER DETAILS & ASSEMBLY
	5	CLOSURE LID ASSEMBLY
	6	CLOSURE LID DETAILS
△5	7	RETAINING WALL DETAILS

REVISION LOG

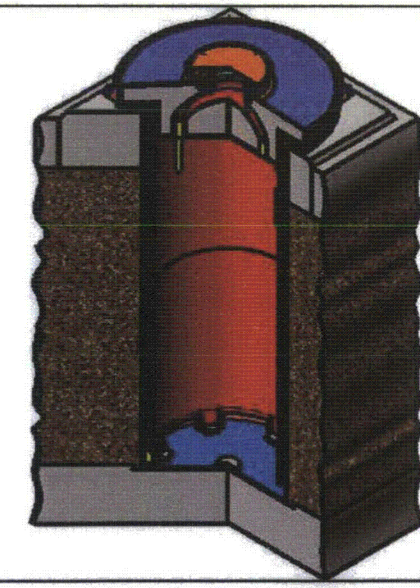
IT IS MANDATORY AT EACH REVISION TO COMPLETE THE REVIEW & APPROVAL LOG STORED IN HOLTEC'S DIRECTORY N:\PDOXWIN\WORKING\DBAL BY ALL RELEVANT TECHNICAL DISCIPLINES. PM AND QA PERSONNEL. EACH ATTACHED DRAWING SHEET CONTAINS ANNOTATED TRIANGLES INDICATING THE REVISION TO THE DRAWING.

REV	AFFECTED DRAWING SHEET NUMBERS	SUMMARY OF CHANGES/ AFFECTED ECOs	PREPARED BY	APPROVAL DATE	VIR# †
0	INITIAL ISSUE	-	D. Butler	05/16/05	95076
1	ALL	COMPLETE REVISION, NO REV. TRIANGLES NOTATED. RECONCILED LICENSING DRAWING WITH THE MANUFACTURING DWG.; INFORMATION REARRANGED FOR CLARITY.	D. Butler	02/17/06	28570
2	ALL SHEETS	ECO# 5014-140 RO	D. Butler	04/25/07	35278
3	SHEETS 1, 2, 3, 4 & 5	ECO# 5014-157 R0	D. Butler	06/06/08	34342
4	SHEETS 1, 2 & 3	ECO# 5014-168 R0	D. Butler	12/16/08	13387
5	SHEETS 1, 2, 3, 4 & 7	ECO# 5014-177 R0	D. Butler	09/10/10	57694

† THE VALIDATION IDENTIFICATION RECORD (VIR) NUMBER IS A COMPUTER GENERATED RANDOM NUMBER WHICH CONFIRMS THAT ALL APPROPRIATE REVIEWS OF THIS DRAWING ARE DOCUMENTED IN COMPANY'S NETWORK.

GENERAL NOTES:

