FINAL SAFETY ANALYSIS REPORT

on

THE HI-STORM UMAX

CANISTER STORAGE SYSTEM

by

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USNRC Docket # 72-1040
Holtec Project 5021
Holtec Report # HI-2115090

Safety Category: Safety Significant

HOLTEC INTERNATIONAL

DOCUMENT NUMBER: HI-2115090

PROJECT NUMBER: 5021

DOCUMENT ISSUANCE AND REVISION STATUS

DOCUMENT NAME: FINAL SAFETY ANALYSIS REPORT ON THE HI-STORM UMAX CANISTER STORAGE SYSTEM

DOCUMENT CATEGORY: ☒ GENERIC ☐ PROJECT SPECIFIC

No.	Document Portion††	REVISION No. 0			REVISION No. 1			REVISION No. ___		
		Author's Initials	Date Approved	VIR #	Author's Initials	Date Approved	VIR #	Author's Initials	Date Approved	VIR #
1.	CHAP1	KPS	6/29/2012	823358	VG	11/20/12	857726			
2.	CHAP2	VG	6/29/2012	922114	VG	11/20/12	793911			
3.	CHAP3	JZ	6/29/2012	75144	CB	11/20/12	165716			
4.	CHAP4	YL	6/29/2012	187264	AHM	11/20/12	73565			
5.	CHAP5	KB	6/29/2012	234799	KB	11/20/12	59687			
6.	CHAP6	KPS	6/29/2012	892465	SPA	11/20/12	195569			
7.	CHAP7	KPS	6/29/2012	367199	KB	11/20/12	704194			
8.	CHAP8	JDG	6/29/2012	175157	VG	11/20/12	757936			
9.	CHAP9	SA	6/29/2012	106162	VG	11/20/12	73714			
10.	CHAP10	JDG	6/29/2012	779523	VG	11/20/12	645258			
11.	CHAP11	KB	6/29/2012	822052	N/A	N/A	N/A			
12.	CHAP12	YL	6/29/2012	547551	AHM	11/20/12	213451			
13.	CHAP13	VG	6/29/2012	498943	VG	11/20/12	136210			
14.	CHAP14	KPS	6/29/2012	444390	N/A	N/A	N/A			
15.	-									

†† Chapter or section number.

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DOCUMENT CATEGORIZATION

In accordance with the Holtec Quality Assurance Manual and associated Holtec Quality Procedures (HQPs), this document is categorized as a:

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☐ Design Criterion Document (Per HQP 3.4) ☐ Design Specification (Per HQP 3.4)

☐ Other (Specify):

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FSAR SECTION REVISION STATUS, LIST OF AFFECTED SECTIONS AND REVISION SUMMARY

FSAR Report No.: HI-2115090	**FSAR Revision Number:** 1

FSAR Title:	Final Safety Analysis Report on the HI-STORM UMAX System

This FSAR is submitted to the USNRC in support of Holtec International's application to secure a CoC under 10CFR Part 72.

FSAR review and verification are controlled at the chapter level and changes are annotated at the chapter level.

A section in a chapter is identified by two numerals separated by a decimal. Each section begins on a fresh page. Unless indicated as a "complete revision" in the summary description of change below, if any change in the content is made, then the change is indicated by a "bar" in the right page margin and the revision number of the entire chapter including applicable figures (annotated in the footer) is changed.

A summary description of change is provided below for each FSAR chapter. Minor editorial changes to this FSAR may not be summarized in the description of change.

Chapter 1

Affected Section or Table No.	Current Revision No.	Summary Description of Change
Table 1.0.1 Section 1.1 Section 1.5	1	Few editorial clarifications in Section 1.0 and Added the Table 1.0.1 to address NRC RSI 1-1(a) Section 1.1: Removed reference to HI-STORM 100 FSAR for FHD design criteria but instead refer to Section 2.5.1.1 [RSI 1-1(c)] and removed redundant information on the next sheet regarding FHD Section 1.5: Added the latest revision of UMAX drawing. Drawing 8446 was revised to add NRC RSI observation

Chapter 2

Section or Table No.	Current Revision No.	Summary Description of Change
Table Section 2.5.1 Section 2.6	1	Few editorial clarifications in Section 2.0.1 and added the Table to address NRC RSI 1-1(a) Added Section 2.5.1 and Section 2.5.1.1 to add FHD design criteria information [address RSI 1-1(c)] Section 2.6: Removed reference to Appendix 1.D of the HI-STORM 100 FSAR for plain concrete information and instead referred to Chapter 8

Chapter 3

Section or Table No.	Current Revision No.	Summary Description of Change
Table Table 3.1.1 Section 3.3.2 Table 3.4.4 Table 3.4.8	1	Added text for editorial clarifications in Section 3.0 and Added the Table to address NRC RSI 1-1(a) Table 3.1.1: Updated reference number to FW FSAR. Section 3.3.2: Removed reference to Appendix 1.D of the HI-STORM 100 FSAR for plain concrete information and instead referred to Chapter 8 Table 3.4.4: Removed reference to 100 U and added reference to UMAX section Table 3.4.8: Updated safety factors and calculated value to be consistent with the calculation package submitted to NRC. (editorial correction- decimal points)

Chapter 4

Section or Table No.	Current Revision No.	Summary Description of Change
Table 4.0.1 Table 4.2.1 Section 4.4.1 Section 4.4.8 Table 4.4.11 Section 4.8	1	Added text for editorial clarifications in Section 4.0 Added Table 4.0.1 to address NRC RSI 1-1(a). Updated the reference to density of concrete to Chapter 2. Added a sentence to clarify that the effective fuel properties are the same as those used in HI-STORM FW FSAR. Added Section 4.4.8 and Table 4.4.11 to address NRC RSI 4-1 on effects of fuel burnup on the thermal performance of HI-STORM UMAX System. Added references to address NRC RSI 4-1 in support of Section 4.4.8 of the UMAX FSAR.

Chapter 5

Section or Table No.	Current Revision No.	Summary Description of Change
Table	1	Added the Table to address NRC RSI 1-1(a)

Chapter 6

Section or Table No.	Current Revision No.	Summary Description of Change
Table Section 6.2	1	Section 6.2: Revised to address NRC RSI 6-1 for MPC flooded with water

Chapter 7 Changes

Section or Table No.	Current Revision No.	Summary Description of Change
Section7.0 and 7.2	1	Editorial clarifications

Chapter 8 Changes

Section or Table No.	Current Revision No.	Summary Description of Change
Table Section 8.2.2 Appendix 8.A	1	Added the Table to address NRC RSI 1-1(a) Section 8.2: Replaced reference to Table 1.2.1 and 1.2.2 of HI-STORM FW FSAR with Section 8.2 of HI-STORM FW FSAR Appendix 8.A: Added excerpted text for plain concrete from Appendix 1.D of HI-STORM 100 FSAR

Chapter 9 Changes

Section or Table No.	Current Revision No.	Summary Description of Change
Table 9.0.1 Section 9.0 and 9.2 Section 9.4.2(7)	1	Added Table 9.0.1 to address NRC RSI 1-1(a) Section 9.0 and 9.2: removed reference to FW CoC Section 9.4.2 (7): Removed the bolt pre- tensioning requirements

Chapter 10 Changes

Section or Table No.	Current Revision No.	Summary Description of Change
Table 10.0.1	1	Added Table 10.0.1 to address NRC RSI 1-1(a)

Chapter 11 Changes

Section or Table No.	Current Revision No.	Summary Description of Change
	0	No Changes

Chapter 12 Changes

Section or Table No.	Current Revision No.	Summary Description of Change
Table 12.0.1	1	Added text in section 12.0 and Table 12.0.1 to address NRC RSI 1-1(a)

Chapter 13 Changes

Section or Table No.	Current Revision No.	Summary Description of Change
Section 13.0	1	Editorial corrections

Chapter 14 Changes

Section or Table No.	Current Revision No.	Summary Description of Change
	0	No Changes

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GLOSSARY OF TERMS USED IN HI-STORM SAFETY ANALYSIS REPORTS

AFR is an acronym for Away from Reactor storage.

ALARA is an acronym for As Low As Reasonably Achievable

Ambient Temperature for Short Term Operations (operations involving use of the HI-TRAC, a Lifting device and/ or a on-site transport device) is defined as the 24 hour average of the local temperature as forecast by the National Weather Service.

Ancillary or Ancillary Equipment is the generic name of a device used to carry out "short term operations.

Bottom Lid means the removable lid that fastens to the bottom of the HI-TRAC transfer cask body to create a gasketed barrier against in-leakage of pool water in the space around the MPC.

Bottom MPC Guides are the MPC Guides located in the bottom region of the MPC storage cavity.

BWR is an acronym for Boiling Water Reactor.

Canister means an all-welded vessel containing used fuel that has been qualified to serve as a confinement boundary under the rules of 10CFR 72.

Cavity Enclosure Container (CEC) means a thick walled cylindrical steel weldment that defines the storage cavity for the MPCs.

CG is an acronym for center of gravity.

Closure Lid means the METCON lid that is installed on the MPC storage cavity to provide physical and shielding protection to the stored MPC.

Commercial Spent Fuel or CSF refers to nuclear fuel used to produce energy in a commercial nuclear power plant.

Confinement Boundary means the outline formed by the sealed, cylindrical enclosure of the Multi-Purpose Canister (MPC) shell welded to a solid baseplate, a lid welded around the top circumference of the shell wall, the port cover plates welded to the lid, and the closure ring welded to the lid and MPC shell providing the redundant sealing.

Confinement System means the Multi-Purpose Canister (MPC) which encloses and confines the spent nuclear fuel during storage.

Container Flange means the ring flange that is welded to the upper extremity of the Container shell.

Container Shell means the cylindrical portion of the Cavity Enclosure Container

Controlled Area means that area immediately surrounding an ISFSI for which the owner/user exercises authority over its use and within which operations are performed.

Controlled Low-Strength Material (CLSM)- Text withheld in Accordance with 10 CFR 2.390.

Cooling Time (or post-irradiation cooling time) for a spent fuel assembly is the time between its final discharge from the reactor to the time it is loaded into the MPC.

Critical Characteristic means a feature of a component or assembly that is necessary for the proper safety function of the component or assembly. Critical characteristics of a material are those attributes that have been identified, in the associated material specification, as necessary to render the material's intended function.

DAS is the abbreviation for the Decontamination and Assembly Station. It means the location where the Transfer Cask is decontaminated and the MPC is processed (i.e., where all operations culminating in lid and closure ring welding are completed).

DBE means Design Basis Earthquake.

DCSS is an acronym for Dry Cask Storage System.

Damaged Fuel Assembly is a fuel assembly with known or suspected cladding defects, as determined by review of records, greater than pinhole leaks or hairline cracks, empty fuel rod locations that are not replaced with dummy fuel rods, missing structural components such as grid spacers, whose structural integrity has been impaired such that geometric rearrangement of fuel or gross failure of the cladding is expected based on engineering evaluations, or those that cannot be handled by normal means. Fuel assemblies that cannot be handled by normal means due to fuel cladding damage are considered fuel debris.

Damaged Fuel Container (or Canister) or DFC means a specially designed enclosure for damaged fuel or fuel debris which permits flow of gaseous and liquid media while minimizing dispersal of gross particulates.

Design Basis Load (DBL) is a loading defined in this SAR to bound one or more events that are applicable to the storage system during its service life. Thus, the pressure loading on the cask's lid specified in this SAR is a DBL because it is set substantially above the pressure from accumulated snow set down in the national consensus standard for the 48 contiguous United States.

Design Heat Load is the computed heat rejection capacity of the HI-STORM system with a certified MPC loaded with CSF stored in uniform storage with the ambient at the normal temperature and the peak cladding temperature (PCT) at 400°C. The Design Heat Load is less than the thermal capacity of the system by a suitable margin that reflects the conservatism in the system thermal analysis.

Design Life is the minimum duration for which the component is engineered to perform its intended function set forth in this SAR, if operated and maintained in accordance with this SAR.

Design Report is a document prepared, reviewed and QA validated in accordance with the provisions of 10CFR72 Subpart G. The Design Report shall demonstrate compliance with the requirements set forth in the Design Specification. A Design Report is mandatory for systems, structures, and components designated as Important to Safety. The SAR serves as the Design Report for the HI-STORM UMAX System.

Design Specification is a document prepared in accordance with the quality assurance requirements of 10CFR72 Subpart G to provide a complete set of design criteria and functional requirements for a system, structure, or component, designated as Important to Safety, intended to be used in the operation, implementation, or decommissioning of the HI-STORM UMAX System. The SAR serves as the Design Specification for the HI-STORM UMAX System.

Divider Shell means a cylindrical shell bearing insulation over most of its inner or outer surface that divides the annular space between the MPC and the CEC shell into two discrete regions for down- flow and up-flow of air..

Duct Extension means a removable, non-structural member fastened to the inlet or outlet duct to move the location of air intake or exhaust, as applicable

Enclosure Wall means an optional circumscribing structure installed to mitigate the incursion of groundwater into the subgrade space of the ISFSI.

Enclosure Vessel (or MPC Enclosure Vessel) means the pressure vessel defined by the cylindrical shell, baseplate, port cover plates, lid, closure ring, and associated welds that provides confinement for the helium gas contained within the MPC. The Enclosure Vessel (EV) and the fuel basket together constitute the multi-purpose canister.

Equivalent (or Equal) Material is a material with critical characteristics (see definition above) that meet or exceed those specified for the designated material.

Fracture Toughness is a property which is a measure of the ability of a material to limit crack propagation under a suddenly applied load.

FSAR is an acronym for Final Safety Analysis Report (10CFR72).

Fuel Basket means a honeycombed structural weldment with square openings which can accept a fuel assembly of the type for which it is designed.

Fuel Building is the generic term used to denote the building in which the fuel loading and where a portion of "short-term operations" will occur.

Fuel Debris is ruptured fuel rods, severed rods, loose fuel pellets, containers or structures that are supporting these loose fuel assembly parts, or fuel assemblies with known or suspected defects which cannot be handled by normal means due to fuel cladding damage.

Fuel Shim is a suitably sized metallic part interposed in the space between the fuel and the MPC cavity at either the top or the bottom (or both) ends of the fuel to minimize the axial displacement of the SNF within the MPC due to longitudinal inertia forces.

High Burnup Fuel, or HBF is a commercial spent fuel assembly with an average burn-up greater than 45,000 MWD/MTU.

HI-PORT is a Holtec trade name for an engineered Low Profile Transporter to that maximizes protection of the cask against overturning under seismic conditions.

HI-TRAC is a generic term for the transfer cask used to house the MPC during MPC fuel loading, unloading, drying, sealing, and on-site transfer operations to a HI-STORM storage module or HI-STAR storage/transportation overpack. The HI-TRAC shields and protects the loaded MPC during short term operations.

HI-STORM VVM means the module that receives and contains the sealed multi-purpose canisters containing spent nuclear fuel for long term storage. It provides the gamma and neutron shielding, ventilation passages, missile protection, and protection against natural phenomena and accidents for the loaded MPC.

HI-STORM UMAX system consists of loaded MPCs stored in the HI-STORM UMAX VVM .

HI-STORM 100 System consists of any loaded MPC model placed within any design variant of the HI-STORM overpack in Docket number 72-1014.

Holtite^{TM}-A is a trademarked Holtec International neutron shield material.

Important to Safety (ITS) means a function or condition required to store spent nuclear fuel safely; to prevent damage to spent nuclear fuel during handling and storage, and to provide reasonable assurance that spent nuclear fuel can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public.

Independent Spent Fuel Storage Installation (ISFSI) means a facility designed, constructed, and licensed for the interim storage of spent nuclear fuel and other radioactive materials associated with spent fuel storage in accordance with 10CFR72.

Intact Fuel Assembly is defined as a fuel assembly without known or suspected cladding defects greater than pinhole leaks and hairline cracks, and which can be handled by normal means. Fuel assemblies without fuel rods in fuel rod locations shall not be classified as Intact Fuel Assemblies unless dummy fuel rods are used to displace an amount of water greater than or equal to that displaced by the fuel rod(s).

Interim Storage means an autonomous monitored canister storage facility from which the stored canister can be retrieved, if necessary.

Interfacing Components means the weldments certified in other dockets that will be used with the HI-STORM UMAX VVM assemblies for transferring and storing MPCs in HI-STORM UMAX. The MPC is an Interfacing Component

ISFSI Pad means the reinforced concrete pad that provides the support surface for the cask handling device.

License Life means the duration for which the system is authorized by virtue of its certification by the U.S. NRC.

Licensing Drawings or Licensing Drawing Package is an integral part of this SAR wherein the essential geometric and material information on HI-STORM UMAX is compiled to enable the safety evaluations pursuant to 10 CFR 72 to be carried out.

Long-term Storage means the time beginning after on-site handling is complete and the loaded overpack is at rest in its designated storage location on the ISFSI pad and lasting up to the end of the licensed life of the HI-STORM 100 System.

Low Profile Transporter (LPT) is the generic name of the ancillary used to move a loaded or empty cask in a plant's "truck bay" and/or the haul path with the cask directly situated on a low lying platform founded on a structurally robust frame such that an uncontrolled lowering (free fall) of the cask is not credible. The LPT must be sufficiently short to insure that the loaded cask can clear the roll-up door in the truck bay.

Lowest Service Temperature (LST) is the minimum metal temperature of a part for the specified service condition.

Maximum Reactivity means the highest possible k-effective including bias, uncertainties, and calculational statistics evaluated for the worst-case combination of fuel basket manufacturing tolerances.

METAMIC® is a trade name for an aluminum/boron carbide composite neutron absorber material qualified for use in the MPCs and in wet storage applications.

METAMIC-HT is the tradename for the metal matrix composite made by imbedding nano-particles of aluminum oxide and fine boron carbide powder on the grain boundaries of aluminum resulting in improved structural strength properties at elevated temperatures.

METCON□ is a trade name for the HI-STORM overpack. The trademark is derived from the metal-concrete composition of the HI-STORM overpack.

MGDS is an acronym for Mined Geological Disposal System.

Minimum Enrichment is the minimum assembly average enrichment. Natural uranium blankets are not considered in determining minimum enrichment.

Moderate Burnup Fuel, or MBF is a commercial spent fuel assembly with an average burnup less than or equal to 45,000 MWD/MTU.

Multi-Purpose Canister or MPC means the sealed canister consisting of a fuel basket for spent nuclear fuel storage, contained in a cylindrical canister shell (the MPC Enclosure Vessel). The MPC is the confinement boundary for storage conditions.

MPC Guides is a generic term to represent Top or Bottom MPC Guides

MPC Transfer means transfer of the MPC between the storage module and the transfer cask which begins when the MPC is lifted off the HI-TRAC bottom lid and ends when the MPC is supported from beneath by the module (or the reverse).