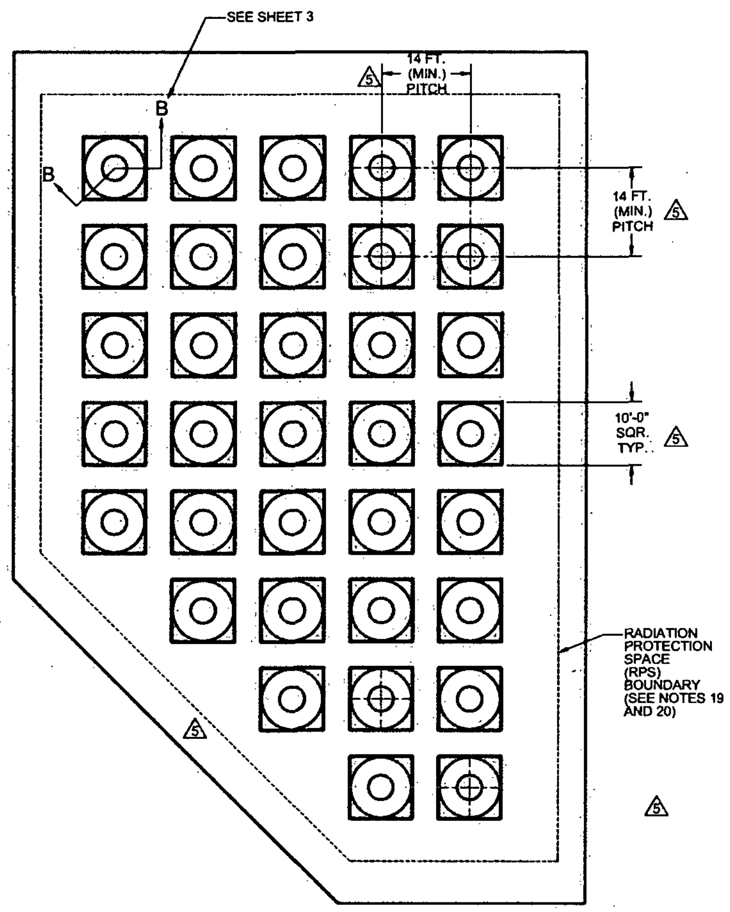
1. THE EQUIPMENT DOCUMENTED IN THIS DRAWING PACKAGE HAS BEEN CONFIRMED BY HOLTEC INTERNATIONAL TO COMPLY WITH THE SAFETY ANALYSES DESCRIBED IN THE HI-STORM FSAR.
2. DIMENSIONAL TOLERANCES ON THIS DRAWING ARE PROVIDED SOLELY FOR LICENSING PURPOSES TO DEFINE LIMITS ON THE NOMINAL DIMENSIONS USED IN LICENSING BASIS ANALYSES. HARDWARE IS FABRICATED IN ACCORDANCE WITH THE FABRICATION DRAWINGS, WHICH HAVE MORE RESTRICTIVE TOLERANCES, TO ENSURE COMPONENT FIT-UP. DO NOT USE WORST-CASE TOLERANCE STACK-UP FROM THIS DRAWING TO DETERMINE COMPONENT FIT-UP.
3. THE REVISION LEVEL OF EACH INDIVIDUAL SHEET IN THE PACKAGE IS THE SAME AS THE REVISION LEVEL OF THIS COVER SHEET. A REVISION TO ANY SHEET(S) IN THIS PACKAGE REQUIRES UPDATING OF REVISION NUMBERS OF ALL SHEETS TO THE NEXT REVISION NUMBER.
4. APPLICABLE CODES AND STANDARDS ARE DELINEATED IN SUPPLEMENT 2.I OF THE FSAR.
5. ALL WELDS REQUIRE VISUAL EXAMINATION. ADDITIONAL NDE INSPECTIONS ARE NOTED ON THE DRAWING IF REQUIRED.
6. UNLESS OTHERWISE NOTED, FULL PENETRATION WELDS MAY BE MADE FROM EITHER SIDE OR BOTH SIDES OF A COMPONENT.
7. THIS COMPONENT IS IMPORTANT-TO-SAFETY, CATEGORY C, BASED ON THE HIGHEST CLASSIFICATION OF ANY SUBCOMPONENT. SUBCOMPONENT CLASSIFICATIONS ARE PROVIDED ON THE FABRICATION DRAWING.
8. △5 ALL WELD SIZES ARE MINIMUMS EXCEPT AS CLARIFIED IN THE FSAR. FABRICATOR MAY ADD WELDS WITH HOLTEC CONCURRENCE.
9. WELDS MAY BE MADE USING PREQUALIFIED WELD PROCEDURES IN ACCORDANCE WITH AWS D1.1. OR ASME SECTION IX.
10. INSULATION MUST BE FOIL FACED OR OTHERWISE WATER RESTISTANT AND MUST BE STABLE TO AT LEAST 400°F. INSULATION WILL BE AFFIXED TO THE OUTER SURFACE OF THE DIVIDER SHELL IN ACCORDANCE WITH MANUFACTURER'S INSTRUCTIONS USING STUDS WELDED TO THE DIVIDER SHELL AND COMPRESSION WASHERS. MANUFACTURER'S SYSTEM IS SUITABLE FOR VIBRATORY CONDITIONS AND BOTH VERTICAL AND HORIZONTAL (INVERTED) ORIENTATIONS.
11. CLOSURE LID CONCRETE IS UNREINFORCED WITH DRY DENSITY 140 LB/FT.^{3} (NOM.)
12. TOLERANCES FOR THICKNESS OF MATERIAL ARE AS SPECIFIED BY THE APPLICABLE ASTM SPECIFICATIONS.
13. DIMENSIONS INDICATED AS "REFERENCE" ARE DERIVED VALUES SUBJECT TO TOLERANCE STACKUPS; DIMENSIONS INDICATED AS "NOMINAL" WILL VARY IN THE MANUFACTURER'S HARDWARE TO THE EXTENT TYPICAL IN APPLICABLE FABRICATION OPERATIONS (SUCH AS ROLLING, PLASMA CUTTING AND MACHINING). DIMENSIONS INDICATED AS A MINIMUM OR MAXIMUM ARE CONSIDERED TO BE CONTROLLED DIMENSIONS.
14. THE DESIGN FEATURES OF THE HI-STORM 100U ARE THE EXCLUSIVE INTELLECTUAL PROPERTY OF HOLTEC INTERNATIONAL UNDER U.S. AND INTERNATIONAL PATENT RIGHTS LAWS.
15. △5 SEVERAL INTERFACING SSCS (SYSTEM, STRUCTURE, AND COMPONENTS) TO THE VVM PER 10CFR72 ARE SHOWN IN PHANTOM IN THIS DRAWING PACKAGE FOR REFERENCE PURPOSES. INTERFACING SSCS INCLUDE:
(A) THE SUPPORT FOUNDATION PAD.
(B) VVM INTERFACE PAD.
(C) THE SUBGRADE SURROUNDING THE VVM.
ALSO SHOWN IN PHANTOM IS THE TOP SURFACE PAD, WHICH IS A PROXIMATE STRUCTURE.
16. △5 THE TOP OF THE TUBULAR MPC GUIDE SHALL BE POSITIONED APPROXIMATELY ½" BELOW THE TOP OF THE MPC LID. FOR THE OPTIONAL PLATE TYPE GUIDE, THE VERTICAL ELEVATION OF THE GUIDE CENTER POINT SHALL BE POSITIONED APPROXIMATELY EVEN WITH THE LOWER SURFACE OF THE MPC LID.
17. DIMENSIONS "E" AND "F" (SHEETS 4 AND 5) AND DIMENSIONS "G" AND "H" (SHEETS 4 AND 5) ARE INTERFACING DIMENSIONS IN THE MATING PARTS; THEY MUST BE COMPATIBLE TO INSURE FIELD FIT-UP.
18. - DELETED -
19. THE "RADIATION PROTECTION SPACE" (RPS) IS THE PRISMATIC SUBGRADE BUFFER ZONE AROUND A LOADED VVM (SEE SHEET 2 - TYPICAL ISFSI LAYOUT). THE RPS BOUNDARY IS LOCATED AT A MINIMUM OF 14 FT. FROM THE CENTERLINE OF A LOADED VVM ON THE PERIPHERY OF AN OPERATING ISFSI AND AT A MINIMUM OF 21 FT. FROM THE CENTERLINE OF A LOADED VVM NOT ON THE PERIPHEREY. THE RPS BOUNDARY SHALL NOT BE ENCROACHED UPON DURING ANY SITE CONSTRUCTION ACTIVITY.
20. △5 AN UNDERGROUND RETAINING WALL MAY BE INSTALLED ON ANY OR ALL SIDES OF THE ISFSI TO PROTECT THE LOADED ISFSI FROM SIGNIFICANT EXCAVATION ACTIVITY. IF USED THE RETAINING WALL SHALL BE PLACED AT OR BEYOND THE RPS. THE OUTER REBAR USED FOR THE RETAINING WALL SHALL RUN IN THE VERTICAL DIRECTION.
21. △5 THE ISFSI STRUCTURE CONCRETE COMPRESSIVE STRENGTH, DENSITY, AND REINFORCEMENT REQUIREMENTS ARE SPECIFIED IN TABLE 2.I.1 OF THE HI-STORM 100 FSAR.
22. △5 EXCAVATION ACTIVITIES ASSOCIATED WITH THE CONSTRUCTION OF A NEW UNDERGROUND ISFSI ARE NOT ALLOWED WITHIN THE EXCAVATION EXCLUSION ZONE (SEE SECTION 2.I.2 OF THE HI-STORM 100 FSAR FOR DEFINITION).
23. △5 THE CLEARANCE GAP AT THE JOINT BETWEEN THE TOP SURFACE PAD AND THE RETAINING WALL SHALL BE GREATER THAN THE LONG-TERM SETTLEMENT OF THE SUBGRADE TO ENSURE THAT THE TOP SURFACE PAD IS FULLY SUPPORTED BY THE UNDERLYING SUBGRADE.
24. △5 UPPER MPC GUIDES MAY BE OF EITHER TUBE OR PLATE DESIGN AS SHOWN. ONLY ONE TYPE MAY BE USED IN A SINGLE VVM.



THIS COVER SHEET MUST BE MAINTAINED WITH THE LATEST REVISIONS OF THE DRAWING IDENTIFIED HEREIN.