NDT is an acronym for Nil Ductility Transition Temperature, which is defined as the temperature at which the fracture stress in a material with a small flaw is equal to the yield stress in the same material if it had no flaws.

Neutron Absorber is a generic term used in this SAR to indicate any neutron absorber material qualified for use in the MPCs certified in a HI-STORM docket.

Neutron Shielding means a material used to thermalize and capture neutrons emanating from the radioactive spent nuclear fuel.

Non-Fuel Hardware is defined as Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs), Wet Annular Burnable Absorbers (WABAs), Rod Cluster Control Assemblies (RCCAs), Control Element Assemblies (CEAs), Neutron Source Assemblies (NSAs), water displacement guide tube plugs, orifice rod assemblies, Instrument Tube Tie Rods (ITTRs), vibration suppressor inserts, and components of these devices such as individual rods.

Planar-Average Initial Enrichment is the average of the distributed fuel rod initial enrichments within a given axial plane of the assembly lattice.

Plain Concrete is concrete that is unreinforced and is of density specified in this FSAR.

Post-Core Decay Time (PCDT) is synonymous with cooling time.

PWR is an acronym for pressurized water reactor.

Reactivity is used synonymously with effective neutron multiplication factor or k-effective.

Regionalized Fuel Loading is a term used to describe an optional fuel loading strategy used in lieu of uniform fuel loading wherein the storage locations are ascribed to two or more distinct regions each with its own maximum allowable specific heat generation rate.

Regionalized Fuel Storage is a term used to describe an optimized fuel loading strategy wherein the storage locations are ascribed to distinct regions each with its own maximum allowable specific heat generation rate.

Removable Shielding Girdle is an ancillary designed to be installed to provide added shielding to the personnel working in the top region of the transfer cask.

SAR is an acronym for Safety Analysis Report.

Self-hardening Engineered Subgrade (or SES) means CLSM or lean concrete in this FSAR.

Service Life means the duration for which the component is reasonably expected to perform its intended function, if operated and maintained in accordance with the provisions of this FSAR. Service Life may be much longer than the Design Life because of the conservatism inherent in the codes, standards, and procedures used to design, fabricate, operate, and maintain the component.

Short-term Operations means those normal operational evolutions necessary to support fuel loading or fuel unloading operations. These include, but are not limited to MPC cavity drying, helium backfill, MPC transfer, and onsite handling of a loaded HI-TRAC transfer cask.

Single Failure Proof means that the handling system is designed so that all directly loaded tension and compression members are engineered to satisfy the enhanced safety criteria of Paragraphs 5.1.6(1)(a) and (b) of NUREG-0612.

SNF is an acronym for spent nuclear fuel.

SSC is an acronym for Structures, Systems and Components.

STP is Standard Temperature and Pressure conditions.

Support Foundation Pad (SFP) means the reinforced concrete pad located underground on which the CECs are situated.

Subgrade is the lateral space between each CEC, the SFP and the ISFSI Pad.

TAL is an acronym for the Tapped Anchor Location.

Thermal Capacity of the HI-STORM system is defined as the amount of heat the storage system, containing an MPC loaded with CSF stored in *uniform storage,* will actually reject with the ambient environment at the normal temperature and the peak fuel cladding temperature (PCT) at 400°C.

Thermo-siphon is the term used to describe the buoyancy-driven natural convection circulation of helium within the MPC fuel basket.

Top MPC Guides and Bottom MPC Guides mean the set of radial plates that are shaped to aid in the insertion and withdrawal of MPCs and serve to restrain the MPC's lateral movement during seismic events.

TOG is an acronym for top-of-the-grade of the ISFSI and identified by the by the riding surface of the cask transporter.

Traveler means the set of sequential instructions used in a controlled manufacturing program to ensure that all required tests and examinations required upon the completion of each significant manufacturing activity are performed and documented for archival reference.

Undamaged Fuel Assembly is defined as a fuel assembly without known or suspected cladding defects greater than pinhole leaks and hairline cracks, and which can be handled by normal means. Fuel assemblies without fuel rods in fuel rod locations shall not be classified as Intact Fuel Assemblies unless dummy fuel rods are used to displace an amount of water greater than or equal to that displaced by the fuel rod(s).

Under-grade is the space below the SFP.

Uniform Fuel Loading is a fuel loading strategy where any authorized fuel assembly may be stored in any fuel storage location, subject to other restrictions in the CoC, such as those applicable to non-fuel hardware, and damaged fuel containers.

Vertical Cask Transporter or VCT is the generic name for a device that has the ability to raise or lower a cask or a canister with the built-in safety of a redundant drop protection system. A VCT may be designed to be limited in its operation space to the ISFSI pad area and/or it may have the capability to translocate the cask over a suitably engineered haul path.

VVM is an acronym for Vertical Ventilated Module

ZPA is an acronym for zero period acceleration.

ZR means any zirconium-based fuel cladding material authorized for use in a commercial nuclear power plant reactor. Any reference to Zircaloy fuel cladding in this FSAR applies to any zirconium-based fuel cladding material.

CHAPTER 1: GENERAL DESCRIPTION OF THE HI-STORM UMAX SYSTEM

1.0 GENERAL INFORMATION

This final safety analysis report (FSAR) describes the Holtec International HI-STORM UMAX Canister Storage System (HI-STORM UMAX) and contains the necessary information and analyses to support a United States Nuclear Regulatory Commission (USNRC) licensing review as a spent nuclear fuel (SNF) dry storage cask under the provisions of 10 CFR 72 [1.0.3]. This report, prepared pursuant to 10 CFR 72.230, describes the basis for NRC approval and issuance of a Certificate of Compliance (CoC) on the HI-STORM UMAX System under 10 CFR 72, Subpart L to safely store spent nuclear fuel (SNF) at an Independent Spent Fuel Storage Installation (ISFSI) under the general license authorized by 10 CFR 72, Subpart K.

The HI-STORM UMAX stores a hermetically sealed canister containing spent nuclear fuel in an in-ground Vertical Ventilated Module (VVM). The safety evaluation and regulatory control is maintained in USNRC docket # 72-1040. The annex identifier UMAX is an acronym of Underground MAXimum capacity. HI-STORM UMAX is designed to provide long-term underground storage of loaded multi-purpose canisters (MPC) previously certified for storage by the USNRC in Holtec International ("Holtec") Docket 72-1032 (HI-STORM FW) [1.0.2]. The HI-STORM UMAX VVM is essentially the underground equivalent of the HI-STORM FW overpack certified in Docket# 72-1032. Although the storage cavity dimensions and the air ventilation system in the HI-STORM UMAX VVM have been selected to enable it to also store all MPCs certified in for storage in the HI-STORM 100 overpack (Docket number 72-1014)[1.0.1], this FSAR does not seek to support their certification at this time. Safety analyses and evaluations of the HI-STORM 100 MPCs under (hypothetical) storage in HI-STORM UMAX are nevertheless included in this FSAR, as appropriate, to provide a comparative reference for the licensing-basis analyses of the HI-STORM FW canisters (MPC-37 & MPC-89). Thus while the safety analyses have been carried out in this FSAR for all MPCs presently certified in docket # 72-1014 (HI-STORM 100) and docket # 72-1032 (HI-STORM FW) , the Certificate-of-Compliance sought pursuant to this licensing submittal is *limited to qualifying only MPC-37 and MPC-89 which have been previously certified in the HI-STORM FW docket.* .Inclusion of the smaller MPCs originally certified in the HI-STORM 100 docket serves to underscore the plausible result that the structural and thermal margins are controlled by the larger canister. Specifically, it is found that MPC-37 governs in respect of structural and thermal margins. MPC-37 is therefore designated as the "governing canister". To insure that the CoC for the HI-STORM UMAX system is autonomously complete, the entire body of the latest versions of the Technical Specification pertaining to MPC-37, MPC-89 and HI-TRAC VW is excerpted from the "FW" docket and included in the proposed Technical Specifications for the HI-STORM UMAX storage system. To facilitate convenient access to the referenced material, the latest revision of the HI-STORM FW FSAR has been placed in this docket and a list of "FW " FSAR sections germane to this chapter is provided in a tabular form. Table 1.0.1 provides a listing of the applicable material adopted in this chapter by reference to the HI-STORM FW FSAR.

Except in cases where clarity of presentation calls for reproduction of the HI-STORM FW FSAR material in this FSAR, the safety analyses for the canisters and the transfer cask documented in the HI-STORM FW FSAR, where applicable, are incorporated by reference. *Directly copied FSAR text matter from the "FW" docket is provided in the "Arial" font to identify its provenance.*

HI-STORM UMAX is intended for dry storage of spent nuclear fuel at an Independent Spent Fuel Storage Installation (ISFSI) under 10CFR 72 [1.0.3] Subpart L. The HI-STORM UMAX ISFSI (illustrated in Figure 1.0.1), which may contain any number of UMAX VVMs, may be co-located at a licensed reactor site or at an away-from-reactor (AFR) site such as an interim storage facility. Certain innovative design features of HI-STORM UMAX are subject to patent action by the USPTO under application number 61625869 dated April 18, 2012. A licensing drawing package depicting the essential geometric details of the HI-STORM UMAX is provided in Section 1.5. The licensing drawings for MPC-37, MPC-89 and the HI-TRAC transfer cask are also reproduced in Section 1.5 from the "FW" docket for configuration control. The glossary preceding this chapter contains the definition of terms and acronyms that may be consulted as necessary.

This safety evaluation follows the guidelines of RG 3.61 [1.0.4] and NUREG-1536 [1.0.5] to qualify the MPC-37 and MPC-89 models previously certified in the HI-STORM FW Holtec docket for storage in the HI-STORM UMAX. This report has been prepared in the format and content suggested in NRC Regulatory Guide 3.61 [1.0.4] and NUREG-1536 Standard Review Plan for Dry Cask Storage Systems [1.0.5]. The only deviation in the format from the formatting instruction in Reg. Guide 3.61 is the insertion of a chapter (Chapter 8) on material compatibility pursuant to ISG-15 and renumbering of all subsequent chapters and only deviation from NUREG-1536 is the order of Chapters 5, 6 and 7 which is similar to HI-STORM FW format.

The Glossary contains a listing of the terminology and notation used in this FSAR.

The safety evaluations in this FSAR are intended to bound the conditions that exist in the vast majority of domestic power reactor sites and potential away-from-reactor storage sites in the contiguous United States. This includes the potential fuel assemblies which will be loaded into the system and the environmental conditions in which the system will be deployed. This FSAR also provides the basis for component fabrication and acceptance, and the requirements for safe operation and maintenance of the components, consistent with the design bases and safety analyses documented herein. In accordance with 10CFR72, Subpart K, site-specific implementation of the generically certified HI-STORM FW System requires that the licensee perform a site-specific evaluation, as defined in 10CFR72.212. The HI-STORM UMAX System FSAR identifies a number of conditions that are site-specific and are to be addressed in the licensee's 10CFR72.212 evaluation. These include:

- Siting of the ISFSI and design of the storage and security system. Site-specific demonstration of compliance with regulatory dose limits. Implementation of a site-specific ALARA program.
- An evaluation of site-specific hazards and design conditions that may exist at the ISFSI site or the transfer route between the plant's cask receiving bay and the ISFSI. These include, but are not limited to, explosion and fire hazards, flooding conditions, landslides, and lightning protection.

- Determination that the physical and nucleonic characteristics and the condition of the SNF assemblies to be stored meet the fuel acceptance requirements of the Certificate of Compliance.
- An evaluation of interface and design conditions that exist within the plant's Fuel Building in which canister fuel loading, canister closure, and canister transfer operations are to be conducted in accordance with the applicable 10CFR50 requirements and technical specifications for the plant.
- Detailed site-specific operating, maintenance, and inspection procedures prepared in accordance with the generic procedures and requirements provided in Chapters 9 and 10, and the Certificate of Compliance.
- Performance of pre-operational testing.
- Implementation of a safeguards and accountability program in accordance with 10CFR73. Preparation of a physical security plan in accordance with 10CFR73.55.
- Review of the reactor emergency plan, quality assurance (QA) program, training program, and radiation protection program.

In presenting the bounding generic analyses of this safety report, selected conditions are drawn from authoritative sources such as Regulatory Guides and NUREGs, where available.

Within this report, all figures, tables and references cited are identified by the double decimal system *m.n.i*, where *m* is the chapter number, *n* is the section number, and *i* is the table number. For a complete listing of Tables and Figure please consult the Table of Contents. For example, Figure 1.2.1 is the first figure in Section 1.2 of Chapter 1. Similarly, the following convention is used in the organization of chapters:

a. A chapter is identified by a whole numeral, say *m* (i.e., *m*=3 means Chapter 3)

b. A section is identified by one decimal separating two numerals. Thus, Section 3.1 is section 1 in Chapter 3.

c. A subsection has three numerals separated by two decimals. Thus, Subsection 3.2.1 is subsection 1 in Section 3.2.

d. A paragraph is denoted by four numerals separated by three decimals. Thus, Paragraph 3.2.1.1 is paragraph 1 in Subsection 3.2.1.

e. A subparagraph has five numerals separated by four decimals. Thus, Subparagraph 3.2.1.1.1 is subparagraph 1 in Paragraph 3.2.1.1.

Tables and figures associated with a section are placed after the text narrative. Drawings are controlled separately within the Holtec QA program and have individual revision numbers and are included in Section 1.5.

TABLE 1.0.1: APPLICABLE SECTIONS OF HI-STORM FW FSAR*		
Location of UMAX FSAR	**Subject of the Reference**	**Location in HI-STORM FW FSAR, Revision 1**
Section 1.1	Limiting load conditions for MPC-37 and MPC-89	Section 2.2
Sub-Section 1.2.1	Acceptance Criteria for manufacturing of MPCs and HI-TRAC	Section 10.1, Tables 10.1.1, 10.1.3 through 10.1.8
Sub-Section 1.2.1	Description of Alloy X	Appendix 1.A
Sub-Section 1.2.1	Applicable codes for manufacturing of HI-TRAC	Table 1.2.6
Paragraph 1.2.3.1	Properties of Metamic-HT	Appendix 1.B
Section 1.2.4	1. Overview of loading operations 2. Preparation of HI-TRAC and MPC 3. MPC Fuel Loading 4. MPC Closure 5. Preparation for Storage 6. MPC Inspection Checklist 7. HI-TRAC Inspection Checklist	1. Section 9.2.1 2. Section 9.2.2 3. Section 9.2.3 4. Section 9.2.4 5. Section 9.2.5 6. Table 9.2.4 7. Table 9.2.5

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* For convenience of reference, the specific revision of the HI-STORM FW FSAR that is referenced in the safety analysis herein is placed in this docket. Updated versions of the HI-STORM FW FSAR shall be placed in this docket as necessary so as to ensure that the safety analyses on the "UMAX" docket (72-1040) remain aligned with the material referenced in the HI-STORM FW FSAR.

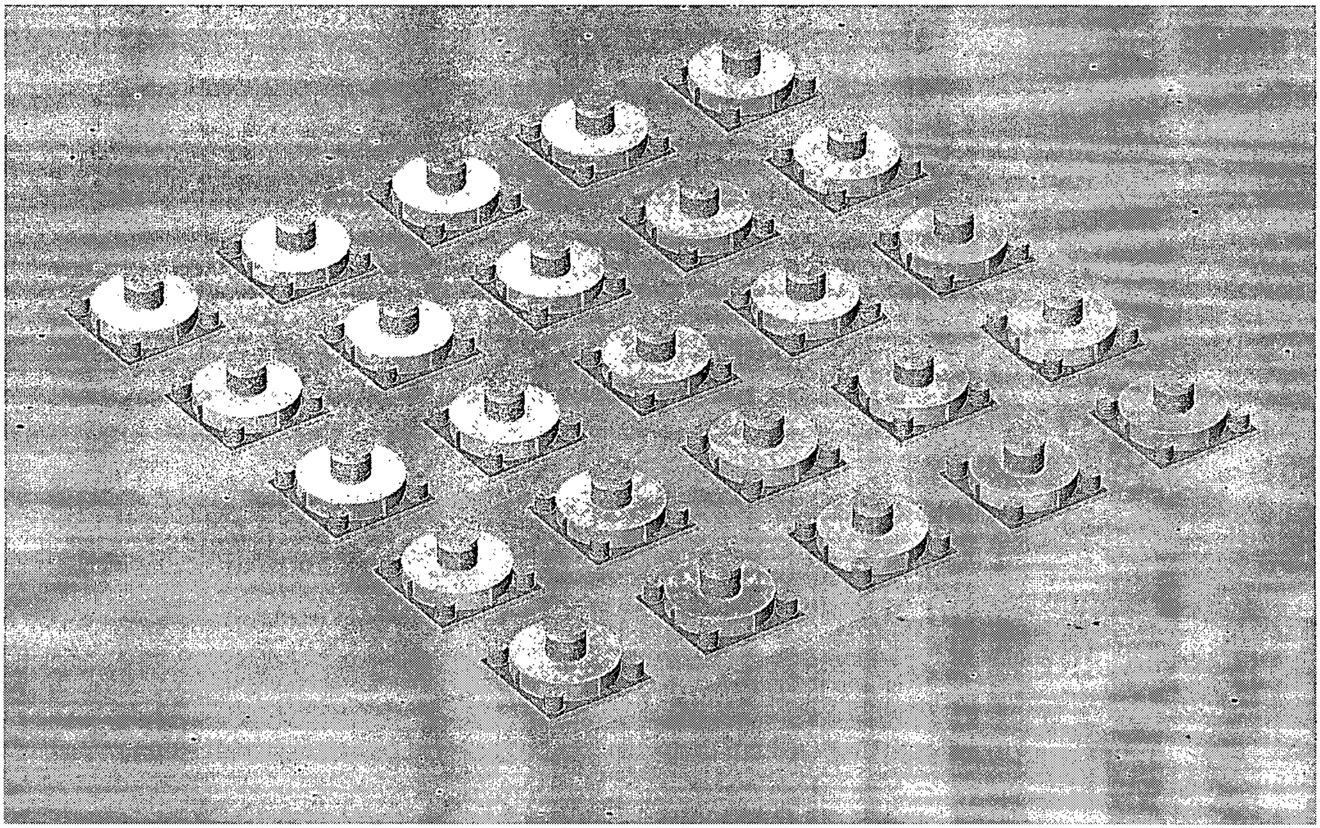

Figure 1.0.1; Pictorial View of a HI-STORM UMAX ISFSI

1.1 INTRODUCTION

HI-STORM UMAX is a dry, in-ground spent fuel storage system consisting of any number of Vertical Ventilated Modules (VVM) each containing one canister. The HI-STORM UMAX is designed to be fully compatible with all HI-TRAC transfer casks and multi-purpose canisters (MPC) presently certified under USNRC Docket No. 72-1014 and 72-1032. Safety analyses documented herein treat all MPCs listed in Table 1.2.1. However, as would be expected, the largest canisters, i.e., those licensed in the HI-STORM FW docket are governing in terms of structural and thermal margins. These largest canisters, namely MPC-37 and MPC-89 are termed "Licensing Basis MPCs" and the certification request for storage in HI-STORM UMAX is limited to these MPCs only. For completeness, the permissible contents from the HI-STORM FW docket are excerpted in Chapter 2 herein and also reproduced in the Technical Specification applicable to the CoC. The safety analyses summarized in this FSAR are intended to demonstrate that the HI-STORM UMAX System can safely store PWR or BWR fuel assemblies, in the MPC-37 or MPC-89, respectively. The MPC is identified by the maximum number of fuel assemblies it can contain in the fuel basket. As presently licensed in the HI-STORM FW docket, the MPC external diameters are identical to allow the use of a single overpack design; however the height of the MPC is varied to accord with the SNF to be loaded.

The MPC is an integrally welded pressure vessel designed to meet the stress limits of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB [1.1.1]. The MPC defines the Confinement Boundary for the stored spent nuclear fuel assemblies. Regardless of the storage cell count, the construction of the MPC is fundamentally the same; the basket is a honeycomb structure comprised of cellular elements. This is positioned within a circumscribing cylindrical canister shell. The egg-crate construction and cell-to-canister shell interface employed in the MPC basket impart the structural stiffness necessary to satisfy the limiting load conditions discussed in Chapter 2 of the HI-STORM FW FSAR. Figures 1.1.1 and 1.1.2 provide cross-sectional views of the PWR and BWR fuel baskets, respectively. Figures 1.1.3 and 1.1.4 provide isometric perspective views of the PWR and BWR fuel baskets, respectively.

The HI-STORM UMAX VVM provides structural protection, cooling, and radiological shielding for the MPC.

The HI-TRAC VW transfer cask (hereafter referred to as HI-TRAC) is required for shielding and protection of the SNF during loading and closure of the MPC and during movement of the loaded MPC from the cask loading area of a nuclear plant spent fuel pool to the storage overpack. Figure 1.1.5 shows a cut away view of the transfer cask. The MPC is placed inside the HI-TRAC transfer cask and moved into the cask loading area of nuclear plant spent fuel pools for fuel loading (or unloading). The HI-TRAC/MPC assembly is designed to prevent (contaminated) pool water from entering the narrow annular space between the HI-TRAC and the MPC while the assembly is submerged. The HI-TRAC transfer cask also allows dry loading (or unloading) of SNF into the MPC in a hot cell.

Design criteria for a forced helium dehydration (FHD) system is provided in Section 2.5.1.

The HI-STORM UMAX is comparable to the HI-STORM 100U ("100U") VVM licensed in NRC Docket No. 72-1014. The major differences between the HI-STORM UMAX and 100U are that the HI-STORM UMAX VVM cavity is larger in diameter and the HI-STORM UMAX closure lid features a modified outlet ventilation duct system.

The HI-STORM UMAX has all the safety attributes that are attributed to in-ground storage, such as enhanced protection from incident projectiles and threats from extreme environmental phenomena such as hurricanes, tornado borne missiles, earthquakes, tsunamis, fires, and explosions. The HI-STORM UMAX VVM is anatomically similar to the HI-STORM 100U VVM in several respects. In particular, the MPCs are stored in-ground and each storage cavity is isolated from the surrounding environment by a thick cylindrical steel weldment. This steel shell is appropriately coated with surface preservatives or by other means to protect it from corrosion from long-term use.

HI-STORM UMAX differs from HI-STORM 100U in two important respects:

a. The placement of the inlet and outlet ducts in HI-STORM UMAX minimizes the reduction of ventilating air flow rate through HI-STORM VVM under wind conditions which, as is noted in Docket #72-1014, has a small de-rating effect on the thermal performance of the ventilation system in HI-STORM 100U. As shown in Chapter 4, the inlet and outlet locations in HI-STORM UMAX are also found to minimize inter-module flow interactions.

b. The storage cavity in the HI-STORM UMAX VVM is sufficiently large in physical dimensions to accommodate all canisters presently licensed by different designers under different 10CFR72 dockets. Therefore, it is theoretically possible to qualify the entire universe of used fuel canisters presently deployed at the ISFSIs around the country for storage in the HI-STORM UMAX system. This would make it possible to unify the long-term storage of all of the presently deployed nation's dry storage canisters at an Interim Storage site in HI-STORM UMAX VVM assemblies in a monitored and retrievable configuration. The present issue of this SAR, however, is limited to supporting the certification of the HI-STORM FW MPCs listed in Table 1.2.1.

The design and operational attributes of the HI-STORM UMAX, 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.

To summarize, the HI-STORM UMAX System has been engineered to:

- maximize shielding and physical protection for the MPC;
- minimize the extent of handling of the SNF;
- minimize dose to operators during loading and handling;
- require minimal ongoing surveillance and maintenance by plant staff;
- facilitate SNF transfer of the loaded MPC to a compatible transport overpack for transportation;

All HI-STORM UMAX System components (VVM, transfer cask, and MPC) are designated ITS and their sub-components are categorized in accordance with NUREG/CR-6407 [1.1.2].

The principal ancillaries used in the site implementation of the HI-STORM UMAX System are similar to HI-STORM FW System and are summarized in Section 1.2 of the HI-STORM FW FSAR and referenced in Chapter 9 of the HI-STORM FW FSAR in the context of loading operations. A listing of common ancillaries needed by the host site is provided in Table 9.2.1 of the HI-STORM FW FSAR. The detailed design of these ancillaries is not specified in this FSAR. In some cases, there are multiple distinct ancillary designs available for a particular application (such as a forced helium dehydrator or a vacuum drying system for drying the MPC) and as such, not every ancillary will be needed by every site. Ancillary designs are typically specific to a site to meet ALARA and personnel safety objectives.