HOLTEC INTERNATIONAL
HOLTEC CENTER
555 LINCOLN CENTER
MARLTON, NJ 08053

CLIENT	GENERAL		
DESCRIPTION	HI-STORM 100U VERTICAL VENTILATED MODULE		
PROJECT NO 1024	DRAWING NO 4501	SHEET 1	TOTAL SHEETS 7 △5
P.O. NO N/A	FILE PATH G:\DRAWINGS\1024\4501		

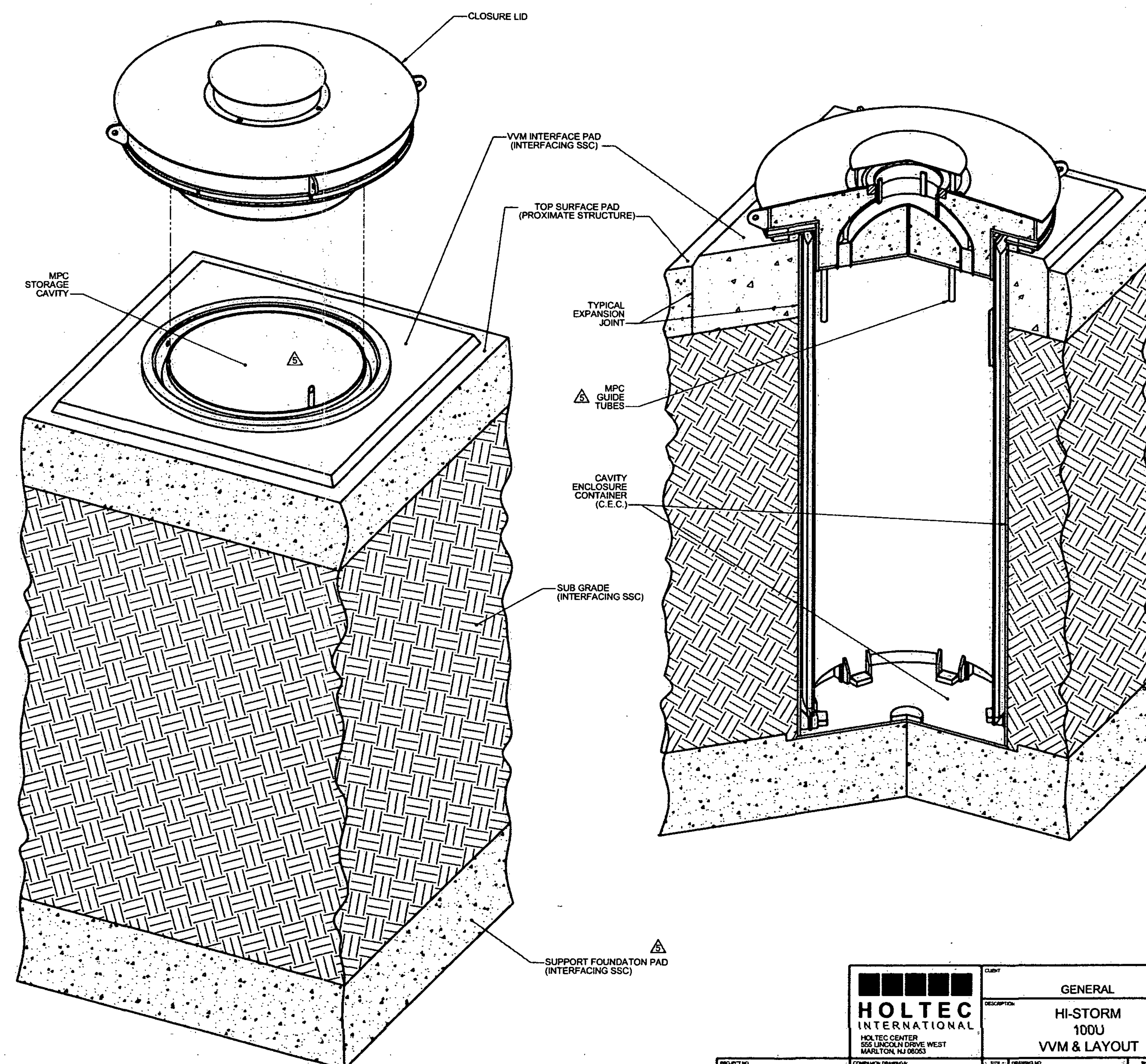


PLAN VIEW

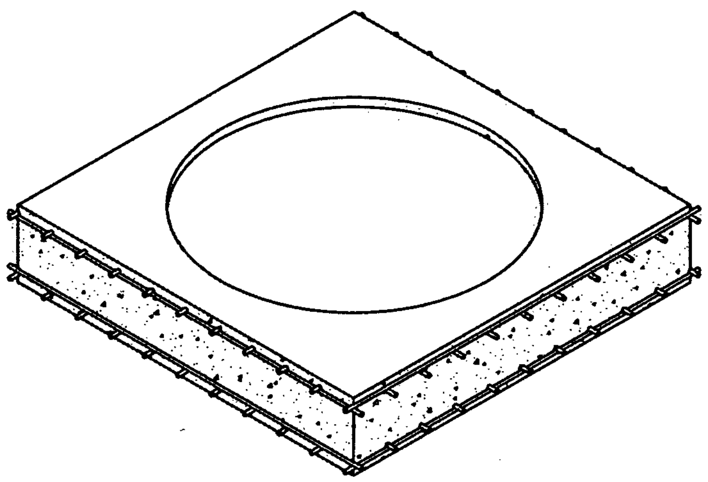
TYPICAL ISFSI LAYOUT

(NON-RECTANGULAR ARRAY SHOWN TO INDICATE LAYOUT FLEXIBILITY)

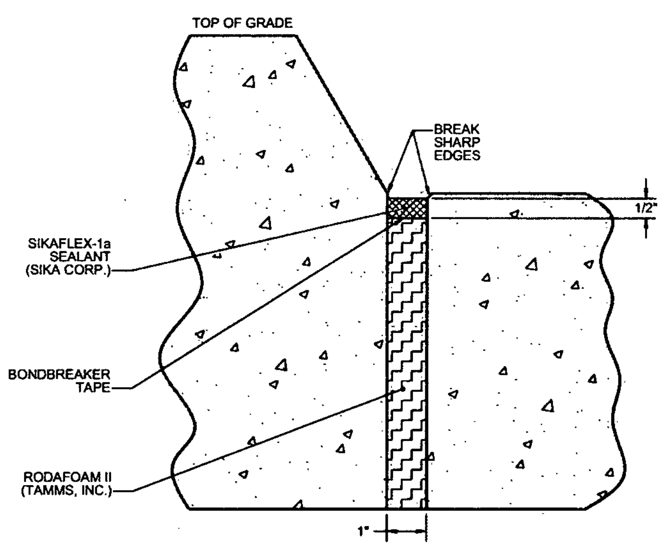
(PITCH IN ONE OR BOTH DIRECTIONS MAY BE GOVERNED BY TRANSPORTER WIDTH)



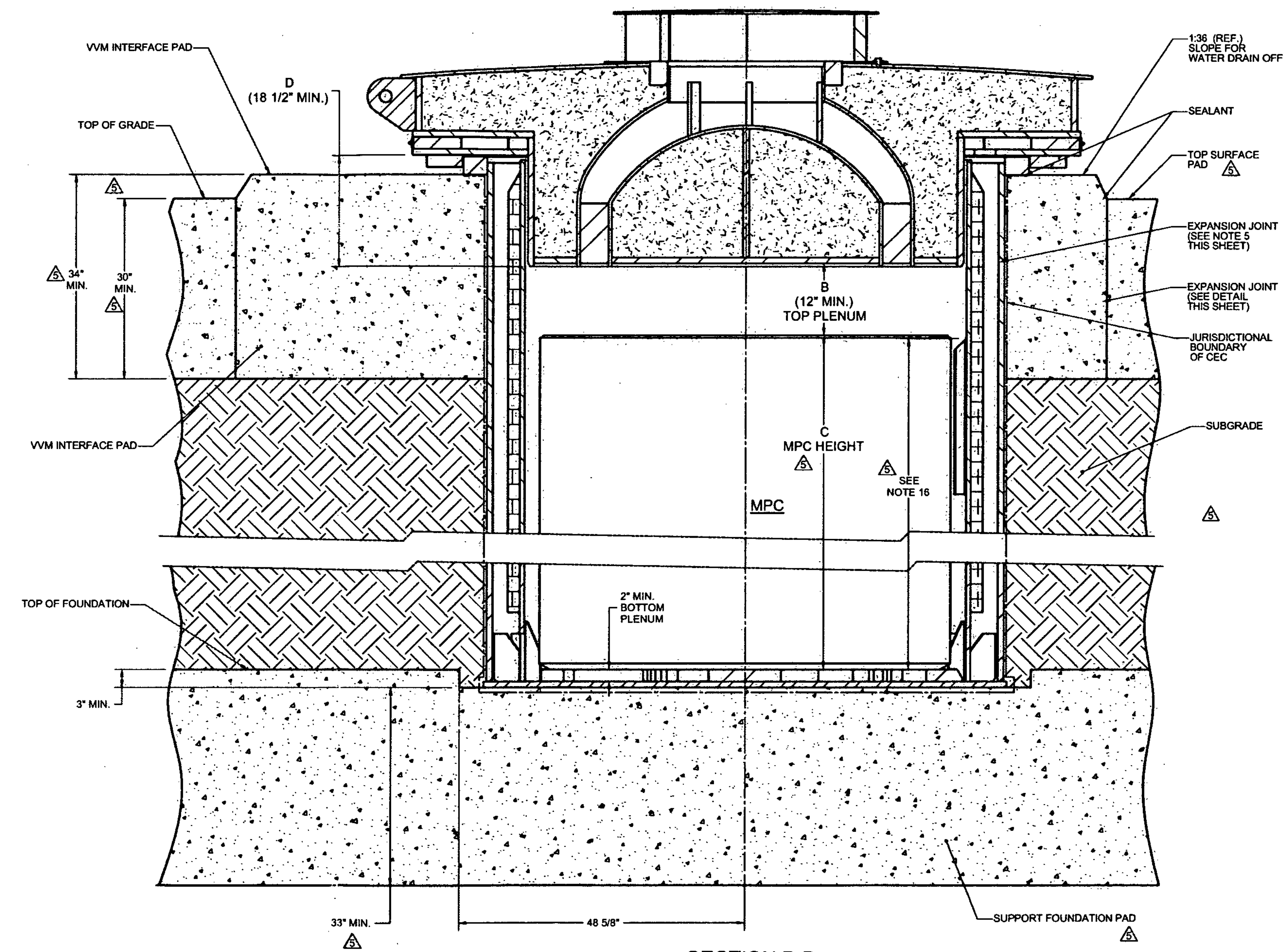
HOLTEC INTERNATIONAL	HOLTEC CENTER, 555 LINCOLN DRIVE WEST, MARLTON, NJ 08053
CLIENT	GENERAL
DESCRIPTION	HI-STORM 100U VVM & LAYOUT
PROJECT NO.	1024
P.O. NO.	N/A
SIZE	D
DRAWING NO.	4501
SHEET	2
REV.	5
SCALE	1:20



A TYPICAL VVM SUPPORT FOUNDATION PAD LAYOUT



EXPANSION JOINT DETAIL
(SEE NOTES 2-4, THIS SHEET)



SECTION B-B

NOTES:

1. - DELETED -
2. CHAMFER JOINT TO REMOVE SHARP EDGES.
3. BRUSH BLAST TOP OF JOINT.
4. PRIME AS NECESSARY FOR UNDERWATER SERVICE.
5. REQUIRED AT ISFSIs WHERE POTENTIAL FOR MACRO-SLIPPAGE BETWEEN THE VVM INTERFACE PAD CONCRETE AND THE CEC CONTAINER SHELL EXISTS. OTHERWISE OPTIONAL. EXPANSION JOINT MAY BE RODAFOAM II (TAMMS, INC) OR OTHER SUITABLE TYPE.