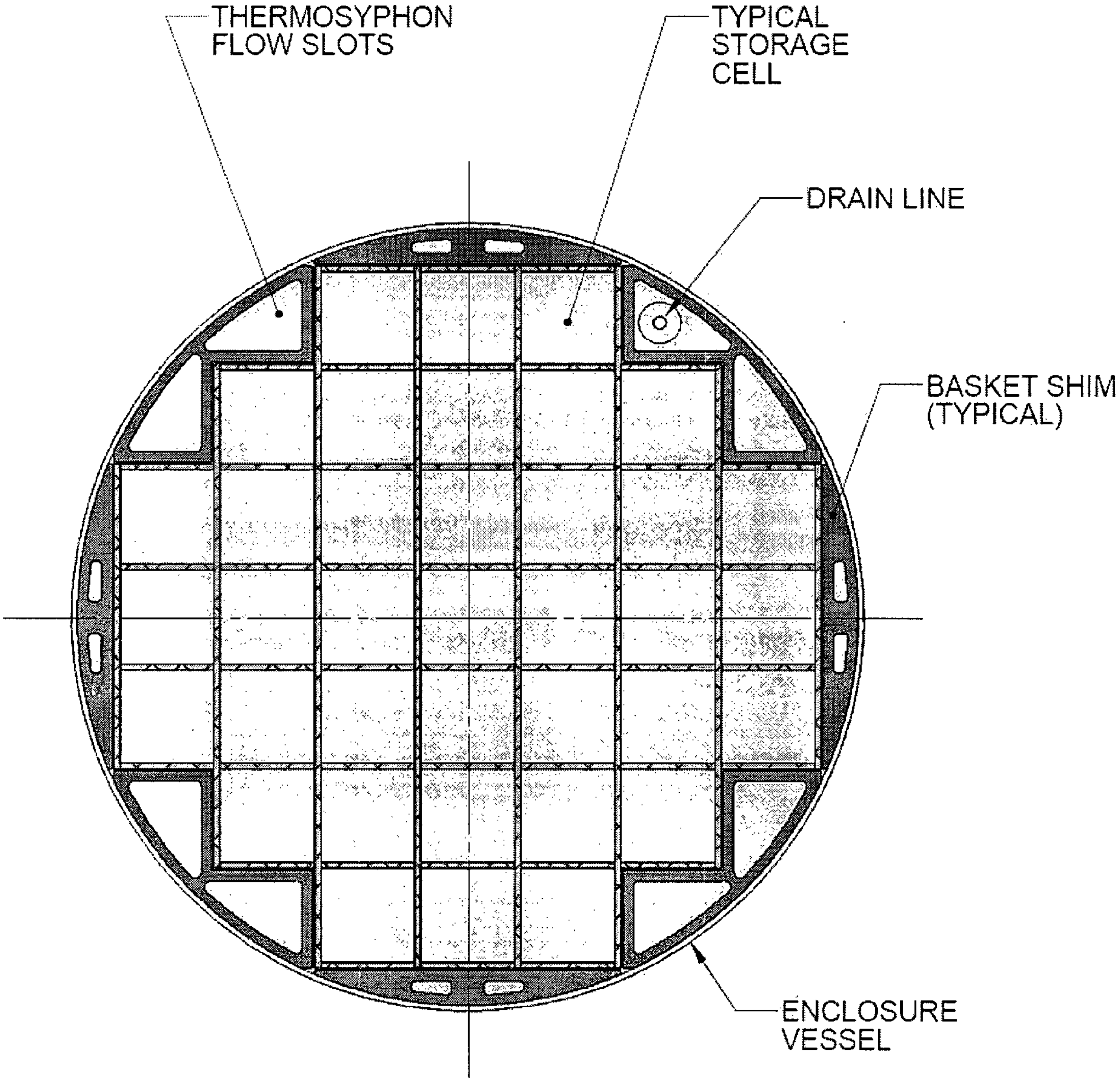

Figure: 1.1.1: MPC -37 in Cross Section

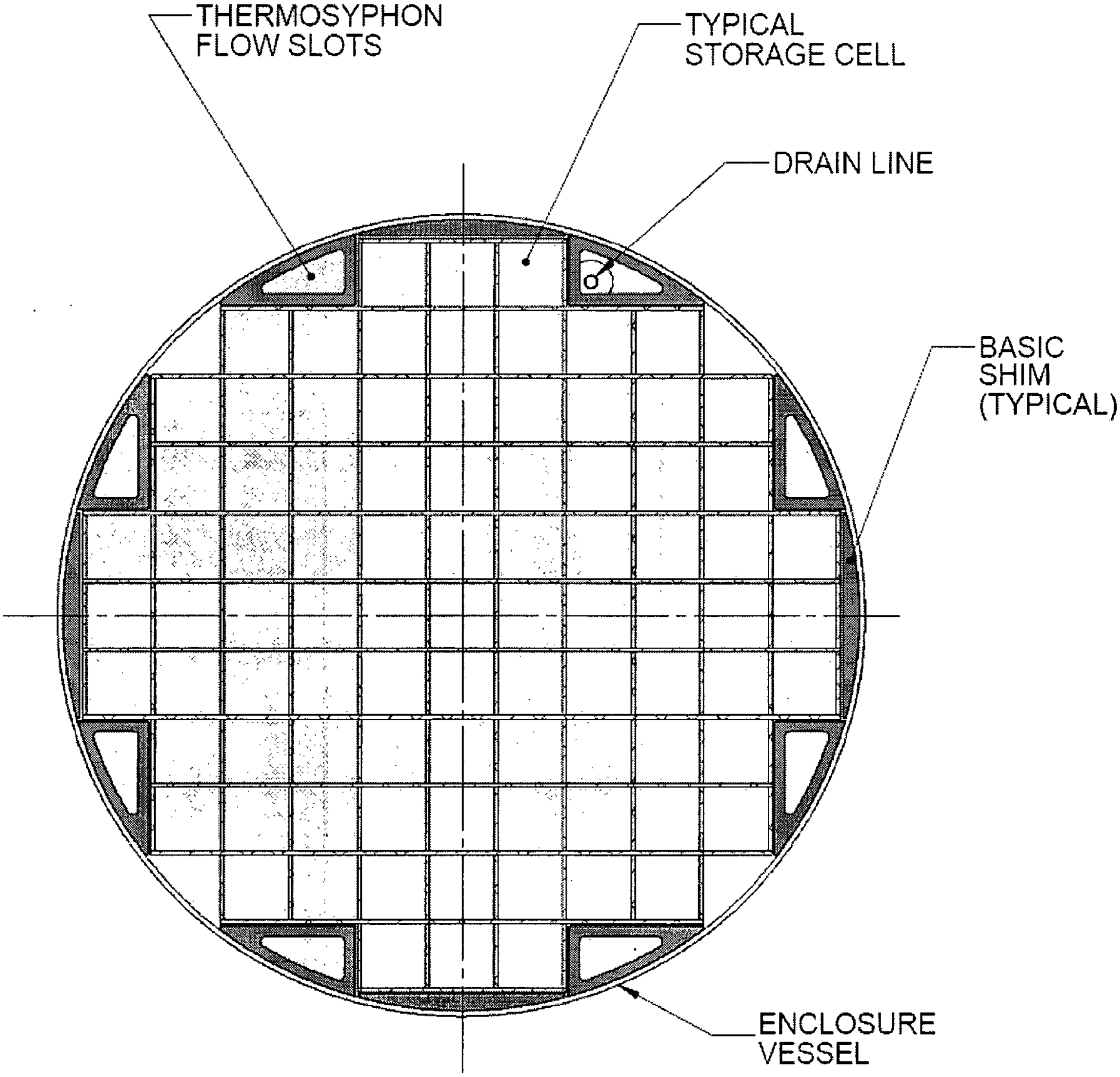

Figure 1.1.2: MPC-89 in Cross Section

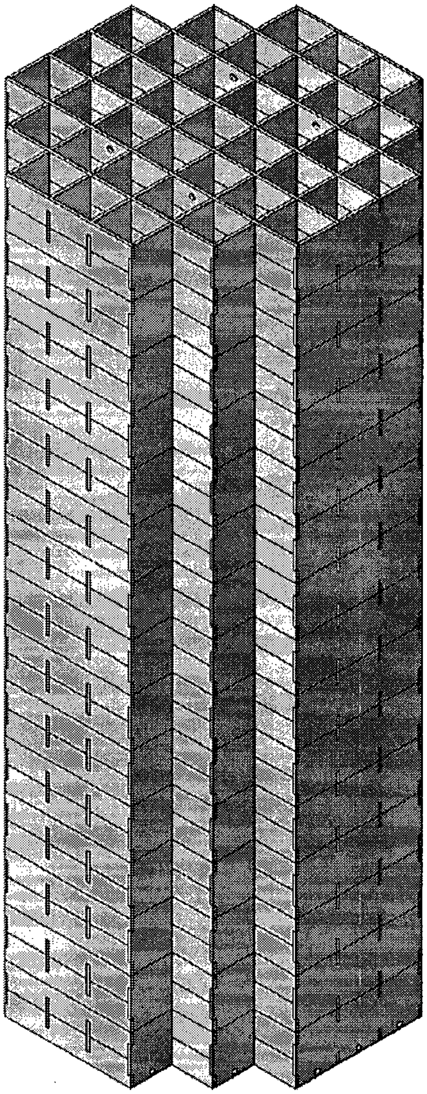

Figure 1.1.3: PWR Fuel Basket (37 Storage Cells) in Perspective View

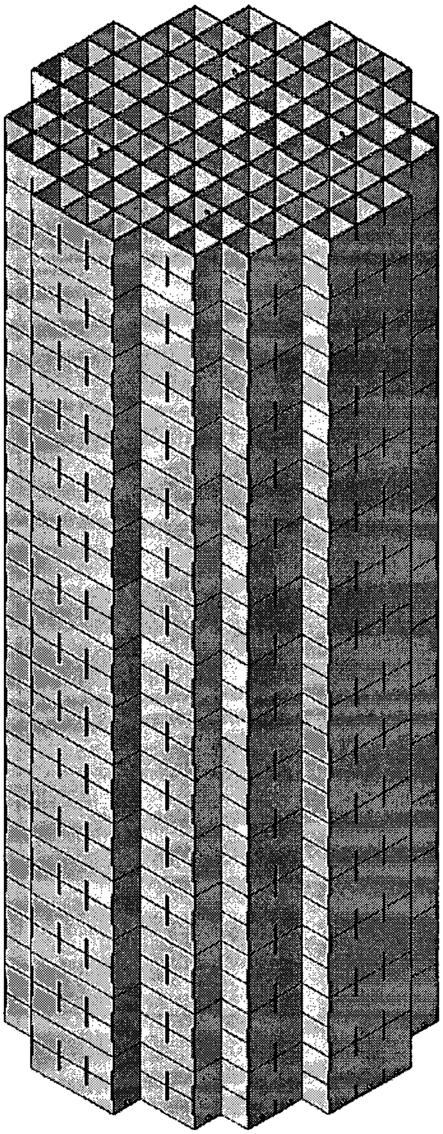

Figure 1.1.4: BWR Fuel Basket (89 Storage Cells) in Perspective View

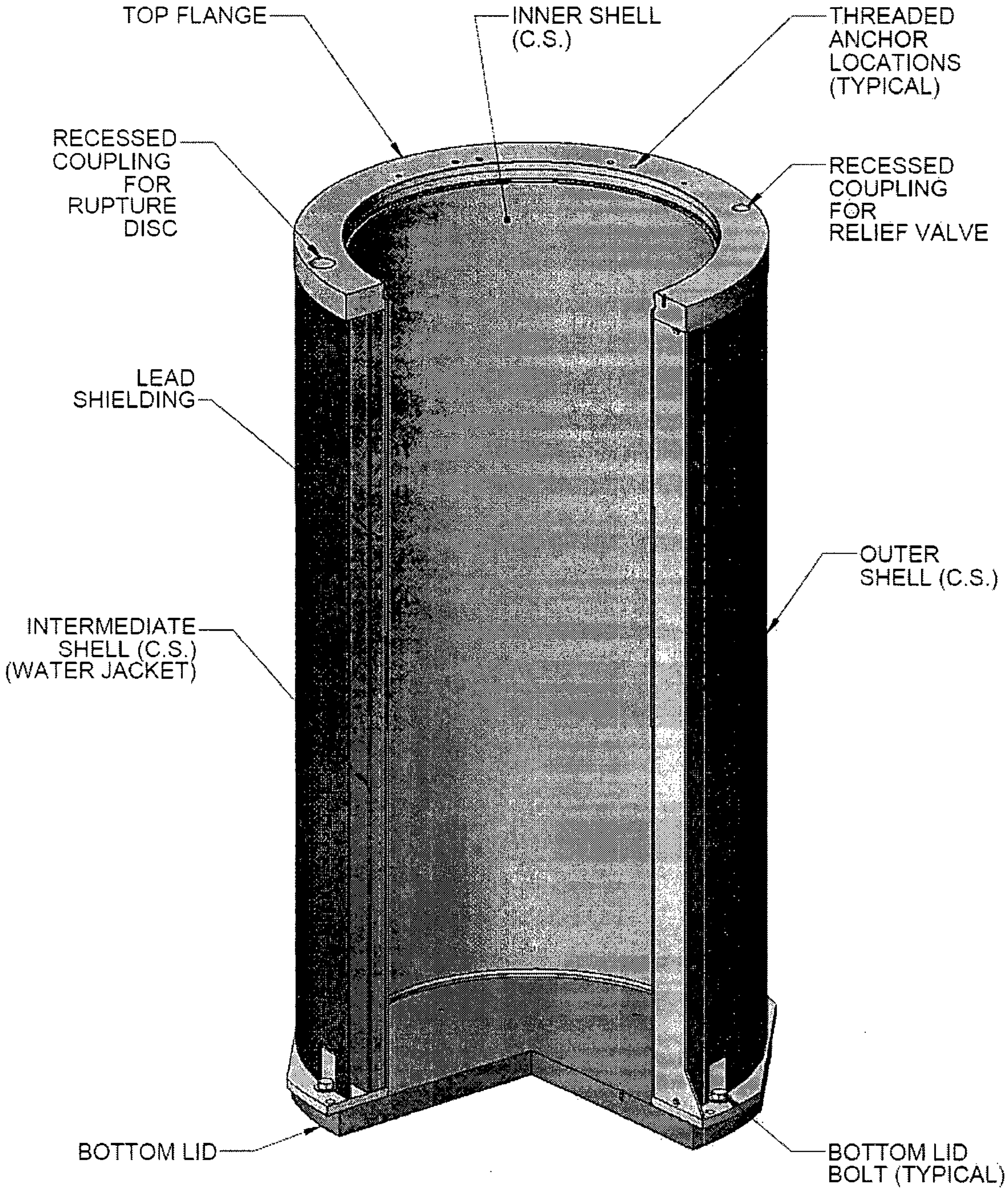

Figure 1.1.5: Cutaway View of HI-TRAC VW

1.2 GENERAL DESCRIPTION OF HI-STORM UMAX SYSTEM

1.2.1 System Characteristics

The HI-STORM UMAX System consists of interchangeable MPCs, which maintain the configuration of the fuel and is the confinement boundary between the stored spent nuclear fuel and the environment; and a storage overpack that provides structural protection and radiation shielding during long-term storage of the MPC. In addition, a transfer cask that provides the structural and radiation protection of an MPC during its loading, unloading, and transfer to the storage overpack is also subject to certification by the USNRC. Description of MPCs and the HI-TRAC transfer cask are provided in Section 1.2 of the HI-STORM FW FSAR. The key parameters for the UMAX MPCs are provided in Table 1.2.2 of the HI-STORM FW FSAR. The principal materials used in the manufacturing of the MPC are listed in the licensing drawings (Section 1.5) and the acceptance criteria are provided in Chapter 10 of HI-STORM FW FSAR. Alloy X description is provided in Appendix 1.A of the HI-STORM FW FSAR. The principal materials used in the manufacturing of the HI-TRAC transfer cask are listed in the licensing drawings in Section 1.5 and the acceptance criteria are provided in Chapter 10 of the HI-STORM FW FSAR. Table 1.2.6 of the HI-STORM FW FSAR provides applicable code paragraphs for manufacturing the HI-TRAC transfer cask.

All structures, systems, and components of the HI-STORM UMAX system, MPCs and HI-TRACs, which are identified as Important-to- Safety (ITS), are specified on the licensing drawings provided in Section 1.5.

1.2.2 Constituents of the HI-STORM UMAX Vertical Ventilated Module

The HI-STORM UMAX VVM, shown in the licensing drawing in Section 1.5, provides for storage of the MPC in a vertical configuration inside a subterranean cylindrical cavity entirely below the top-of-grade (TOG) of the ISFSI. The key constituents of a HI-STORM UMAX VVM (see Figure 1.2.1 and Figure 1.2.2) are:

a. The Cavity Enclosure Container (CEC)
b. The Closure Lid
c. The ISFSI Pad
d. The Support Foundation Pad
e. The Subgrade and Under-grade
f. The Enclosure Walls (optional)

A brief description of each constituent part is provided in the following:

a. The Cavity Enclosure Container:

The Cavity Enclosure Container (CEC) consists of a thick walled shell integrally welded to a bottom plate. The top of the container shell is stiffened by a ring shaped flange which is also integrally welded. As shown in the licensing drawing provided in Section 1.5, all of the constituent parts of the CEC are made of low carbon steel plate. In its installed configuration, the CEC is interfaced with the surrounding subgrade for most of its height except for the top region where it is girdled by the ISFSI pad.

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 CEC. Likewise, any water that may be introduced into the CEC through the air passages in the top lid will not drain into the groundwater.

The MPC Bearing surfaces and the Divider Shell, two parts internal to the CEC, are important to the thermal performance of the VVM system. The top surfaces of the MPC support system are made of stainless steel so that the MPC is not resting directly on carbon steel components. The Divider Shell, as its name implies, is a vertical cylindrical shell concentrically situated in the CEC that divides the CEC into an inlet flow downcomer and an outlet flow passage. The Divider Shell divides the radial space between the MPC and the CEC cavity into two annuli. The bottom end of the Divider Shell has cutouts to enable movement of air from the downcomer to the up-flow region around the MPC. 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. This design feature is important to ensure adequate thermal performance of the system if flood water would stop air flow. The Divider Shell is not attached to the CEC which allows its convenient removal for decommissioning or for any in-service maintenance that may be required.

As the licensing drawing in Section 1.5 shows, the lower end of the MPC is restrained by a set of radial guides at the MPC's Baseplate elevation. The top lid of the MPC is likewise laterally restrained by a set of radial guides attached to the Divider Shell. The radial guides serve as an aid during insertion of the canister into the CEC and also provide the means to limit the lateral movement of the free-standing canisters during an earthquake. By limiting the lateral movement of the MPC, the guides protect against excessive inertia loads during seismic events.

The cylindrical surface of the Divider Shell is equipped with insulation to prevent significant preheating of the inlet air. The insulation material is selected to be water and radiation resistant as well as non-degradable under accidental wetting.

The chief distinguishing features of the VVM are its low profile and in-ground configuration. The MPC is below the ISFSI Pad for its entire height allowing the earth, ISFSI pad and Closure Lid to provide shielding of the stored fuel.

b. The Closure Lid:

The Closure Lid is a steel structure filled with plain concrete that can withstand the impact of the Design Basis Missiles defined in Chapter 2. Both the inlet and outlet vents are located at the grade level. A set of inlet passage located on top of the CEC provide maximum separation from the large outlet passage which is located in the center of the lid. Using a flue extension, the air exhaust from the outlet passage is set to be several feet higher than the inlet and prevents significant preheating of the incoming air. As shown in Chapter 4, the geometry of the inlet and outlet ducts, as depicted in the licensing drawings, make the HI-STORM UMAX VVM essentially insensitive to the speed of the wind.

The Closure Lid fulfills the following principal performance objectives:

1. Because there are no lateral streaming paths in the VVM body and the outlet air passage is located in the Closure Lid, there is no lateral radiation leakage paths during the MPC lowering or raising operation. Thus, the need for shield blocks (necessary to close off vents in certain aboveground HI-STORM 100 models) is eliminated.
2. The air passages in the Closure Lid are configured in such a manner that the aerodynamics in the system is not affected by the change in the horizontal direction of the wind.
3. The Closure Lid is physically restrained against horizontal movement during a Design Basis Earthquake event or a tornado missile strike.
4. To minimize the radiation emitted from the storage cavity, 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.
5. As can be seen from the drawings in Section 1.5, the Closure Lid is substantially larger in diameter than 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. 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) that have been a standard and established requirement in the HI-STORM dockets.

c. The ISFSI Pad:

The ISFSI Pad serves to augment shielding, to provide a sufficiently stiff riding surface for the cask transporter, to act as a barrier against gravity-induced seepage of rain or floodwater around the VVM body as well as to shield against a missile. The ISFSI pad is a monolithic reinforced concrete structure that provides the load bearing surface for the cask transporter. The portion of the ISFSI pad adjacent to the VVM is slightly sloped and thicker than the rest of the ISFSI pad to ensure that rain water will be directed away from the VVM. The appropriate requirements on the structural strength of the ISFSI pad and the applicable industry code are specified in Chapter 2.

d. The Support Foundation Pad:

The Support Foundation Pad (SFP) is the underground pad which supports the HI-STORM UMAX ISFSI. The SFP on which the VVM rests must be designed to minimize long-term settlement. The Support Foundation Pad (SFP) has circular recessed regions to provide lateral support to the CEC. The SFP and the under-grade must have sufficient strength to support the weight of all the loaded VVMs during long-term storage and earthquake conditions. As the weight of the loaded VVM is comparable to the weight of the subgrade which it replaces, the additional pressure acting on the SFP is quite small. The appropriate requirements on the structural strength of the SFP and the applicable industry code are specified in Chapter 2.

e. The Subgrade and Under-grade:

The lateral space between each CEC, the SFP and the ISFSI pad is referred to as the subgrade and is filled with a suitable engineered fill or native soil. The fill or soil must meet the shear velocity and density requirements in Chapter 2. The space below the SFP is referred to as the under-grade.

As discussed in Chapters 3 and 8 corrosion mitigation measures commensurate with site-specific conditions are implemented on the below grade external surfaces of the CEC.

f. The Enclosure Wall:

The Enclosure Wall is an optional structure which may be utilized to mitigate groundwater intrusion at sites with a high water table.

Analyses in Chapter 3 show that the Self-hardening Engineered Subgrade (SES) provides a stable lateral support system to the ISFSI under the Design Basis Earthquake. In the absence of an Enclosure wall, the interface between the SES and the native subgrade defines the radiation protection boundary of the ISFSI. As stated in the Technical Specification and demonstrated by the seismic analysis in Chapter 3 of this FSAR, excavation of the sub-grade adjacent to the interface of an operating storage system is permitted but only down to the top of the Support Foundation pad elevation.

1.2.3 Design Characteristics of the HI-STORM UMAX VVM

The minimum depth of the storage cavity is governed by the height of the MPC stored. The nominal gap between the top of the MPC and the bottom of the Closure Lid is specified in the licensing drawing. All Holtec MPC models certified for storage in Docket 72-1032 can be stored in HI-STORM UMAX. The difference in the MPC diameters is accommodated by different sized MPC guides. The location of the MPC Guides on the divider shell is aligned with the bottom of the MPC lid. The pitch between the CEC cavities allows the Cask Transporter to traverse over any storage cavity and independently access any storage location. Thus, any MPC located in any storage cavity can be independently accessed and retrieved using an already certified transfer cask.

As explained in the chapter on operations, the transfer of the MPCs into or out of the storage cavity will occur in an identical manner to HI-STORM 100U using a certified transfer cask. Screens are installed on the air inlet and outlet openings. The flue in the inlet and outlet plenum is equipped with a rain guard. The flue shell is lightweight and fastened to the outlet duct to allow easy installation and removal.

The essential design and operational features of the HI-STORM UMAX System are:

a. Because of its underground staging in HI-STORM UMAX, tip-over of the canister in storage is not possible.

b. 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.

c. 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.

d. 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 the air inlet or outlet passageways.

e. As discussed in Section 3.4, all practical efforts are made to coat exposed surfaces of the VVM with proven low VOC and/or ANSI/NSF Standard 61 [1.2.1] compliant surface preservatives to preclude toxicological effects on the environment to the maximum reasonable extent.

1.2.3.1 Shielding Materials

Steel, concrete, and the subgrade are the principal shielding materials in the HI-STORM UMAX. The steel and concrete shielding materials in the Closure lid provide additional gamma and neutron attenuation to reduce dose rates.

Steel, lead, and water are the principal shielding materials in the HI-TRAC transfer cask. The combination of these three shielding materials ensures that the radiation and exposure objectives of 10CFR72.106 and ALARA are met. The extent and location of shielding in the transfer cask plays an important role in minimizing the personnel doses during loading, handling, and transfer.

The MPC fuel basket structure provides the initial attenuation of gamma and neutron radiation emitted by the radioactive contents. The MPC shell, baseplate, and thick lid provide additional gamma attenuation to reduce direct radiation.

1.2.3.1.1 Neutron Absorber – Metamic HT

Metamic-HT is the designated neutron absorber in the HI-STORM FW MPC baskets. It is also the structural material of the basket. The properties of Metamic-HT and key characteristics, necessary for ensuring nuclear reactivity control, thermal, and structural performance of the basket, are presented in Appendix 1.B of the "FW" FSAR(placed in this docket).

1.2.3.1.2 Neutron Shielding

The HI-TRAC transfer cask is equipped with a water jacket providing radial neutron shielding. The water in the water jacket may be fortified with ethylene glycol to prevent freezing under low temperature operations [1.2.3].

During certain evolutions in the short term handling operations, the MPC may contain water which will supplement neutron shielding.

1.2.3.1.3 Gamma Shielding

In the HI-TRAC transfer cask, the primary gamma shielding is provided by lead. As in the storage overpack, carbon steel supplements the lead gamma shielding of the HI-TRAC transfer cask.

In the MPC, the gamma shielding is provided by its stainless steel enclosure vessel (including a thick lid); and its aluminum based fuel basket and aluminum alloy basket shims.

1.2.3.2 Lifting Devices

Lifting and handling devices used to load or unload an MPC into the HI-STORM UMAX VVM shall be designed per Section 1.2.1 of the HI-STORM FW FSAR (placed in this docket).

The lifting and handling of all heavy loads that are within Part 72 jurisdiction, such as the Closure Lid, to be carried out using single failure proof (see definition in the Glossary) equipment with below-the-hook lifting devices that comply with the stress limits of ANSI N14.6 [1.2.2] and/or slings designed as single failure proof to render an uncontrolled lowering of the Lid a non-credible event.

1.2.3.3 Threaded Anchor Locations

Threaded anchor locations (TALs) are provided in the CEC Flange region of each CEC. These will serve as the anchoring location for the device used for MPC transfer (see Chapter 9). The TALs serve no function during long term storage.

1.2.3.4 Design Life

The design life of the HI-STORM UMAX System is 60 years. This is accomplished by using materials of construction with a long proven history in the nuclear industry, specifying materials known to withstand their operating environments with little to no degradation (see Chapter 8), and protecting material from corrosion by using appropriate mitigation measures.

A maintenance program, as specified in Chapter 10, is also implemented to ensure that the service life will exceed the design life. The design considerations that assure the HI-STORM UMAX System performs as designed include the following:

HI-STORM UMAX VVM and HI-TRAC Transfer Cask

a. Exposure to Environmental Effects
b. Material Degradation
c. Maintenance and Inspection Provisions

MPCs

a. Corrosion
b. Structural Fatigue Effects
c. Maintenance of Helium Atmosphere
d. Allowable Fuel Cladding Temperatures
e. Neutron Absorber Boron Depletion

The adequacy of the materials for the designated design life is discussed in Chapter 8.

1.2.4 Operational Characteristics of the HI-STORM UMAX

Fuel loading operations, MPC preparation, and requirements during the use of the transfer cask are described in the HI-STORM FW Final Safety Analysis Report. The HI-TRAC transfer cask is used for on-site transport of the loaded MPC from the Fuel Building to the ISFSI. Prior to loading the VVM, the Closure Lid or other temporary lid is removed and a suitable device which will connect the transfer cask to the CEC is installed. The cask transporter carrying the transfer cask with the loaded MPC aligns over the top of the CEC and the transfer cask is connected. The MPC inside the transfer cask is lifted slightly by the cask transporter to allow the transfer cask pool lid to be removed. The MPC is slowly lowered into the VVM cavity below. The transfer equipment is removed and the Closure Lid is installed. The principal operational characteristics of short term operations at an ISFSI are:

a. The MPC is kept in the vertical configuration at all times during handling operations. This eliminates the handling risk of down-ending or upending and maintains the thermal performance of the MPC (which is somewhat dependent on its orientation) undisturbed.

b. The vertical insertion (or withdrawal) of the MPC eliminates the risk of gouging or binding of the MPC with the CEC parts.

c. The HI-TRAC transfer cask is mounted on the VVM cavity (with an interposed Mating Device) with large fasteners that are sized to protect the transfer cask from tip over under the site's DBE.

d. All load handling operations are carried out using the Vertical Cask Transporter (VCT) or an equivalent crane that is *single failure proof.*

Details of the generic operational steps involving either installation or removal of the loaded MPC at a HI-STORM UMAX ISFSI are provided in Chapter 9 along with reference to certain recommended safety measures that are known from experience to avert human performance errors. A visual depiction of the required operational steps is also provided in Chapter 9.

1.2.4.1 Design Features

The design features of the HI-STORM UMAX System are intended to meet the following principal performance characteristics under all credible modes of operation:

a. Prevent unacceptable release of contained radioactive material at all times.
b. Minimize occupational and site boundary dose.
c. Permit retrievability of contents (fuel must be retrievable from the MPC under normal and off-normal conditions in accordance with ISG-2 and the MPC only must be recoverable after accident conditions in accordance with ISG-3).

Chapter 11 identifies the many design features built into the HI-STORM UMAX System to minimize dose and maximize personnel safety. Among the design features intrinsic to the system that facilitate meeting the above objectives are:

a. The loaded MPC is always maintained in a vertical orientation during its handling at the ISFSI and is handled using an ANSI N14.6 compliant lift cleats.
b. The height of the HI-STORM UMAX cavity is minimized consistent with the length of the MPCs to optimize the depth of excavation needed to establish the ISFSI.
c. Almost all personnel activities during MPC transfer occur at ground level which helps promote safety and ALARA.

1.2.4.2 Identification of Subjects for Safety and Reliability Analysis

1.2.4.2.1 Criticality Prevention

Criticality is controlled by geometry and neutron absorbing materials in the fuel basket. The entire basket is made of Metamic-HT, a uniform dispersoid of boron carbide and nano-particles of alumina in an aluminum matrix, serves as the neutron absorber. This accrues four major safety and reliability advantages:

(i) The larger B-10 areal density in the Metamic-HT allows higher enriched fuel (i.e., BWR fuel with planar average initial enrichments greater than 4.5 wt% U-235) without relying on gadolinium or burn-up credit.
(ii) The neutron absorber cannot be removed from the basket or displaced within it.
(iii) Axial movement of the fuel with respect to the basket has no reactivity consequence because the entire length of the basket contains the B-10 isotope.
(iv) The larger B-10 areal density in the Metamic-HT reduces the reliance on soluble boron credit during loading/unloading of PWR fuel.

1.2.4.1.2 Chemical Safety

There are no chemical safety hazards associated with operations of the HI-STORM UMAX System. A detailed evaluation is provided in Section 3.4.

1.2.4.2.3 Operation Shutdown Modes

The HI-STORM UMAX System is totally passive and consequently, operation shutdown modes are unnecessary.

1.2.4.2.4 Instrumentation

As stated earlier, the HI-STORM UMAX MPC, which is seal welded, non-destructively examined, and pressure tested, confines the radioactive contents. The HI-STORM UMAX is a completely passive system with appropriate margins of safety; therefore, it is not necessary to deploy any instrumentation to monitor the cask in the storage mode.

1.2.4.2.5 Maintenance Technique

Because of its passive nature, the HI-STORM UMAX System requires minimal maintenance over its lifetime. No special maintenance program is required. Chapter 10 describes the maintenance program set forth for the HI-STORM UMAX System.

1.2.5 Cask Contents

This sub-section contains information on the cask contents pursuant to 10 CFR72, paragraphs 72.2(a)(1),(b) and 72.236(a),(c),(h),(m).

The HI-STORM UMAX System is designed to house both BWR and PWR spent nuclear fuel assemblies. Table 1.2.3 provides key system data and parameters for the MPCs. A description of acceptable fuel assemblies for storage in the MPCs is provided in Section 2.1. This includes fuel assemblies classified as damaged fuel assemblies and fuel debris in accordance with the definitions of these terms in the Glossary. All fuel assemblies, non-fuel hardware, and neutron sources authorized for packaging in the MPCs must meet the fuel specifications provided in Section 2.1. All fuel assemblies classified as damaged fuel or fuel debris must be stored in damaged fuel containers (DFC).

As shown in Figure 2.1.7 (MPC-37) and Figure 2.1.8 (MPC-89), each storage location is assigned to one of three regions, denoted as Region 1, Region 2, and Region 3 with an associated cell identification number. For example, cell identified as 2-4 is Cell 4 in Region 2. A DFC can be stored in the outer peripheral locations of both MPC-37 and MPC-89 as shown in Figures 2.1.1 and 2.1.2, respectively. The permissible heat loads for each cell, region, and the total canister are given in Tables 2.1.8 and 2.1.9 for MPC-37 and MPC-89, respectively.

Table 1.2.1

MULTI-PURPOSE CANISTER MODELS GEOMETRICALLY COMPATIBLE FOR STORAGE IN HI-STORM UMAX

USNRC Docket Number	**MPC Model I.D.(Note 1)**
72-1014	MPC-32/32F
	MPC-24
	MPC-24E/24EF
	MPC-68/68FF
	MPC-68F
	MPC-68M
72-1032	MPC-37
	MPC-89

Note 1: This issue of the FSAR seeks certification of only MPC-89 and MPC-37, termed as "licensing basis canisters" for HI-STORM UMAX. The analyses performed on other MPCs are for reference purposes only.

Table 1.2.2

HI-TRAC MODELS IN HI-STORM DOCKETS CORRESPONDING TO THE MPCs IN TABLE 1.2.1

USNRC Docket Number	**Model ID (Note 1)**
72-1014	HI-TRAC 100
	HI-TRAC 100D
	HI-TRAC 125
	HI-TRAC 125D
72-1032	HI-TRAC VW

Note 1: This issue of the FSAR seeks certification of only MPC-89 and MPC-37, termed as "licensing basis canisters" for HI-STORM UMAX. The analyses performed on other MPCs are for reference purposes only.

Table 1.2.3

KEY SYSTEM DATA FOR HI-STORM UMAX SYSTEM

ITEM	QUANTITY	NOTES
Types of MPCs	2	1 for PWR 1 for BWR
MPC storage capacity[†]:	MPC-37	Up to 37 undamaged ZR clad PWR fuel assemblies with or without non-fuel hardware. Up to 12 damaged fuel containers containing PWR damaged fuel and/or fuel debris may be stored in the locations denoted in Figure 2.1.1 with the remaining basket cells containing undamaged fuel assemblies, up to a total of 37.
MPC storage capacity[†]:	MPC-89	Up to 89 undamaged ZR clad BWR fuel assemblies. Up to 16 damaged fuel containers containing BWR damaged fuel and/or fuel debris may be stored in locations denoted in Figure 2.1.2 with the remaining basket cells containing undamaged fuel assemblies, up to a total of 89.

[†] See Chapter 2 for a complete description of authorized cask contents and fuel specifications.

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Figure 1.2.1 – Key Constituent Parts of a HI-STORM UMAX VVM

Note: The design features of the HI-STORM UMAX System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM UMAX depicted here may vary slightly from the licensing drawings in Section 1.5. This figure is for illustrative purposes only.

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Figure 1.2.2 – HI-STORM UMAX VVM Shown within the ISFSI Structure

Note: The design features of the HI-STORM UMAX System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM UMAX depicted here may vary slightly from the licensing drawings in Section 1.5. This figure is for illustrative purposes only.

1.3 IDENTIFICATION OF AGENTS AND CONTRACTORS

This section contains the necessary information to fulfill the requirements pertaining to the qualifications of the applicant pursuant to 10 CFR72.2(a)(1),(b) and 72.230(a). Holtec International, based in Marlton, NJ, is the system designer and applicant for certification of the HI-STORM UMAX system.

Holtec International is an engineering technology company with a principal focus on the power industry. Holtec International Nuclear Power Division (NPD) specializes in spent fuel storage technologies. NPD has carried out turnkey wet storage capacity expansions (engineering, licensing, fabrication, removal of existing racks, performance of underwater modifications, volume reduction of the old racks and hardware, installation of new racks, and commissioning of the fuel pool for increased storage capacity) in numerous nuclear plants around the world. Over 90 plants in the U.S., Britain, Brazil, Korea, Mexico, China and Taiwan have utilized the Company's wet storage technology to establish their state-of-the-art in-pool storage capacities.

Holtec's NPD is also a turnkey provider of dry storage and transportation technologies to nuclear plants around the globe. The company is contracted by over 45 nuclear units in the U.S. to provide the company's vertical ventilated dry storage technology. Utilities in China, Korea, Spain, Ukraine, the United Kingdom and Switzerland are also active users of Holtec International's dry storage and transport systems.

Four U.S. commercial plants, namely, Dresden Unit 1, Trojan, Indian Point Unit 1, and Humboldt Bay have thus far been completely defueled using Holtec International's technology. For many of its dry storage clients, Holtec International provides all phases of dry storage including: the required site-specific safety evaluations; ancillary designs; manufacturing of all capital equipment; preparation of site construction procedures; personnel training; dry runs; and fuel loading. The USNRC dockets in parts 71 and 72 currently maintained by the Company are listed in Table 1.3.1

Holtec International's corporate engineering consists of professional engineers and experts with extensive experience in every discipline germane to the fuel storage technologies, namely structural mechanics, heat transfer, computational fluid dynamics, and nuclear physics. Virtually all engineering analyses for Holtec's fuel storage projects (including HI-STORM UMAX) are carried out by the company's full-time staff. The Company is actively engaged in a continuous improvement program of the state-of-the-art in dry storage and transport of spent nuclear fuel. The active patents and patent applications in the areas of dry storage and transport of SNF held by the Company (ca. January 2012) are listed in Table 1.3.2. Table 1.3.3 lists Holtec patents on dry storage technologies that have been published by the US patent office (as of Jan .2012) but not yet granted. Many of these listed patents have been utilized in the design of the HI-STORM UMAX System.

Holtec International's quality assurance (QA) program was originally developed to meet NRC requirements delineated in 10CFR50 [1.3.1], Appendix B, and was expanded to include provisions of 10CFR71 [1.3.2], Subpart H, and 10CFR72, Subpart G, for structures, systems, and components designated as important to safety. The Holtec quality assurance program, which satisfies all 18 criteria in 10CFR72, Subpart G, that apply to the design, fabrication, construction, testing, operation, modification, and decommissioning of structures, systems, and components important to safety is incorporated by reference into this FSAR. Holtec International's QA program has been certified by the USNRC (Certificate No. 71-0784).

The HI-STORM UMAX System will be fabricated by the Holtec International Manufacturing Division (HMD) located in Pittsburgh, Pennsylvania with subcontract services from the Company's smaller plants in other parts of the country, namely Nanotec Metals Division (NMD) in Lakeland, FL and Orrvilon in Orrville, Ohio. HMD is a long-term ASME N-Stamp holder and fabricator of nuclear components. In particular, HMD has been manufacturing HI-STORM and HI-STAR system components since the inception of Holtec International's dry storage and transportation program in the 1990s. HMD routinely manufactures ASME code components for use in the U.S. and overseas nuclear plants. Holtec International's engineering organization, based in Marlton, NJ and the HMD subsidiary in Pittsburgh, PA have been subject to triennial inspections by the USNRC. If another fabricator is to be used for the fabrication of any part of the HI-STORM UMAX System, the proposed fabricator will be evaluated and audited in accordance with Holtec International's QA program approved by the USNRC.

Holtec International's Nuclear Power Division (NPD) also carries out site services for dry storage deployments at nuclear power plants. Several nuclear plants, such as Trojan and Waterford 3 (both completed) and Comanche Peak (ongoing, ca. January 2012) have deployed dry storage at their sites using a turnkey contract with Holtec International.

Table 1.3.1

USNRC DOCKETS ASSIGNED TO HOLTEC INTERNATIONAL

System Name	**Docket Number**
HI-STORM 100 (Storage)	72-1014
HI-STAR 100 (Storage)	72-1008
HI-STAR 100 (Transportation)	71-9261
HI-STAR 180 (Transportation)	71-9325
HI-STAR 60 (Transportation)	71-9336
Holtec Quality Assurance Program	71-0784
HI-STORM FW (Storage)	72-1032
HI-STORM UMAX	72-1040

Table 1.3.2
DRY STORAGE AND TRANSPORT PATENTS HELD BY HOLTEC INTERNATIONAL

Item No.	Colloquial Name of the Patent	USPTO Patent Number
1.	Honeycomb Fuel Basket	5,898,747
2.	Radiation Absorbing Refractory Composition (METAMIC)	5,965,829
3.	HI-STORM 100S Overpack	6,064,710
4.	Extrusion Fabrication Process for Discontinuous Carbide Particulate Metal Matrix Composites and Super Hypereutectic A1/S1(METAMIC-CLASSIC)	6,042,779
5.	Duct Photon Attenuator	6,519,307B1
6.	HI-TRAC Operation	6,587,536B1
7.	Cask Mating Device (Hermetically Sealable Transfer Cask)	6,625,246B1
8.	Improved Ventilator Overpack	6,718,000B2
9.	Below Grade Transfer Facility	6,793,450B2
10.	HERMIT (Seismic Cask Stabilization Device)	6,848,223B2
11.	Cask Mating Device (operation)	6,853,697
12.	Davit Crane	6,957,942B2
13.	Duct-Fed Underground HI-STORM	7,068,748B2
14.	Forced Helium Dehydrator (design)	7,096,600B2
15.	Below Grade Cask Transfer Facility	7,139,358B2
16.	Forced Gas Flow Canister Dehydration (alternate embodiment)	7,210,247B2
17.	HI-TRAC Operation (Maximizing Radiation Shielding During Cask Transfer Procedures)	7,330,525
18.	HI-STORM 100U	7,330,526B2
19.	Flood Resistant HI-STORM	7,590,213B1
20.	HI-STORM 100M (Underground Manifolded module assembly)	7,676,016B2
21.	Dew Point Temperature Based Canister Dehydration	7,707,741B2
22.	Optimized Weight Transfer Cask with Detachable Shielding	7,786,456B2
23.	VESCAP (Apparatus, System, and Method for Facilitating Transfer of High Level Radioactive Waste to and/or From a Pool	7,820,870B2
24.	HI-STORM 100F (Counter-flow Underground Vertical Ventilated Module)	7,933,374B2
25.	Apparatus for Transporting and/or Storing Radioactive Materials Having Jacket Adapted to Facilitate Thermo-siphon Fluid Flow	7,994,380B2
26.	Method of Removing Radioactive Materials from Submerged State and/or Preparing Spent Nuclear Fuel for Dry Storage	8,067,659B2
27.	HI-STORM 100US	8,098,790B1
28.	Canister Apparatus and Basket for Transporting, Storing and/or Supporting Spent Nuclear Fuel(Double Wall Canister)	8,135,107B2

Table 1.3.3

HOLTEC INTERNATIONAL PENDING PATENTS ON FUEL STORAGE

	Title	**Submittal Date**	***USPTO FILE NUMBER***	
1.	System And Method For The Ventilated Storage Of High Level Radioactive Waste In A Clustered Arrangement(HIC-Storm)	22-Dec-08	*12340948*	US20090159550
2.	System And Method For Preparing A Container Loaded With Wet Radioactive Elements For Dry Storage(Inter-Unit Transfer)	22-Dec-08	*12342022*	US20090158614
3.	Apparatus And Method For Supporting Fuel Assemblies In An Underwater Environment Having Lateral Access Loading	31-Mar-10	*12751717*	US20100232563
4.	Neutron Shielding Ring, Apparatus And Method Using The Same For Storing High Level Radioactive Waste (HI-STAR 180)	02-Jul-07	*11772581*	US20080084958
5.	Fuel Basket Spacer, Apparatus And Method Using The Same For Storing High Level Radioactive Waste (HI-STAR 180)	02-Jul-07	*11772620*	US20080031397
6.	Spent Fuel Basket, Apparatus And Method Using The Same For Storing High Level Radioactive Waste (HI-STAR 180)	02-Jul-07	*11772610*	US20080031396
7.	Method And Apparatus For Dehydrating High Level Waste Based On Dew Point Temperature Measurements (FGD)	18-Dec-09	*12641378*	US20100212182
8.	System And Method For Storing Spent Nuclear Fuel Having Manifolded Underground Vertical Ventilated Module (100M)	19-Feb-10	*12709094*	US20100150297

Table 1.3.3

HOLTEC INTERNATIONAL PENDING PATENTS ON FUEL STORAGE

	Title	**Submittal Date**	***USPTO FILE NUMBER***	
9.	Cask Apparatus, System And Method For Transporting And/Or Storing High Level Waste (HI-SAFE)	28-Apr-10	*12769622*	US20100272225
10.	Spent Fuel Basket For Storing High Level Radioactive Waste (HEXCOMB Racks)	29-Oct-08	*12260914*	US20090175404
11.	System and Method for Reclaiming Energy from Heat Emanating from Spent Nuclear Fuel	21-Apr-11	*13092143*	US20110286567
12.	Method Of Storing High Level Waste (100F)	26-Apr-11	*13094498*	US20110255647
13.	Single-Plate Neutron Absorbing Apparatus And Method Of Manufacturing The Same	23-Dec-09	*12645846*	US20110033019
14.	Apparatus For Storing And/Or Transporting High Level Radioactive Waste, And Method For Manufacturing The Same	06-May-10	*12774944*	US20100284506
15.	System, Method And Apparatus For Providing Additional Radiation Shielding To High Level Radioactive Materials	05-Nov-10	*12940804*	US20110172484
16.	Atomized Pico-scale Composite Aluminum Alloy And Method Thereof	24-Apr-09	*12312089*	US20100028193

1.4 GENERIC CASK ARRAYS

An ISFSI deploying the HI-STORM UMAX System may use an unlimited number of VVM. The preferred embodiment of the VVM array is a rectangular configuration as illustrated in the licensing drawing in Section 1.5. The reference pitch (center-to-center distance between centerlines of adjacent CECs in the two orthogonal directions) between the VVMs is shown on the licensing drawing. In either or both directions, the reference pitch spacing can be adjusted by the site to ensure that any commercially available cask transporters can traverse the VVM arrays to provide autonomous access to each stored MPC. This reference pitch spacing also serves to provide adequate shielding around each storage cavity.

No limit is placed on the maximum spacing between VVMs. If there are multiple VVMs in an ISFSI they should be founded on a continuous SFP, to the extent practicable, to enhance the seismic response characteristics of the ISFSI.

1.5 FIGURES AND DRAWINGS

The licensing drawing for the HI-STORM UMAX System, pursuant to the requirements of 10CFR72.24(c)(3), is provided in this section. The material list on the licensing drawing contains sufficient information to articulate major design features and general operational characteristics of "UMAX". Further, it is intended to serve as the control information to guide the preparation of the documents required to manufacture the components under Holtec's Quality Assurance Program. Holtec's Quality Assurance Program requires that the entire array of manufacturing documents must remain in complete conformance with the Licensing Drawing Package at all times.

The MPC and HI-TRAC drawings listed below are excerpted from the HI-STORM FW docket.

Drawing Package Number	Description	Revision
8446	HI-STORM UMAX Canister Storage System	4
6514	HI-TRAC VW – MPC-37	2
6799	HI-TRAC VW – MPC-89	2
6505	MPC-37 ENCLOSURE VESSEL	4
6506	MPC-37 FUEL BASKET	5
6512	MPC-89 ENCLOSURE VESSEL	4
6507	MPC-89 FUEL BASKET	5

Drawings withheld in Accordance with 10CFR2.390

1.6 REFERENCES

[1.0.1] USNRC Docket 72-1014, "Final Safety Analysis Report for the HI-STORM 100 Cask System", Holtec Report No. HI-2002444, latest revision.

[1.0.2] "Final Safety Analysis Report on the HI-STORM FW System", Holtec Report No. HI-2114830, latest revision.

[1.0.3] 10 CFR Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-level Radioactive Waste, and Reactor-Related Greater than Class C Waste", Title 10 of the Code of Federal Regulations- Energy, Office of the Federal Register, Washington, D.C.

[1.0.4] USNRC Regulatory Guide 3.61 (Task CE.306-4) "Standard Format for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Cask", February 1989.

[1.0.5] USNRC NUREG-1536, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility", Revision 1, July 2010.

[1.1.1] ASME Boiler & Pressure Vessel Code, Section III, Subsection NB, American Society of Mechanical Engineers, New York, 2010.

[1.1.2] NUREG/CR-6407, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety", U.S. Nuclear Regulatory Commission, February 1996.

[1.2.1] ANSI/NSF Standard 61, "Drinking Water System Components – Health Effects".

[1.2.2] ANSI N14.6-1993, "American National Standard for Radioactive Materials - Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4,500 Kg) or More", American National Standards Institute, Inc., Washington D.C., June 1993.