HOLTEC INTERNATIONAL
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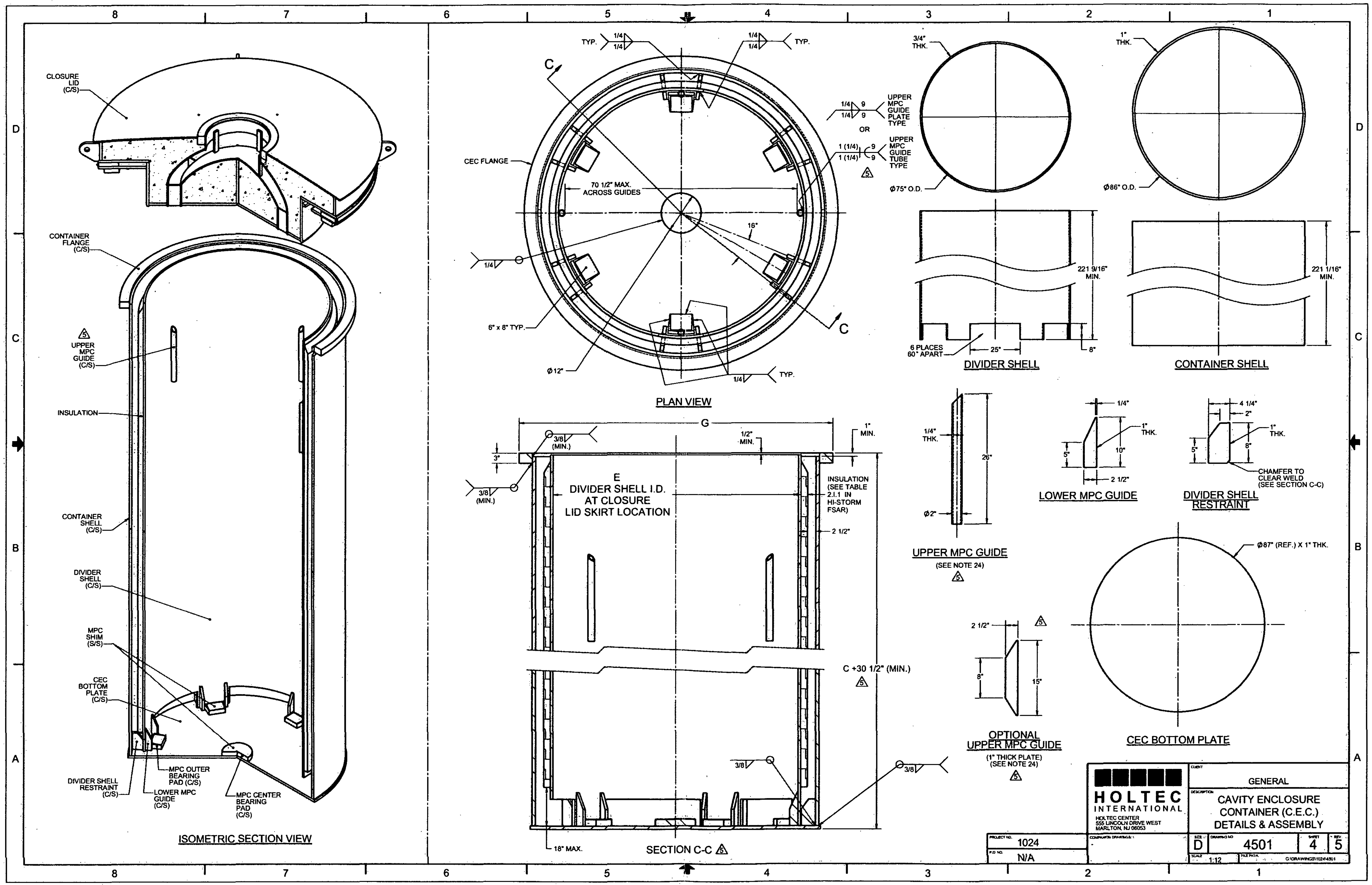
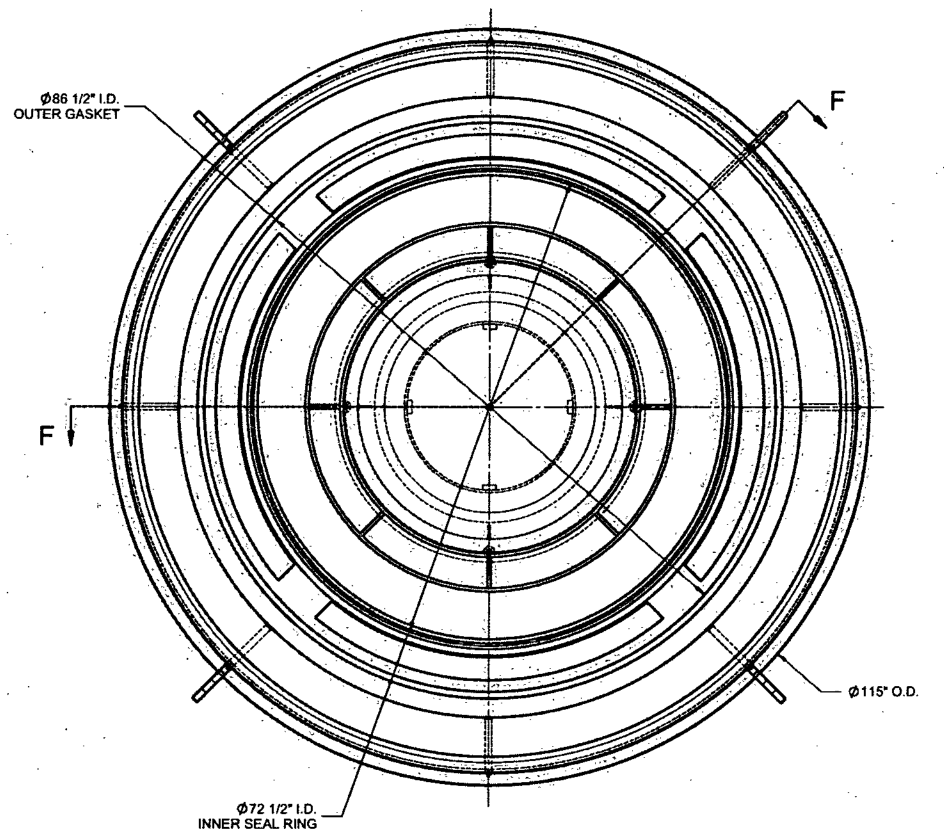
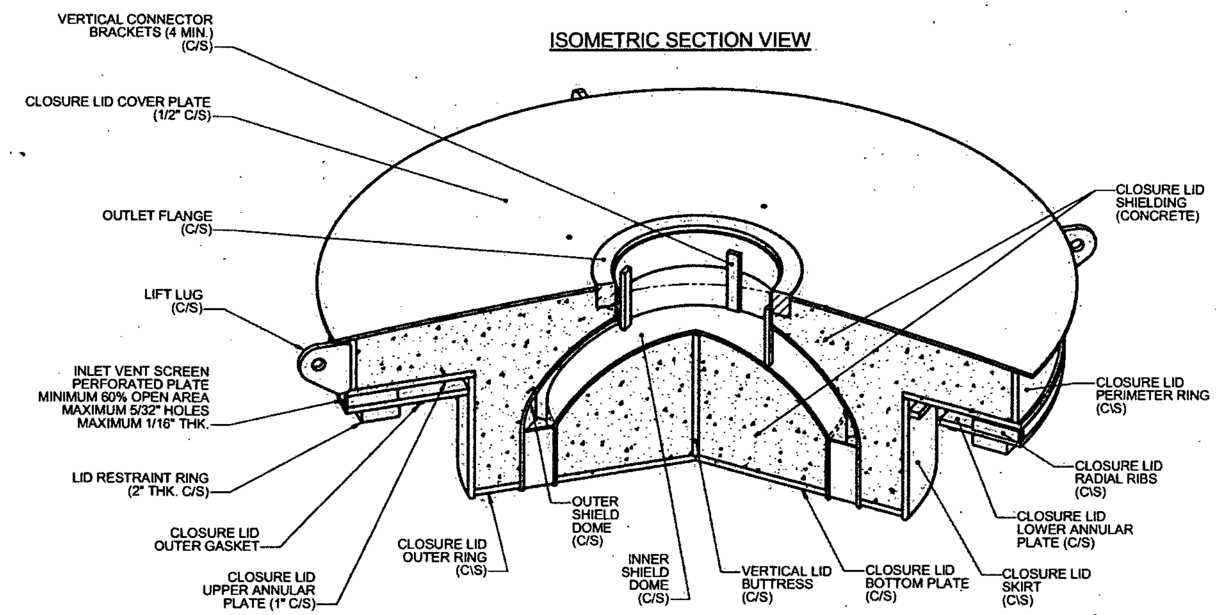
PROJECT NO.	1024
P.O. NO.	N/A
CLIENT	GENERAL
DESCRIPTION	HI-STORM 100U VVM IN CROSS SECTION
SIZE	D
DRAWING NO.	4501
SHEET	3
REV.	5
SCALE	1:10