[1.2.3] Companion Guide to the ASME Boiler & Pressure Vessel Code, K.R. Rao (editor), Chapter 56, " Management of Spent Nuclear Fuel", Third Edition, ASME (2009)

[1.3.1] 10CFR Part 50, "Domestic Licensing of Production and Utilization Facilities", Title 10 of the Code of Federal Regulations, Office of the Federal Register, Washington, D.C.

[1.3.2] 10CFR Part 71, "Packaging and Transportation of Radioactive Material", Title 10 of the Code of Federal Regulations, Office of the Federal Register, Washington, D.C.

CHAPTER 2: PRINCIPAL DESIGN CRITERIA

2.0 OVERVIEW OF THE PRINCIPAL DESIGN CRITERIA

2.0.1 General

This chapter provides a systematic presentation of the loadings that must be considered for a complete safety evaluation of the HI-STORM UMAX System. As discussed in Chapter 1, this FSAR does not introduce any new MPC or transfer cask model. Rather, it envisages previously approved MPCs under docket 72-1032 [2.0.1] to be stored in a HI-STORM UMAX VVM. The drawings of the previously certified MPC-37 and MPC-89 are reproduced from the HI-STORM FW docket in Section 1.5 herein. Although the safety analyses of these previously certified MPCs are adopted from the HI-STORM FW FSAR by reference, additional safety evaluations are necessary to ensure that their licensed limits set forth in this CoC are not exceeded when they are stored in the HI-STORM UMAX VVM. Likewise, it is necessary to ensure that the licensed limits of the HI-TRAC VW transfer cask, certified along with the MPC-37 and MPC-89 in docket number 72-1032, are not exceeded when it is used to transfer the MPC at the HI-STORM UMAX ISFSI.

Section 1.5 contains the Licensing drawings for the MPC-37, MPC-89 and HI-TRAC VW cask excerpted from the HI-STORM FW docket where it was originally certified.

Design Criteria pertaining to the loadings and components common to the HI-STORM FW and the HI-STORM UMAX systems, such as the MPC and the HI-TRAC, are referenced in this FSAR, as appropriate, to the HI-STORM FW FSAR. To facilitate convenient access to the referenced material, the latest edition of the HI-STORM FW FSAR has been placed in this docket and a list of HI-STORM FW FSAR sections germane to this chapter is provided in a tabular form below.

HI-STORM FW FSAR material referenced in this FSAR		
Location of UMAX FSAR	**Subject of the Reference**	**Location in HI-STORM FW FSAR, Revision 1**
Sub-Section 2.0.1	Design Characteristics of MPC	Sub-Section 1.2.1
Sub-Section 2.0.1	Design Characteristics of HI-TRAC	Paragraph 1.2.1.3
Sub-Section 2.0.2	Structural analysis for qualifying the MPC closure welds	Sub-Section 3.4.3 and sub-Section 3.4.4
Sub-Section 2.0.2	MPC design analyzed for all design basis normal, off-normal and postulated accident conditions	Sub-Sections 2.2.1, 2.2.2, and 2.2.3
Sub-Section 2.0.2	HI-TRAC design analyzed for all design basis normal, off-normal and postulated accident conditions	Sub-Sections 2.2.1, 2.2.2, and 2.2.3
Sub-Section 2.0.3	HI-TRAC designed for off-normal environmental cold conditions	Section 2.2.2
Sub-Section 2.0.3	Evaluation of potential for brittle fracture in structural steel materials	Sub-Section 3.1.2.4 and Table 3.1.9
Sub-Section 2.0.4	HI-TRAC accident condition- loss of water in the water jacket	Sub-Section 5.1.2
Sub-Section 2.0.5	MPC providing criticality control for all design basis normal, off-normal and postulated accident conditions	Section 6.1
Sub-Section 2.0.6	MPC meeting the guidance of ISG-18	Section 7.1
Sub-Section 2.0.8	Acceptance Criteria for manufacturing of MPCs and HI-TRAC	Section 10.1, Tables 10.1.1, 10.1.3 through 10.1.8
Sub-Section 2.0.8	Maintenance Program for MPCs and HI-TRAC	Section 10.2, Table 10.2.1
Sub-Section 2.3.1	Applicable loads to MPC and HI-TRAC	Tables 2.2.6, 2.2.7, 2.2.13 and 3.1.1

HI-STORM FW FSAR material referenced in this FSAR*		
Location of UMAX FSAR	**Subject of the Reference**	**Location in HI-STORM FW FSAR, Revision 1**
Subsection 2.3.4	Confinement Boundary Leakage	Section 7.1
Sub-Section 2.7.2	Inspections and tests to verify integrity of the confinement boundary	Sub-Section 10.1.4

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* For convenience of reference, the specific revision of the HI-STORM FW FSAR that is referenced in the safety analysis herein is placed in this docket. Updated versions of the HI-STORM FW FSAR shall be placed in this docket as necessary so as to ensure that the safety analyses on the "UMAX" docket (72-1040) remain aligned with the material referenced in the HI-STORM FW FSAR.

The applicable design criteria for the MPC and the HI-TRAC transfer cask are based on their licensing bases in the HI-STORM FW docket. MPC design criteria information extracted from the HI-STORM FW FSAR is provided in "Arial" font throughout this chapter.

Tables 2.0.1, et.seq. in the HI-STORM FW FSAR contain the ITS designations of the subparts of the MPCs and transfer cask that constitute the components of the HI-STORM UMAX system.

The MPC is engineered for a 60 year design life, while satisfying the requirements of 10CFR72. The adequacy of the MPC to meet the above design life is discussed in Section 3.4 of the HI-STORM FW FSAR. The design characteristics of the MPC are described in Section 1.2 of the HI-STORM FW FSAR.

The HI-TRAC VW transfer cask is engineered for a 60 year design life. The adequacy of the HI-TRAC VW to meet the above design life commitment is discussed in Section 3.4 of HI-STORM FW FSAR. The design characteristics of the HI-TRAC VW cask are presented in Section 1.2 the HI-STORM FW FSAR.

A description of the HI-STORM UMAX VVM is provided in Section 1.2. The applicable loads, affected parts under each loading condition, and the applicable structural acceptance criteria are compiled in this Chapter to provide a complete framework for the required qualifying safety analyses in the rest of the safety analysis report. 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 UMAX VVM in Section 1.5 provides information on the necessary *critical characteristics* that define the HI-STORM UMAX system. The constituents of the HI-STORM UMAX ISFSI fall into two broad categories, namely:

a. VVM components

b. ISFSI structures

The safety analyses address both the VVM components and the ISFSI structures. The VVM components consist of:

a. The Cavity Enclosure Container (CEC)

b. The Divider Shell

c. The Closure Lid

The ISFSI Structures consist of:

a. The Support Foundation Pad (SFP)

b. The ISFSI Pad;

c. The Enclosure Wall (optional)

d. The Subgrade and Under-grade

Figure 1.2.1 denotes the key constituent parts of the HI-STORM UMAX VVM and Figure 2.4.4 depicts the subgrade and under-grade nomenclature for the ISFSI. The analysis basis density and shear wave velocities of sub-grade and under-grade spaces are given in Table 2.3.2. The spaces shown in Figure 2.4.4 are further explained below.

a. Space A is the Self-hardening Engineered Subgrade (SES) below the ISFSI Pad after the construction of the SFP. The candidate materials of SES include Controlled Low-Strength Material (CLSM) and lean concrete.

b. 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 A and Space B may be separated by an Enclosure Wall.

c. Space C is the under-grade below the SFP and extending 100 feet down from the top of grade elevation.

d. Space D is the under-grade surrounding Space C extending 100 feet down from the top of grade elevation.

2.0.2 Structural

MPC Design Criteria

The MPC is classified as important-to-safety. The MPC structural components include the fuel basket and the enclosure vessel. The fuel basket is designed and fabricated to meet a more stringent displacement limit under mechanical loadings than those implicit in the stress limits of the ASME code (see Section 2.2 of the HI-STORM FW FSAR). The MPC enclosure vessel is designed and fabricated as a Class 1 pressure vessel in accordance with Section III, Subsection NB of the ASME Code, with certain necessary alternatives, as discussed in Section 2.2 of the HI-STORM FW FSAR. The principal exception to the above Code pertains to the MPC lid, vent and drain port cover plates, and closure ring welds to the MPC lid and shell, as discussed in Section 2.2 of HI-STORM FW FSAR. In addition, Threaded Anchor Locations (TALs) in the MPC lid are designed in accordance with the requirements of NUREG-0612 for critical lifts to facilitate handling of the loaded MPC.

The MPC closure welds are partial penetration welds that are structurally qualified by analysis in Chapter 3 of the HI-STORM FW FSAR. The MPC lid and closure ring welds are inspected by performing a liquid penetrant examination in accordance with the drawings contained in Section 1.5. The integrity of the MPC lid-to-shell weld is further verified by performing a progressive liquid penetrant examination of the weld layers, and a Code pressure test.

The structural analysis of the MPC, in conjunction with the redundant closures and nondestructive examination, pressure testing, and helium leak testing provides assurance of canister closure integrity in lieu of the specific weld joint configuration requirements of Section III, Subsection NB.

Compliance with the ASME Code, with respect to the design and fabrication of the MPC, and the associated justification are discussed in Section 2.2 of the HI-STORM FW FSAR. The MPC design is analyzed for all design basis normal, off-normal, and postulated accident conditions, as defined in Section 2.2 of the HI-STORM FW FSAR.

The required characteristics of the fuel assemblies to be stored in the MPC are limited in accordance with Section 2.1 of the HI-STORM FW FSAR.

HI-TRAC Design Criteria

The HI-TRAC transfer cask includes both structural and non-structural radiation shielding components that are classified as important-to-safety. The structural steel components of the HI-TRAC are designed to meet the stress limits of Section III, Subsection NF, of the ASME Code for normal and off-normal storage conditions. The threaded anchor locations for lifting and handling of the transfer cask are designed in accordance with the requirements of NUREG-0612 and Regulatory Guide 3.61 for interfacing lift points.

The HI-TRAC transfer cask design is analyzed for all normal, off-normal, and design basis accident condition loadings, as defined in Section 2.2 of the HI-STORM FW FSAR. Under accident conditions, the HI-TRAC transfer cask must protect the MPC from unacceptable deformation, provide continued shielding, and remain in a condition such that the MPC can be removed from it. The loads applicable to the HI-TRAC transfer cask are defined in Tables 2.2.6, 2.2.13 and Table 3.1.1 of the HI-STORM FW FSAR. The physical characteristics of each MPC for which the HI-TRAC VW is designed are presented in Subsection 1.2 of the HI-STORM FW FSAR.

HI-STORM VVM Design Criteria

All required information on the design bases and criteria for the VVM is compiled in this Chapter and fulfills the requirements of 10CFR72.24(c) (3) and 72.44(d). The VVM structure described in Chapter 1 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 SFP and the ISFSI pad are categorized as important-to-safety (ITS) structures and are included in the structural analyses in Chapter 3, and in other chapters, as applicable. ACI-318 (05) [2.6.2] is specified as the reference code for the design qualification of the SFP and the ISFSI pad using the load combinations specified in Table 2.4.3. The seismic qualification of the storage system is performed in Chapter 3.

The material types used in the VVM are identified in Table 2.6.2. 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 to substitute materials with equivalent materials in the manufacture of the equipment.

The term Equivalent Material* has a specific meaning in this FSAR (and other FSARs in Holtec dockets listed in Table 1.2.1). 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.

The equivalence of materials is directly tied to the notion of *critical characteristics*. A critical characteristic of a material is a 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 lies specific gravity and thermal expansion coefficient for the VVM components.

Table 2.6.3 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 category types, namely structural, thermal, and radiation compliance. The material properties listed in Table 2.6.4 are the ones that apply to the VVM components.

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.

For ITS materials, recourse to equivalent materials shall be made only in the extenuating circumstances where the designated material 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

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* This text matter on Equivalent Materials is adapted from previously approved FSARs [2.0.1, 2.6.3].

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:

a. Material yield strength, σ_y

b. Material ultimate strength, σ_u

c. Elongation, ε

d. Charpy impact strength at the lowest service temperature for the part, C_i (unless exempted by other provisions in the governing code)

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. The above *critical characteristics* apply to all materials used in the structural parts of the CEC.

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 and materials of construction, the maximum magnitude of Design Basis Earthquake for the HI-STORM UMAX ISFSI is also specified. A non-linear time-history solution procedure implemented on LS-DYNA is used in Chapter 3 to qualify the ISFSI including the storage system. This same non-linear time-history solution procedure must be used to perform safety evaluation under 10CFR72.212 at a host site. Likewise, the loadings from the extreme environmental phenomena, defined in this chapter, are considered in Chapter 3. Site specific loadings that deviate from those analyzed in Chapter 3 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 2.4.1. The physical characteristics of the MPC intended for storage in the VVM are presented in Chapter 1.

The design bases and criteria provided in this Chapter 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).

2.0.3 Thermal

MPC Design Criteria

The thermal design and operation of the MPC in the HI-STORM UMAX System meets the intent of the review guidance contained in ISG-11, Revision 3 [2.4.6]. Specifically, the ISG-11 provisions that are explicitly invoked and satisfied are:

i. The thermal acceptance criteria for all commercial spent fuel (CSF) authorized by the USNRC for operation in a commercial reactor are unified into one set of requirements.

ii. The maximum value of the calculated temperature for all CSF under long-term normal conditions of storage must remain below 400°C (752°F). For short-term operations, including canister drying, helium backfill, and on-site cask transport operations, the fuel cladding temperature must not exceed 400°C (752°F) for high burnup fuel (HBF) and 570°C (1058°F) for moderate burnup fuel.

iii. The maximum fuel cladding temperature as a result of an off-normal or accident event must not exceed 570°C (1058°F).

iv. For HBF, operating restrictions are imposed to limit the maximum temperature excursion during short-term operations to 65°C (117°F) and the number of excursions to less than 10.

To achieve compliance with the above criteria, certain design and operational changes are necessary, as summarized below.

i The peak fuel cladding temperature limit (PCT) for long term storage operations and short term operations is generally set at 400°C (752°F). However, for MPCs containing all moderate burnup fuel, the fuel cladding temperature limit for short-term operations is set at 570°C (1058°F) because the nominal fuel cladding stress is shown to be less than 90 MPa [2.0.2]. Appropriate analyses have been performed as discussed in Chapter 4 and operating restrictions have been added to ensure these limits are met.

ii. A method of drying, such as forced helium dehydration (FHD) is used if the above temperature limits for short-term operations cannot be met.

iii. The off-normal and accident condition PCT limit remains unchanged at 570 °C (1058°F).

The MPC cavity is dried, either with FHD or vacuum drying, and then it is backfilled with high purity helium to promote heat transfer and prevent cladding degradation.

The normal condition design temperatures for the stainless steel components in the MPC are provided in Table 2.3.7.

Each MPC model allows for regionalized storage where the basket is segregated into three regions as shown in Figures 2.1.7 and 2.1.8. Decay heat limits for regionalized loading are presented in Tables 2.1.8 and 2.1.9 for MPC-37 and MPC-89, respectively. Specific requirements, such as approved locations for DFCs and non-fuel hardware are given in Section 2.1.

HI-TRAC Design Criteria

The allowable temperatures for the HI-TRAC transfer cask structural steel components are based on the maximum temperature for material properties and allowable stress values provided in Section II of the ASME Code. The allowable temperatures for the structural steel and shielding components of the HI-TRAC are provided in Table 2.3.7. The HI-TRAC is designed for off-normal environmental cold conditions, as discussed in Subsection 2.2.2 of the HI-STORM FW FSAR. The evaluation of the potential for brittle fracture in structural steel materials is presented in Section 3.1 of the HI-STORM FW FSAR.

The HI-TRAC is designed and evaluated for the maximum heat load analyzed for storage operations. The maximum allowable temperature of water in the HI-TRAC jacket is a function of the internal pressure. To preclude over- pressurization of the water jacket due to boiling of the neutron shield liquid (water), the maximum temperature of the water is restricted to be less than the saturation temperature at the shell design pressure. Even though the analysis shows that the water jacket will not over-pressurize, a relief device is placed at the top of the water jacket shell. In addition, the water is precluded from freezing during off-normal cold conditions by limiting the minimum allowable operating temperature and by adding ethylene glycol. The thermal characteristics of the fuel for each MPC for which the transfer cask is designed are defined in Section 2.1. The working area ambient temperature limit for loading operations is limited in accordance with Table 2.3.6.

HI-STORM VVM Design Criteria

The HI-STORM VVM rejects heat from the stored MPCs by delivering cool ambient air to the annular space around the MPC. The ambient air undergoes progressive heating and reduction in density as it rises in the cylindrical space surrounding the MPC through convective heat transfer with the MPC shell, and exits the cell through the vertical flue mounted on the central region of the closure lid. The storage cavities have a constant out flow of air which will tend to retard the deposition of air borne particulates and debris in the storage space. The accumulated solids can be vacuumed out of the storage cavity by standard means. As shown in Chapter 4, the VVMs are 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 VVM is designed for extreme cold conditions. The safety of structural steel material used for the VVM from brittle fracture is discussed in Chapter 8.

2.0.4 Shielding

The HI-TRAC transfer cask provides shielding to maintain occupational exposures ALARA in accordance with 10CFR20, while also maintaining the maximum load on the plant's crane hook below the rated capacity of the crane. As discussed in Subsection 1.2.1 of the HI-STORM FW FSAR, the shielding in HI-TRAC is maximized within the constraint of the allowable weight at a plant site. The HI-TRAC calculated dose rates for a set of reference conditions are reported in Section 5.1 of HI-TRAC FW FSAR. These dose rates are used to perform a generic occupational exposure estimate for MPC loading, closure, and transfer operations, as described in Chapter 11 of the HI-STORM FW FSAR. A postulated HI-TRAC accident condition, which includes the loss of the liquid neutron shield (water), is also evaluated in Chapter 5 of the HI-STORM FW FSAR.

The annular area between the MPC outer surface and the HI-TRAC inner surface can be isolated to minimize the potential for surface contamination of the MPC by spent fuel pool water during wet loading operations. The HI-TRAC surfaces expected to require decontamination are coated with a suitable coating. The maximum permissible surface contamination for the HI-TRAC is in accordance with plant-specific procedures and ALARA requirements (discussed in Chapter 11 of the HI-STORM FW FSAR).

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 UMAX System are provided in Chapter 5. 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 HI-STORM UMAX 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 VVMs significantly reduces the radiation from the ISFSI at the site boundary compared to an aboveground cask. The calculated VVM dose rates, including dose rates during site construction next to an operating ISFSI, are discussed in Chapter 5.

2.0.5 Criticality

The MPC provides criticality control for all design basis normal, off-normal, and postulated accident conditions, as discussed in Section 6.1 of the HI-STORM FW FSAR. The effective neutron multiplication factor is limited to $k_{eff} < 0.95$ for fresh (unirradiated) fuel with optimum water moderation with due consideration of all biases, uncertainties, and manufacturing tolerances.

Criticality control is maintained by the geometric spacing of the fuel assemblies and the spatially distributed B-10 isotope in the Metamic-HT fuel basket, and for the PWR MPC model, the additional soluble boron in the MPC water. The minimum specified boron concentration in the purchasing specification for Metamic-HT must be met in every lot of the material manufactured. The guaranteed B-10 value in the neutron absorber, assured by the manufacturing process, is further reduced by 10% (90% credit is taken for the Metamic-HT) to accord with NUREG/CR-5661. No credit is taken for fuel burnup or integral poisons such as gadolinia in BWR fuel. The soluble boron concentration requirements (for PWR fuel only) based on the initial enrichment of the fuel assemblies are delineated in Section 2.1 consistent with the criticality analysis described in Chapter 6 of the HI-STORM FW FSAR [2.0.1].

The HI-STORM UMAX VVM does not perform any criticality control function. The MPCs provide criticality control for all design basis normal, off-normal and postulated accident conditions.

2.0.6 Confinement

The MPC provides for confinement of all radioactive materials for all design basis normal, off-normal, and postulated accident conditions. As discussed in Chapter 7 of the HI-STORM FW, MPC design meets the guidance in the Interim Staff Guidance (ISG)-18 so that leakage of radiological matter from the confinement boundary is non-credible. Therefore, no confinement dose analysis is required or performed. The confinement function of the MPC is verified through pressure testing, helium leak testing, and a rigorous weld examination regimen executed in accordance with the acceptance test program in Chapter 10 of the HI-STORM FW FSAR.

The HI-TRAC transfer cask does not perform any confinement function. The HI-TRAC provides physical protection and radiation shielding of the MPC contents during MPC loading, unloading, and transfer operations.

The VVM does not perform any confinement function. Confinement during storage is provided by the MPC and is addressed above.

2.0.7 Operations

There are no radioactive effluents that result from storage of transfer operations. Effluents generated during MPC fuel loading are handled by the plant's radioactive waste system and procedures.

The cask operations unique to the HI-STORM UMAX (and common with the HI-STORM 100U in the HI-STORM 100 docket) begin with the arrival of the loaded transfer cask at the HI-STORM UMAX ISFSI. The cask transporter is typically used to move the loaded transfer cask to the ISFSI and to transfer the MPC into the VVM cavities. Generic operating procedures for the HI-STORM UMAX System are provided in Chapter 9. Detailed operating procedures will be developed by the licensee using the information provided in Chapter 9 along with the site-specific requirements that comply with the 10CFR50 Technical Specifications for the plan, and applicable Certificate(s) of Compliance (CoC).

The following overarching requirements apply to all SSCs used in the HI-STORM UMAX operations:

a. All threaded parts shall have provisions to prevent rust build up.

b. All rigging components shall be inspected for visible indications of damage or degradation prior to use.
c. All ancillaries used in heavy load handling shall comply with the brittle fracture criteria set down for cask components in this FSAR.

2.0.8 Acceptance Tests and Maintenance

The acceptance criteria and maintenance program to be applied to the MPC are described in Chapter 10 of the HI-STORM FW FSAR. The operational controls and limits to be applied to the MPC are discussed in Chapter 13. Application of these requirements will assure that the MPC is fabricated, operated, and maintained in a manner that satisfies the design criteria defined in this chapter.

The acceptance criteria and maintenance program to be applied to the HI-TRAC Transfer Cask are described in Chapter 10 of the HI-STORM FW FSAR. The operational controls and limits to be applied to the HI-TRAC are contained in Chapter 13. Application of these requirements will assure that the HI-TRAC is fabricated, operated, and maintained in a manner that satisfies the design criteria given in this chapter.

The fabrication acceptance bases and maintenance program to be applied to the VVMs are described in Chapter 10. Application of these requirements will assure that the VVMs are fabricated and maintained in a manner that satisfies all applicable design criteria.

2.0.9 Decommissioning

The MPC is designed to be transportable in a HI-STAR overpack and is not required to be unloaded prior to shipment off-site.

Decommissioning considerations for the HI-STORM UMAX System including HI-TRAC are addressed in Section 2.11.

Table 2.0.1 – MPC-37 Enclosure Vessel (Drawing # 6505)		
Item Number*	Part Name	ITS QA Safety Category
1	Shell, Enclosure Vessel	A
2	Plate, Enclosure Vessel Base	A
3	Plate, Enclosure Vessel Lift Lug	C
4	Plate, Enclosure Vessel Upper Lid	A
5	Plate, Enclosure Vessel Lower Lid	B
6	Ring, Enclosure Vessel Closure	A
7	Block, Enclosure Vessel Vent/Drain Upper	B
9	Block, Enclosure Vessel Drain Shielding	C
10	Block, Enclosure Vessel Lower Drain	C
12	Block, Enclosure Vessel Vent Shielding	C
13	Plate, Enclosure Vessel Vent/Drain Port Cover	A
14	Cap, Enclosure Vessel Vent/Drain	C
20	Shim, Enclosure Vessel Type 1 PWR Fuel Basket	C
21	Shim, Enclosure Vessel Type 2 PWR Fuel Basket	C

*Item Numbers are non-consecutive because they are consistent with Parts List on drawing.

Table 2.0.2 – Assembly, MPC-37 Fuel Basket (Drawing # 6506)		
Item Number	Part Name	ITS QA Safety Category
1	Panel, Type 1 Cell Wall	A
2	Panel, Type 2 Cell Wall	A
3	Panel, Type 3 Cell Wall	A
4	Panel, Type 4 Cell Wall	A
5	Panel, Type 5 Cell Wall	A
6	Panel, Type 6 Cell Wall	A

Table 2.0.3 – Assembly, MPC-89 Fuel Basket (Drawing # 6507)		
Item Number	Part Name	ITS QA Safety Category
1	Panel, Type 1 Cell Wall	A
2	Panel, Type 2 Cell Wall	A
3	Panel, Type 3 Cell Wall	A
4	Panel, Type 4 Cell Wall	A
5	Panel, Type 5 Cell Wall	A
6	Panel, Type 6 Cell Wall	A
7	Panel, Type 7 Cell Wall	A
8	Panel, Type 8 Cell Wall	A

Table 2.0.4 – MPC-89 Enclosure Vessel (Drawing # 6512)

Item Number*	Part Name	ITS QA Safety Category
1	Shell, Enclosure Vessel	A
2	Plate, Enclosure Vessel Base	A
3	Plate, Enclosure Vessel Lift Lug	C
4	Plate, Enclosure Vessel Upper Lid	A
5	Plate, Enclosure Vessel Lower Lid	B
6	Ring, Enclosure Vessel Closure	A
7	Block, Enclosure Vessel Vent/Drain Upper	B
9	Block, Enclosure Vessel Drain Shielding	C
10	Block, Enclosure Vessel Lower Drain	C
12	Block, Enclosure Vessel Vent Shielding	C
13	Plate, Enclosure Vessel Vent/Drain Port Cover	A
14	Cap, Enclosure Vessel Vent/Drain	C
20	Shim, Enclosure Vessel Type 1 BWR Fuel Basket	C
21	Shim, Enclosure Vessel Type 2 BWR Fuel Basket	C
22	Shim, Enclosure Vessel Type 3 BWR Fuel Basket	C

*Item Numbers are non-consecutive because they are consistent with Parts List on drawing.

Table 2.0.5 – HI-TRAC VW – MPC-37 (Drawing # 6514)		
Item Number*	Part Name	ITS QA Safety Category
1	Flange, Bottom	B
3	Hex Bolt, 2-4 ½ UNC X 6" LG.	B
4	Shell, Inner	B
5	Shielding, Gamma	B
6	Flange, Top	B
7	Shell, Water Jacket	B
10	Pipe, Bolt Recess	B
11	Cap, Bolt Recess	B
12	Bottom Lid	B
13	Shell, Outer	B
14	Rib, Extended	B
15	Rib, Short	B

*Item Numbers are non-consecutive because they are consistent with Parts List on drawing.

Table 2.0.6 – HI-TRAC VW – MPC-89 (Drawing # 6799)		
Item Number*	Part Name	ITS QA Safety Category
1	Flange, Bottom	B
3	Hex Bolt, 2-4 ½ UNC X 6" LG.	B
4	Shell, Inner	B
5	Shielding, Gamma	B
6	Flange, Top	A
7	Shell, Water Jacket	B
10	Pipe, Bolt Recess	B
11	Cap, Bolt Recess	B
12	Bottom Lid	B
13	Shell, Outer	B
14	Rib, Extended	B
15	Rib, Short	B

*Item Numbers are non-consecutive because they are consistent with Parts List on drawing.

2.1 SPENT FUEL TO BE STORED AND SERVICE LIMITS

2.1.1 Determination of the Design Basis Fuel

A central object in the design of the HI-STORM UMAX System is to ensure that all SNF discharged from the U.S. reactors can be stored in the HI-STORM UMAX MPC upon meeting the burn up, cooling time and content conditions requirements set forth in this FSAR. Publications such as references [2.1.1] and [2.1.2] provide a comprehensive description of fuel discharged from U.S. reactors.

The cell openings in the fuel baskets have been sized to accommodate BWR and PWR assemblies. The cavity length of the MPC will be determined for a specific site to accord with the fuel assembly length used at that site, including non-fuel hardware and damaged fuel containers, as applicable.

Table 2.1.1 summarizes the authorized contents for the HI-STORM UMAX System. Tables 2.1.2 and 2.1.3, which are referenced in Table 2.1.1, provide the fuel characteristics of all groups of fuel assembly types determined to be acceptable for storage in the HI-STORM UMAX System. Any fuel assembly that has fuel characteristics within the range of Tables 2.1.2 and 2.1.3 and meets the other limits specified in Table 2.1.1 is acceptable for storage in the HI-STORM UMAX System. The groups of fuel assembly types presented in Tables 2.1.2 and 2.1.3 are defined as "array/classes" as described in further detail in Chapter 6 of HI-STORM FW FSAR. Table 2.1.4 lists the BWR and PWR fuel assembly designs which are found to govern for three qualification criteria, namely reactivity, shielding, and thermal, or that are used as reference assembly design is those analyses. Additional information on the design basis fuel definition is presented in the following subsections.

2.1.2 Undamaged SNF Specifications

Undamaged fuel is defined in the Glossary.

2.1.3 Damaged SNF and Fuel Debris Specifications

Damaged fuel and fuel debris are defined in the Glossary.

Damaged fuel assemblies and fuel debris will be loaded into damaged fuel containers (DFCs) (Figure 2.1.6) that have mesh screens on the top and bottom. The DFC will have a removable lid to allow the fuel assembly to be inserted. In storage, the lid will be latched in place. DFC's used to move fuel assemblies will be designed for lifting with either the lid installed or with a separate handling lid. DFC's used to handle fuel and the associated lifting tools will designed in accordance with the requirements of NUREG-0612. The DFC will be fabricated from structural aluminum or stainless steel. The appropriate structural, thermal, shielding, criticality, and confinement evaluations have been performed to account for damaged fuel and fuel debris and are described in their respective chapters that follow. The limiting design characteristics for damaged fuel assemblies and restrictions on the number and location of damaged fuel containers authorized for loading in each MPC model are provided in this chapter.

2.1.4 Structural Parameters for Design Basis SNF

The main physical parameters of an SNF assembly applicable to the structural evaluation are the fuel assembly length, cross sectional dimensions, and weight. These parameters, which define the mechanical and structural design, are specified in Subsection 2.1.8. An appropriate axial clearance is provided to prevent interference due to the irradiation and thermal growth of the fuel assemblies.

2.1.5 Thermal Parameters for Design Basis SNF

The principal thermal design parameter for the stored fuel is the fuel's peak cladding temperature (PCT) which is a function of the maximum decay heat per assembly and the decay heat removal capabilities of the HI-STORM UMAX System.

To ensure the permissible PCT limits are not exceeded, Subsection 2.1.9 specifies the maximum allowable decay heat per assembly for each MPC model in the three-region configuration.

The fuel cladding temperature is also affected by the heat transfer characteristics of the fuel assemblies. The design basis fuel assembly for thermal calculations for both PWR and BWR fuel is provided in Table 2.1.4.

Finally, the axial variation in the heat generation rate in the design basis fuel assembly is defined based on the axial burnup distribution. For this purpose, the data provided in references [2.1.3] and [2.1.4] are utilized and summarized in Table 2.1.5 and Figures 2.1.3 and 2.1.4. These distributions are representative of fuel assemblies with the design basis burnup levels considered. These distributions are used for analyses only, and do not provide a criteria for fuel assembly acceptability for storage in the HI-STORM UMAX System.

2.1.6 Radiological Parameters for Design Basis SNF

The principal radiological design criteria for the HI-STORM UMAX System are the 10CFR72 §104 and §106 operator-controlled boundary dose rate limits, and the requirement to maintain operational dose rates as low as reasonably achievable (ALARA). The radiation dose is directly affected by the gamma and neutron source terms of the assembly, which is a function of the assembly type, and the burnup, enrichment and cooling time of the assemblies. Dose rates are further directly affected by the size and arrangement of the ISFSI, and the specifics of the loading operations. All these parameters are site-dependent, and the compliance with the regulatory dose rate requirements are performed in site-specific calculations. The evaluations here are therefore performed with reference fuel assemblies, and with parameters that result in reasonably conservative dose rates. The reference assemblies given in Table 1.0.4 of the HI-STORM FW FSAR are the predominant assemblies used in the industry.

The design basis dose rates can be met by a variety of burnup levels and cooling times. Table 2.1.1 provides the acceptable ranges of burnup, enrichment and cooling time for all of the authorized fuel assembly array/classes. Table 2.1.5 and Figures 2.1.3 and 2.1.4 provide the axial distribution for the radiological source terms for PWR and BWR fuel assemblies based on the axial burnup distribution. The axial burnup distributions are representative of fuel assemblies with the design basis burnup levels considered. These distributions are used for analyses only, and do not provide a criteria for fuel assembly acceptability for storage in the HI-STORM UMAX System.

Non-fuel hardware, as defined in the Glossary, has been evaluated and is also authorized for storage in the PWR MPCs as specified in Table 2.1.1.

2.1.7 Criticality Parameters for Design Basis SNF

The criticality analyses for the MPC-37 are performed with credit taken for soluble boron in the MPC water during wet loading and unloading operations. Table 2.1.6 provides the required soluble boron concentrations for this MPC.

2.1.8 Summary of Authorized Contents

Tables 2.1.1 through 2.1.3 specify the limits for spent fuel and non-fuel hardware authorized for storage in the HI-STORM FW System. The limits in these tables are derived from the safety analyses described in the following chapters of this FSAR.

2.1.9 Permissible Heat Load for MPC-37 and MPC-89

MPC-89 (BWR) and MPC-37 (PWR) canisters are previously licensed in Docket 72-1032 for storage of spent fuel and are permitted for storage in HI-STORM UMAX with permissible heat load reduction factors incorporated as specified in Table 2.1.7. As shown in Figures 2.1.7 and 2.1.8 for MPC-37 and MPC-89 respectively, each storage location is assigned to one of three regions, denoted as Region 1, Region 2, and Region 3 with an associated cell identification number. For example, cell identified as 2-4 is Cell 4 in Region 2. The permissible heat loads for each cell, region, and the aggregate heat load in the canister for storage in the HI-STORM UMAX VVM are given in Tables 2.1.8 and 2.1.9 for MPC-37 and MPC-89 respectively.

2.1.10 Permissible Heat Load for MPC-24, MPC-32 and MPC-68

The authorized heat loads in the HI-STORM 100 docket for the MPCs certified for storage in the HI-STORM 100 will be used to determine the acceptability of storing them in HI-STORM UMAX. These analyses will be performed to characterize the thermal behavior of the "UMAX" system; they are not intended to secure certification of the MPCs in docket # 72-1014 at this time.

Regionalized loading of SNF in two regions are permitted in MPC-24, MPC-32 and MPC-68 models. The definition of the two regions for each MPC model is provided in Table 2.1.10. The inner region (Region 1) and the outer region (Region 2), shown in Figures 2.1.9, 2.1.10 and 2.1.11 for different MPC types have maximum permitted specific heat loads denoted by q_1 and q_2, respectively. The maximum permitted values of q_1 and q_2 are related through the ratio X,

where,

$X = q_1/q_2$.

The special case where q_1 and q_2 are equal (X= 1) is referred to as "uniform storage". Table 2.1.11 provides the maximum allowable decay heat per fuel storage location for ZR-clad fuel in a uniform fuel loading pattern for each MPC. (Regionalized fuel loading is not permitted in MPC-68F.) The following procedure is specified in Docket # 72-1014 to determine q_1 and q_2 for any chosen value of X:

(i) Choose a value of X in the permissible range ($0.5 \leq X \leq 3$)

(ii) Calculate q_2 using the following equation:

$$q_2 = \frac{2 \times Q_d}{\left(1 + X^y\right) \times \left(n_1 \times X + n_2\right)}$$

where:

$y = 0.23/X^{0.1}$
q_2 = Maximum allowable decay heat per fuel storage location in Region 2 (kW)
Q_d= Maximum uniform storage MPC decay heat (34 kW)
X = Ratio of q_1 to q_2 chosen in Step (i)
n_1 = Number of fuel storage locations in Region 1 from Table 2.1.10
n_2 = Number of fuel storage locations in Region 2 from Table 2.1.10

(iii) Calculate q_1 using the following equation:

$$q_1 = X \times q_2$$

Additional details of maximum allowable heat load per fuel storage location are provided in Section 2.1.9.1 of the HI-STORM 100 FSAR [2.6.3].