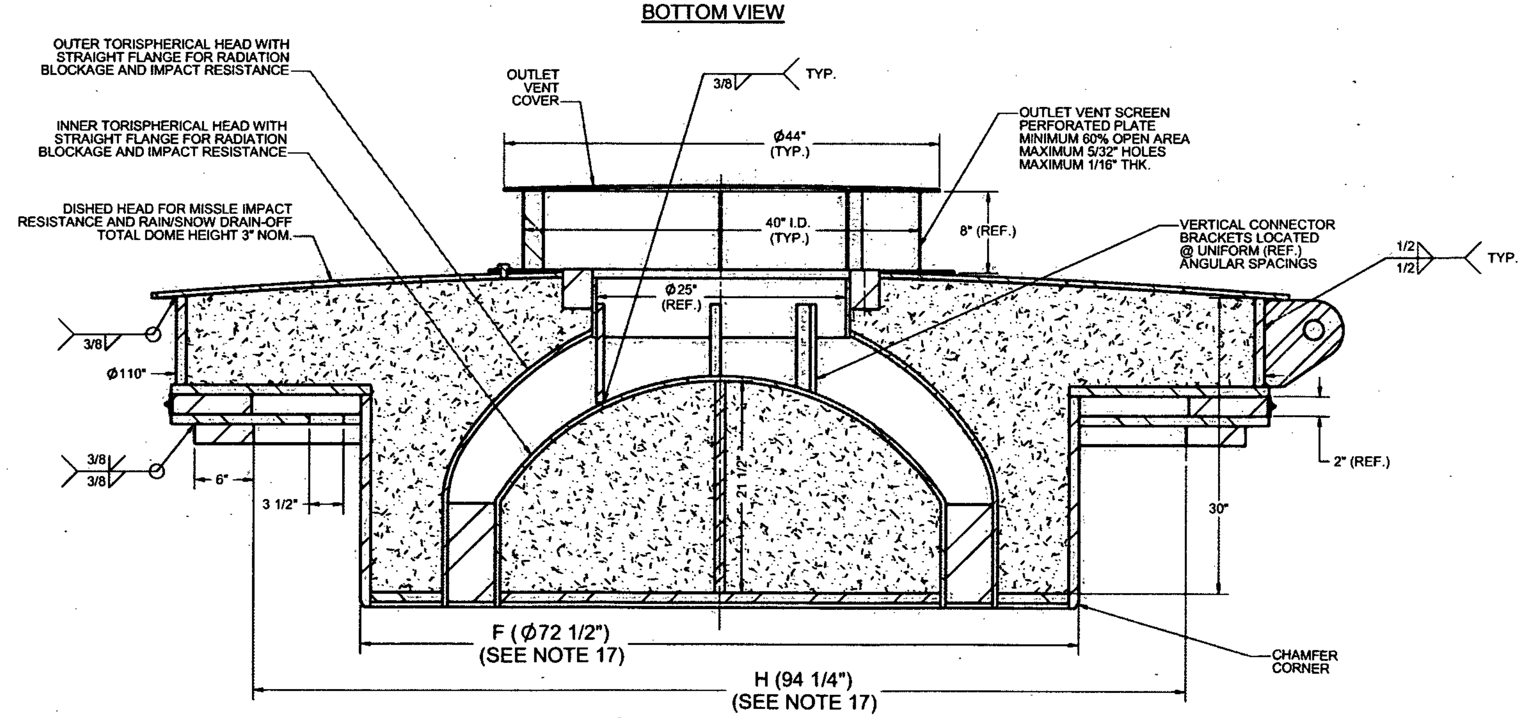
CLOSURE LID (C/S)
CONTAINER FLANGE (C/S)
UPPER MPC GUIDE (C/S)
INSULATION
CONTAINER SHELL (C/S)
DIVIDER SHELL (C/S)
MPC SHIM (S/S)
CEC BOTTOM PLATE (C/S)
DIVIDER SHELL RESTRAINT (C/S)
LOWER MPC GUIDE (C/S)
MPC OUTER BEARING PAD (C/S)
MPC CENTER BEARING PAD (C/S)
ISOMETRIC SECTION VIEW
CEC FLANGE
70 1/2" MAX. ACROSS GUIDES
16"
6" x 8" TYP.
Ø12"
TYP.
PLAN VIEW
UPPER MPC GUIDE PLATE TYPE
OR
UPPER MPC GUIDE TUBE TYPE
G
3/8 (MIN.)
1/2" MIN.
1" MIN.
3"
E
DIVIDER SHELL I.D.
AT CLOSURE
LID SKIRT LOCATION
INSULATION (SEE TABLE 2.1.1 IN HI-STORM FSAR)
2 1/2"
C +30 1/2" (MIN.)
18" MAX.
SECTION C-C
3/4" THK.
Ø75" O.D.
1" THK.
Ø86" O.D.
221 9/16" MIN.
221 1/16" MIN.
6 PLACES 60° APART
25"
8"
DIVIDER SHELL
CONTAINER SHELL
1/4" THK.
26"
Ø2"
UPPER MPC GUIDE
(SEE NOTE 24)
1/4"
1" THK.
10"
5"
2 1/2"
LOWER MPC GUIDE
4 1/4"
2"
8"
CHAMFER TO CLEAR WELD (SEE SECTION C-C)
DIVIDER SHELL RESTRAINT
Ø87" (REF.) X 1" THK.
2 1/2"
15"
OPTIONAL UPPER MPC GUIDE
(1" THICK PLATE)
(SEE NOTE 24)
CEC BOTTOM PLATE
HOLTEC INTERNATIONAL
HOLTEC CENTER
555 LINCOLN DRIVE WEST
MARLTON, NJ 08053
GENERAL
CAVITY ENCLOSURE CONTAINER (C.E.C.) DETAILS & ASSEMBLY
PROJECT NO. 1024
P.O. NO. N/A
D
4501
4
5
1:12



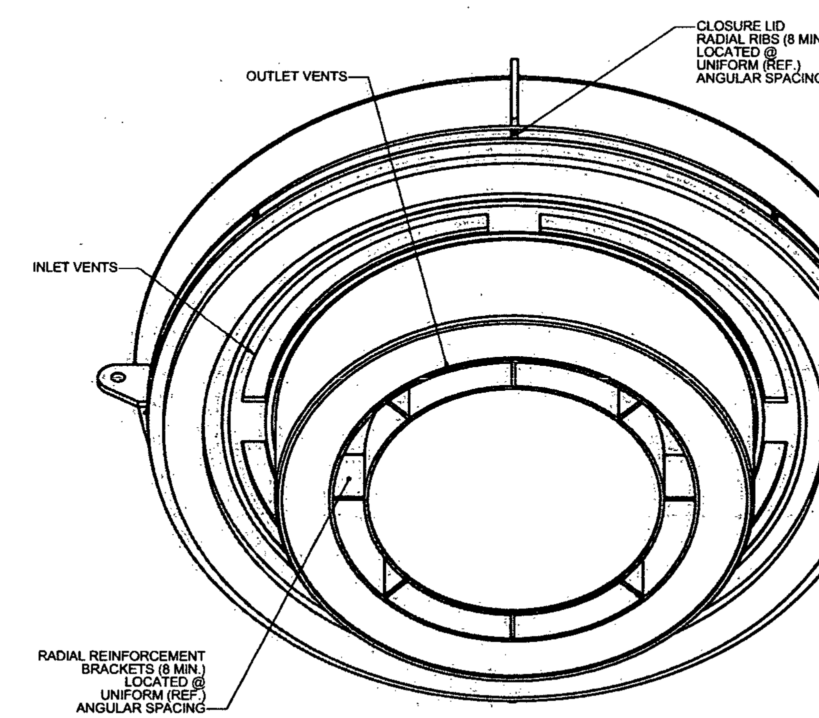
BOTTOM VIEW



ISOMETRIC SECTION VIEW

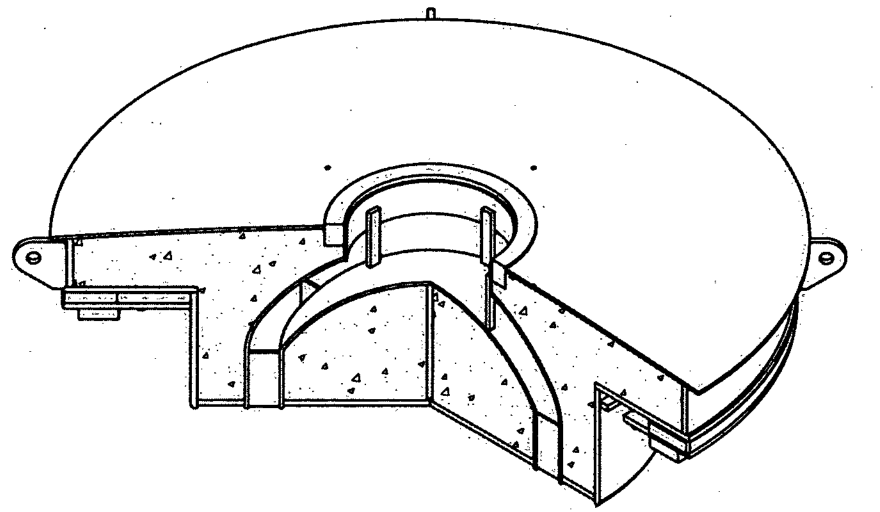


SECTION F-F
SCALE 1 : 8

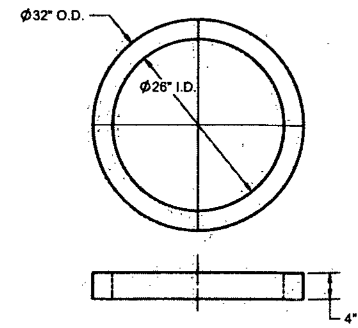


ISOMETRIC BOTTOM VIEW

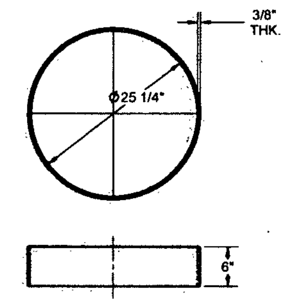
CLIENT	GENERAL
HOLTEC INTERNATIONAL, HOLTEC CENTER, 555 LINCOLN DRIVE WEST, MARLTON, NJ 08053	DESCRIPTION: HI-STORM 100U CLOSURE LID ASSEMBLY
PROJECT NO. 1024	COMPANION DRAWING NO. -
P.O. NO. N/A	SIZE D; DRAWING NO. 4501; SHEET 5; REV. 5
SCALE 1:12	FILE PATH G:\DRAWINGS\1024\4501



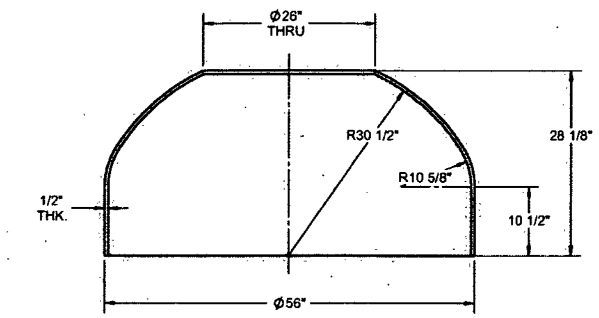
ISOMETRIC SECTION VIEW



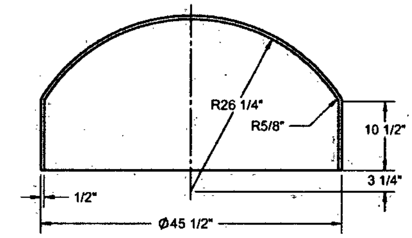
OUTLET FLANGE



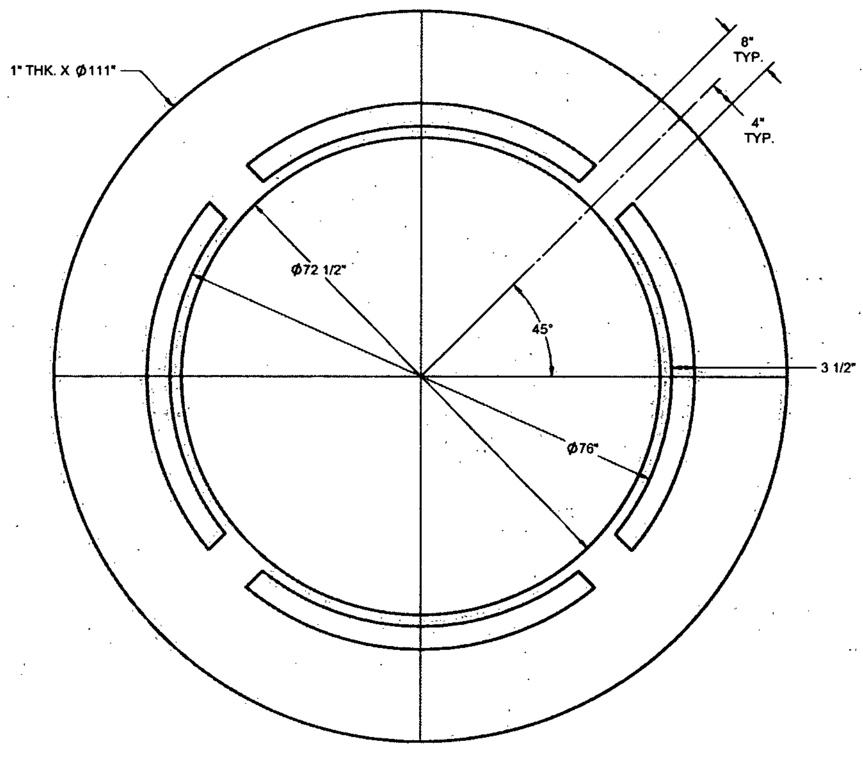
OUTLET RING



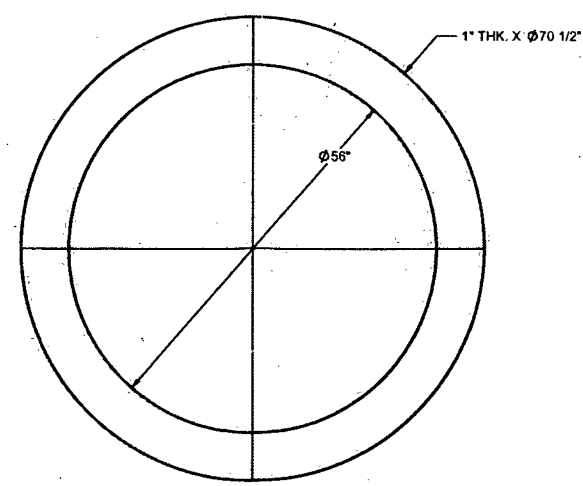
OUTER SHIELD DOME



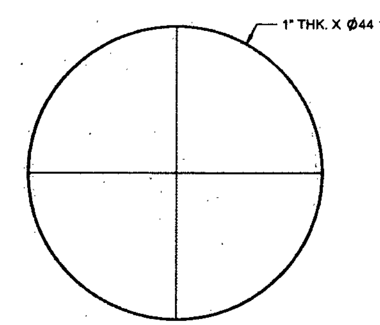
INNER SHIELD DOME



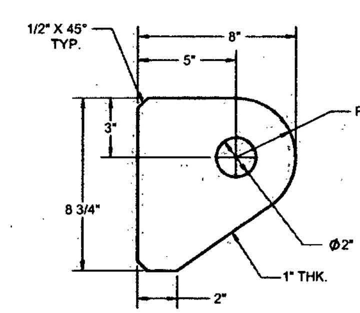
LOWER ANNULAR PLATE



CLOSURE LID OUTER RING



CLOSURE LID BOTTOM PLATE



LIFT LUG

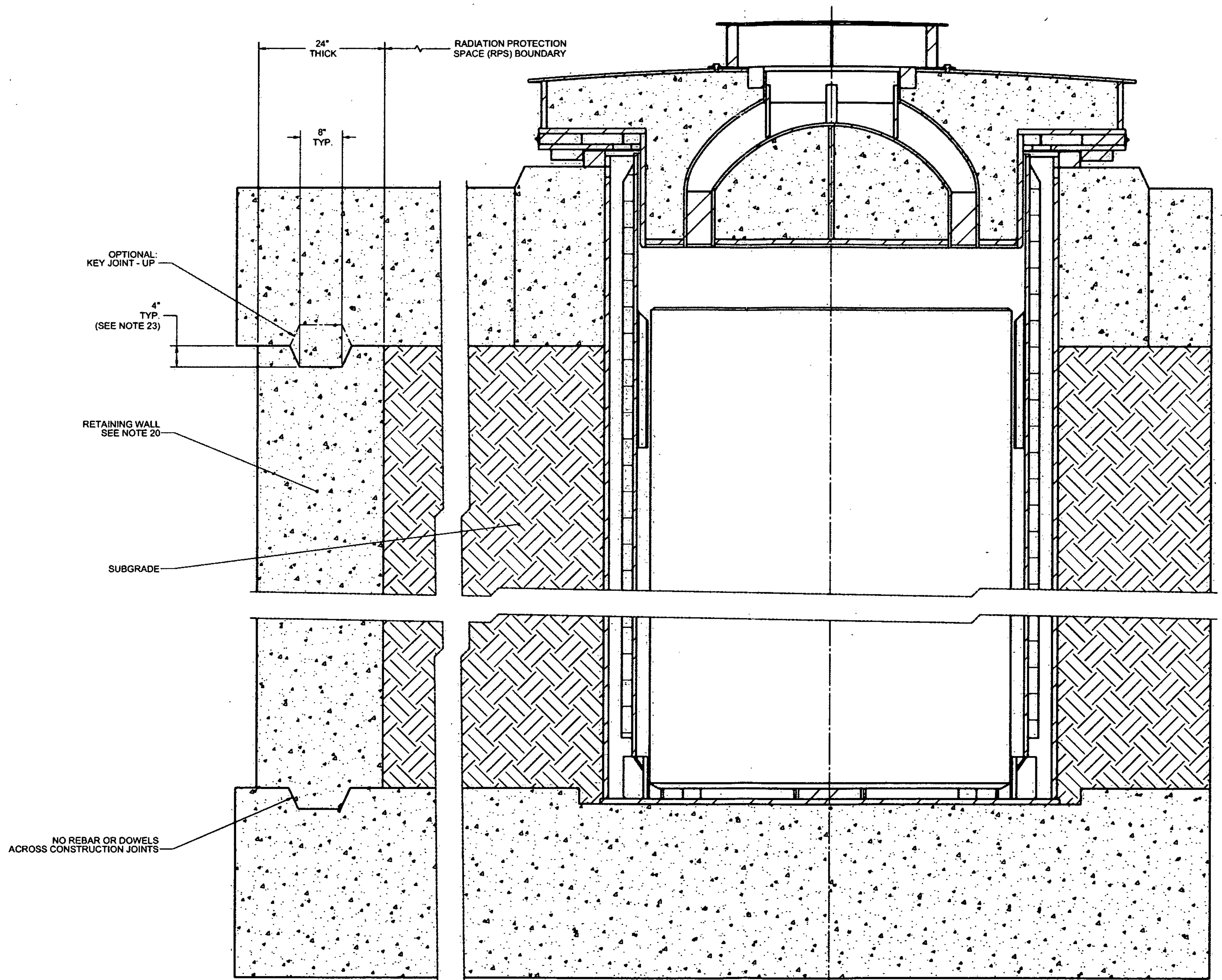
HOLTEC INTERNATIONAL
HOLTEC CENTER
555 LINCOLN DRIVE WEST
MARLTON, NJ 08053

CLIENT: GENERAL

DESCRIPTION: HI-STORM 100U CLOSURE LID DETAILS

PROJECT NO. 1024
P.O. NO. N/A

SIZE D | DRAWING NO. 4501 | SHEET 6 | REV 5
SCALE 1:12



RETAINING WALL DETAIL

5

HOLTEC INTERNATIONAL HOLTEC CENTER 555 LINCOLN DRIVE WEST MARLTON, NJ 08053	CLIENT: GENERAL
	DESCRIPTION: HI-STORM 100U RETAINING WALL DETAILS
PROJECT NO. 1024	COMPANION DRAWINGS: -
P.O. NO. N/A	SIZE: D; DRAWING NO. 4501; SHEET 7; REV 5
	SCALE 1:10; FILE PATH: G:\DRAWINGS\1024\4501