Table 2.1.1*

MATERIAL TO BE STORED

PARAMETER	**VALUE (Note 1)**	
	MPC-37	MPC-89
Fuel Type	Uranium oxide undamaged fuel assemblies, damaged fuel assemblies, and fuel debris meeting the limits in Table 2.1.2 for the applicable array/class.	Uranium oxide undamaged fuel assemblies, damaged fuel assemblies, with or without channels, fuel debris meeting the limits in Table 2.1.3 for the applicable array/class.
Cladding Type	ZR (see Glossary for definition)	ZR (see Glossary for definition)
Maximum Initial Rod Enrichment	Depending on soluble boron levels and assembly array/class as specified in Table 2.1.6	≤ 5.0 wt. % U-235
Post-irradiation cooling time and average burnup per assembly	Minimum Cooling Time: 3 years Maximum Assembly Average Burnup: 68.2 GWd/mtU	Minimum Cooling Time: 3 years Maximum Assembly Average Burnup: 65 GWd/mtU

*** The text matter in the "arial" font is excerpted from the HI-STORM FW FSAR with minor editorial changes ,as appropriate**

Table 2.1.1*

MATERIAL TO BE STORED

PARAMETER	VALUE (Note 1)	
	MPC-37	MPC-89
Non-fuel hardware post-irradiation cooling time and burnup	Minimum Cooling Time: 3 years Maximum Burnup†: - BPRAs, WABAs and vibration suppressors: 60 GWd/mtU - TPDs, NSAs, APSRs, RCCAs, CRAs, CEAs, water displacement guide tube plugs and orifice rod assemblies: 630 GWd/mtU - ITTRs: not applicable	N/A
Decay heat per fuel storage location	Regionalized Loading: See Table 2.1.8	Regionalized Loading: See Table 2.1.9
Fuel Assembly Nominal Length (in.)	Minimum: 157 (with NFH) Reference: 167.2 (with NFH) Maximum: 199.2 (with NFH and DFC)	Minimum: 171 Reference: 176.5 Maximum: 176.5 (without DFC)
Fuel Assembly Width (in.)	≤ 8.54 (nominal design)	≤ 5.95 (nominal design)

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† Burnups for non-fuel hardware are to be determined based on the burnup and uranium mass of the fuel assemblies in which the component was inserted during reactor operation. Burnup not applicable for ITTRs since installed post-irradiation.

Table 2.1.1*

MATERIAL TO BE STORED

PARAMETER	**VALUE (Note 1)**	
	MPC-37	MPC-89
Fuel Assembly Weight (lb)	Reference: 1600 (without NFH) 1750 (with NFH), 1850 (with NFH and DFC) Maximum: 2050 (including NFH and DFC)	Reference: 750 (without DFC), 850 (with DFC) Maximum: 850 (including DFC)

Table 2.1.1*

MATERIAL TO BE STORED

PARAMETER	**VALUE (Note 1)**	
	MPC-37	MPC-89
Other Limitations	▪ Quantity is limited to 37 undamaged ZR clad PWR fuel assemblies with or without non-fuel hardware. Up to 12 damaged fuel containers containing PWR damaged fuel and/or fuel debris may be stored in the locations denoted in Figure 2.1.1 with the remaining basket cells containing undamaged ZR fuel assemblies, up to a total of 37. ▪ One NSA. ▪ Up to 30 BPRAs. ▪ BPRAs, TPDs, WABAs, water displacement guide tube plugs, orifice rod assemblies, and/or vibration suppressor inserts may be stored with fuel assemblies in any fuel cell location. ▪ CRAs, RCCAs, CEAs, NSAs, and/or APSRs may be stored with fuel assemblies in fuel cell locations specified in Figure 2.1.5.	Quantity is limited to 89 undamaged ZR clad BWR fuel assemblies. Up to 16 damaged fuel containers containing BWR damaged fuel and/or fuel debris may be stored in locations denoted in Figure 2.1.2 with the remaining basket cells containing undamaged ZR fuel assemblies, up to a total of 89.

Table 2.1.2

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/ Class	**14x14 A**	**14x14 B**	**14x14 C**	**15x15 B**	**15x15 C**
No. of Fuel Rod Locations	179	179	176	204	204
Fuel Clad O.D. (in.)	≥ 0.400	≥ 0.417	≥ 0.440	≥ 0.420	≥ 0.417
Fuel Clad I.D. (in.)	≤ 0.3514	≤ 0.3734	≤ 0.3880	≤ 0.3736	≤ 0.3640
Fuel Pellet Dia. (in.) (Note 3)	≤ 0.3444	≤ 0.3659	≤ 0.3805	≤ 0.3671	≤ 0.3570
Fuel Rod Pitch (in.)	≤ 0.556	≤ 0.556	≤ 0.580	≤ 0.563	≤ 0.563
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	17	17	5 (Note 2)	21	21
Guide/Instrument Tube Thickness (in.)	≥ 0.017	≥ 0.017	≥ 0.038	≥ 0.015	≥ 0.0165

Table 2.1.2 (continued)

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array/Class	**15x15 D**	**15x15 E**	**15x15 F**	**15x15 H**	**15x15 I**
No. of Fuel Rod Locations	208	208	208	208	216
Fuel Clad O.D. (in.)	≥ 0.430	≥ 0.428	≥ 0.428	≥ 0.414	≥ 0.413
Fuel Clad I.D. (in.)	≤ 0.3800	≤ 0.3790	≤ 0.3820	≤ 0.3700	≤ 0.3670
Fuel Pellet Dia. (in.) (Note 3)	≤ 0.3735	≤ 0.3707	≤ 0.3742	≤ 0.3622	≤ 0.3600
Fuel Rod Pitch (in.)	≤ 0.568	≤ 0.568	≤ 0.568	≤ 0.568	≤ 0.550
Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	17	17	17	17	9 (Note 4)
Guide/Instrument Tube Thickness (in.)	≥ 0.0150	≥ 0.0140	≥ 0.0140	≥ 0.0140	≥ 0.0140

Table 2.1.2 (continued)

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**16x16 A**	**17x17A**	**17x17 B**	**17x17 C**	**17x17 D**	**17x17 E**
No. of Fuel Rod Locations	236	264	264	264	264	265
Fuel Clad O.D. (in.)	≥ 0.382	≥ 0.360	≥ 0.372	≥ 0.377	≥ 0.372	≥ 0.372
Fuel Clad I.D. (in.)	≤ 0.3350	≤ 0.3150	≤ 0.3310	≤ 0.3330	≤ 0.3310	≤ 0.3310
Fuel Pellet Dia. (in.) (Note 3)	≤ 0.3255	≤ 0.3088	≤ 0.3232	≤ 0.3252	≤ 0.3232	≤ 0.3232
Fuel Rod Pitch (in.)	≤ 0.506	≤ 0.496	≤ 0.496	≤ 0.502	≤ 0.496	≤ 0.496
Active Fuel length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 170	≤ 170
No. of Guide and/or Instrument Tubes	5 (Note 2)	25	25	25	25	24
Guide/Instrument Tube Thickness (in.)	≥ 0.0350	≥ 0.016	≥ 0.014	≥ 0.020	≥ 0.014	≥ 0.014

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. Each guide tube replaces four fuel rods.
3. Annular fuel pellets are allowed in the top and bottom 12" of the active fuel length.
4. One Instrument Tube and eight Guide Bars (Solid ZR).

Table 2.1.3

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**7x7 B**	**8x8 B**	**8x8 C**	**8x8 D**	**8x8 E**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U)	≤ 4.8	≤ 4.8	≤ 4.8	≤ 4.8	≤ 4.8
No. of Fuel Rod Locations	49	63 or 64	62	60 or 61	59
Fuel Clad O.D. (in.)	≥ 0.5630	≥ 0.4840	≥ 0.4830	≥ 0.4830	≥ 0.4930
Fuel Clad I.D. (in.)	≤ 0.4990	≤ 0.4295	≤ 0.4250	≤ 0.4230	≤ 0.4250
Fuel Pellet Dia. (in.)	≤ 0.4910	≤ 0.4195	≤ 0.4160	≤ 0.4140	≤ 0.4160
Fuel Rod Pitch (in.)	≤ 0.738	≤ 0.642	≤ 0.641	≤ 0.640	≤ 0.640
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 10)	0	1 or 0	2	1 - 4 (Note 6)	5
Water Rod Thickness (in.)	N/A	≥ 0.034	> 0.00	> 0.00	≥ 0.034
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.100

Table 2.1.3 (continued)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**8x8F**	**9x9 A**	**9x9 B**	**9x9 C**	**9x9 D**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U)	≤ 4.5 (Note 12)	≤ 4.8	≤ 4.8	≤ 4.8	≤ 4.8
No. of Fuel Rod Locations	64	74/66 (Note 4)	72	80	79
Fuel Clad O.D. (in.)	≥ 0.4576	≥ 0.4400	≥ 0.4330	≥ 0.4230	≥ 0.4240
Fuel Clad I.D. (in.)	≤ 0.3996	≤ 0.3840	≤ 0.3810	≤ 0.3640	≤ 0.3640
Fuel Pellet Dia. (in.)	≤ 0.3913	≤ 0.3760	≤ 0.3740	≤ 0.3565	≤ 0.3565
Fuel Rod Pitch (in.)	≤ 0.609	≤ 0.566	≤ 0.572	≤ 0.572	≤ 0.572
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 10)	N/A (Note 2)	2	1 (Note 5)	1	2
Water Rod Thickness (in.)	≥ 0.0315	> 0.00	> 0.00	≥ 0.020	≥ 0.0300
Channel Thickness (in.)	≤ 0.055	≤ 0.120	≤ 0.120	≤ 0.100	≤ 0.100

Table 2.1.3 (continued)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**9x9 E (Note 3)**	**9x9 F (Note 3)**	**9x9 G**	**10x10 A**	**10x10 B**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U)	≤ 4.5 (Note 12)	≤ 4.5 (Note 12)	≤ 4.8	≤ 4.8	≤ 4.8
No. of Fuel Rod Locations	76	76	72	92/78 (Note 7)	91/83 (Note 8)
Fuel Clad O.D. (in.)	≥ 0.4170	≥ 0.4430	≥ 0.4240	≥ 0.4040	≥ 0.3957
Fuel Clad I.D. (in.)	≤ 0.3640	≤ 0.3860	≤ 0.3640	≤ 0.3520	≤ 0.3480
Fuel Pellet Dia. (in.)	≤ 0.3530	≤ 0.3745	≤ 0.3565	≤ 0.3455	≤ 0.3420
Fuel Rod Pitch (in.)	≤ 0.572	≤ 0.572	≤ 0.572	≤ 0.510	≤ 0.510
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 10)	5	5	1 (Note 5)	2	1 (Note 5)
Water Rod Thickness (in.)	≥ 0.0120	≥ 0.0120	≥ 0.0320	≥ 0.030	> 0.00
Channel Thickness (in.)	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.120	≤ 0.120

Table 2.1.3 (continued)

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)

Fuel Assembly Array and Class	**10x10 C**	**10x10 F**	**10x10 G**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U) (Note 14)	≤ 4.8	≤ 4.7 (Note 13)	≤ 4.6 (Note 12)
No. of Fuel Rod Locations	96	92/78 (Note 7)	96/84
Fuel Clad O.D. (in.)	≥ 0.3780	≥ 0.4035	≥ 0.387
Fuel Clad I.D. (in.)	≤ 0.3294	≤ 0.3570	≤ 0.340
Fuel Pellet Dia. (in.)	≤ 0.3224	≤ 0.3500	≤ 0.334
Fuel Rod Pitch (in.)	≤ 0.488	≤ 0.510	≤ 0.512
Design Active Fuel Length (in.)	≤ 150	≤ 150	≤ 150
No. of Water Rods (Note 10)	5 (Note 9)	2	5 (Note 9)
Water Rod Thickness (in.)	≥ 0.031	≥ 0.030	≥ 0.031
Channel Thickness (in.)	≤ 0.055	≤ 0.120	≤ 0.060

Table 2.1.3 (continued)

BWR FUEL ASSEMBLY CHARACTERISTICS

NOTES:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. This assembly is known as "QUAD+." It has four rectangular water cross segments dividing the assembly into four quadrants.
3. For the SPC 9x9-5 fuel assembly, each fuel rod must meet either the 9x9E or the 9x9F set of limits or clad O.D., clad I.D., and pellet diameter.
4. This assembly class contains 74 total rods; 66 full length rods and 8 partial length rods.
5. Square, replacing nine fuel rods.
6. Variable.
7. This assembly contains 92 total fuel rods; 78 full length rods and 14 partial length rods.
8. This assembly class contains 91 total fuel rods; 83 full length rods and 8 partial length rods.
9. One diamond-shaped water rod replacing the four center fuel rods and four rectangular water rods dividing the assembly into four quadrants.
10. These rods may also be sealed at both ends and contain ZR material in lieu of water.
11. Not Used
12. Fuel assemblies classified as damaged fuel assemblies are limited to 4.0 wt.% U-235.
13. Fuel assemblies classified as damaged fuel assemblies are limited to 4.6 wt.% U-235.

Table 2.1.4

DESIGN BASIS FUEL ASSEMBLY FOR EACH DESIGN CRITERION

Criterion	BWR	PWR
Reactivity/Criticality	GE-12/14 10x10 (Array/Class 10x10A)	Westinghouse 17x17 OFA (Array/Class 17x17B)
Shielding	GE-12/14 10x10	Westinghouse 17x17 OFA
Thermal-Hydraulic	GE-12/14 10x10	Westinghouse 17x17 OFA

Table 2.1.5
NORMALIZED DISTRIBUTION BASED ON BURNUP PROFILE

PWR DISTRIBUTION[1]		
Interval	**Axial Distance From Bottom of Active Fuel (% of Active Fuel Length)**	**Normalized Distribution**
1	0% to 4-1/6%	0.5485
2	4-1/6% to 8-1/3%	0.8477
3	8-1/3% to 16-2/3%	1.0770
4	16-2/3% to 33-1/3%	1.1050
5	33-1/3% to 50%	1.0980
6	50% to 66-2/3%	1.0790
7	66-2/3% to 83-1/3%	1.0501
8	83-1/3% to 91-2/3%	0.9604
9	91-2/3% to 95-5/6%	0.7338
10	95-5/6% to 100%	0.4670

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[1] Reference 2.1.7

Table 2.1.5 (continued)

NORMALIZED DISTRIBUTION BASED ON BURNUP PROFILE

BWR DISTRIBUTION[2]

Interval	Axial Distance From Bottom of Active Fuel (% of Active Fuel Length)	Normalized Distribution
1	0% to 4-1/6%	0.2200
2	4-1/6% to 8-1/3%	0.7600
3	8-1/3% to 16-2/3%	1.0350
4	16-2/3% to 33-1/3%	1.1675
5	33-1/3% to 50%	1.1950
6	50% to 66-2/3%	1.1625
7	66-2/3% to 83-1/3%	1.0725
8	83-1/3% to 91-2/3%	0.8650
9	91-2/3% to 95-5/6%	0.6200
10	95-5/6% to 100%	0.2200

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[2] Reference 2.1.8

Table 2.1.6

Soluble Boron Requirements for MPC-37 Wet Loading and Unloading Operations

Array/Class	All Undamaged Fuel Assemblies		One or More Damaged Fuel Assemblies and/or Fuel Debris	
	Maximum Initial Enrichment $\leq$ 4.0 wt% ^{235}U (ppmb)	Maximum Initial Enrichment 5.0 wt% ^{235}U (ppmb)	Maximum Initial Enrichment $\leq$ 4.0 wt% ^{235}U (ppmb)	Maximum Initial Enrichment 5.0 wt% ^{235}U (ppmb)
All 14x14 and 16x16A	1,000	1,500	1,300	1,800
All 15x15 and 17x17	1,500	2,000	1,800	2,300

Note:

1. For maximum initial enrichments between 4.0 wt% and 5.0 wt% ^{235}U, the minimum soluble boron concentration may be determined by linear interpolation between the minimum soluble boron concentrations at 4.0 wt% and 5.0 wt% ^{235}U.

Table 2.1.7

APPLICABLE COC AMENDMENTS AND ALLOWABLE HEAT LOAD REDUCTION FACTORS FOR MPCS ANALYZED* FOR STORAGE IN THE HI-STORM UMAX

MPC Type	**Docket Number**	**CoC Amendment Number**	**Heat Load Reduction Factor**
All	72-1014	5 to 10	1.0 (no reduction)
MPC-89	72-1032	0 and 1	1.0 (no reduction)
MPC-37	72-1032	0 and 1	
	Short Fuel: 128 inches ≤ L < 144 inches		0.95
	Standard Fuel: 144 inches ≤ L < 168 inches		0.95
	Long Fuel: L ≥ 168 inches		1.0

Notes:

1. L means "nominal active fuel length".
2. The allowable heat load is obtained by multiplying the per-storage cell heat load permitted in the reference CoC amendment by the *Reduction factor*.

*This issue of the FSAR seeks certification of only MPC-89 and MPC-37, termed as "governing canisters" in HI-STORM UMAX. The analysis performed on other MPCs is for reference purposes only.

TABLE 2.1.8

HI-STORM UMAX MPC-37 HEAT LOAD DATA (See Figure 2.1.7)

Number of Regions: 3

Number of Storage Cells: 37

Fuel	Region No.	Decay Heat Limit per Cell, kW	Number of Cells per Region
Short and Standard Fuel (see Table 2.1.7 for length data)	**PATTERN A - Maximum Heat Load: 44.685 kW**		
	1	1.073	9
	2	1.691	12
	3	0.921	16
	PATTERN B - Maximum Heat Load: 44.452 kW		
	1	1.140	9
	2	1.140	12
	3	1.282	16
Long Fuel (Table 2.1.7)	**PATTERN A - Maximum Heat Load: 47.05 kW**		
	1	1.13	9
	2	1.78	12
	3	0.97	16
	PATTERN B - Maximum Heat Load: 46.80 kW		
	1	1.20	9
	2	1.20	12
	3	1.35	16

Note: All heat loads reported in this table are obtained by applying the heat load reduction factor defined in Table 2.1.7 to the heat load specified in applicable HI-STORM FW CoC amendment.

TABLE 2.1.9

HI-STORM UMAX MPC-89 HEAT LOAD DATA (See Figure 2.1.8)

Number of Regions: 3

Number of Storage Cells: 89

Maximum Heat Load: 46.36 kW

Region No.	Decay Heat Limit per Cell, kW	Number of Cells per Region
1	0.44	9
2	0.62	40
3	0.44	40

Table 2.1.10

MPC FUEL STORAGE REGIONS FOR MPCS LICENSED IN DOCKET 72-1014

MPC	Number of Storage Cells		Storage Cell IDs*	
	Inner Region (n_1)	Outer Region (n_2)	Inner Region	Outer Region
MPC-24/24E/24EF	12	12	4, 5 8 through 11 14 through 17 20 and 21	All other locations
MPC-32/32F	12	20	7, 8, 12 through 15, 18 through 21, 25 and 26	All other locations
MPC-68/68FF/68M	32	36	11 through 14, 18 through 23, 27 through 32, 37 through 42, 46 through 51, 55 through 58	All other locations

* See Figures 2.1.9 through 2.1.11 for storage cell numbering.

Table 2.1.11

HI-STORM UMAX MPC (LICENSED IN DOCKET 72-1014) DESIGN HEAT EMISSION RATES FOR UNIFORM LOADING PATTERN

MPC	Decay Heat (kW)	
	Per Intact Fuel Assembly	Per MPC
MPC-24/24E/24EF	1.416	34
MPC-32/32F	1.062	34
MPC-68/68FF/68M	0.5	34

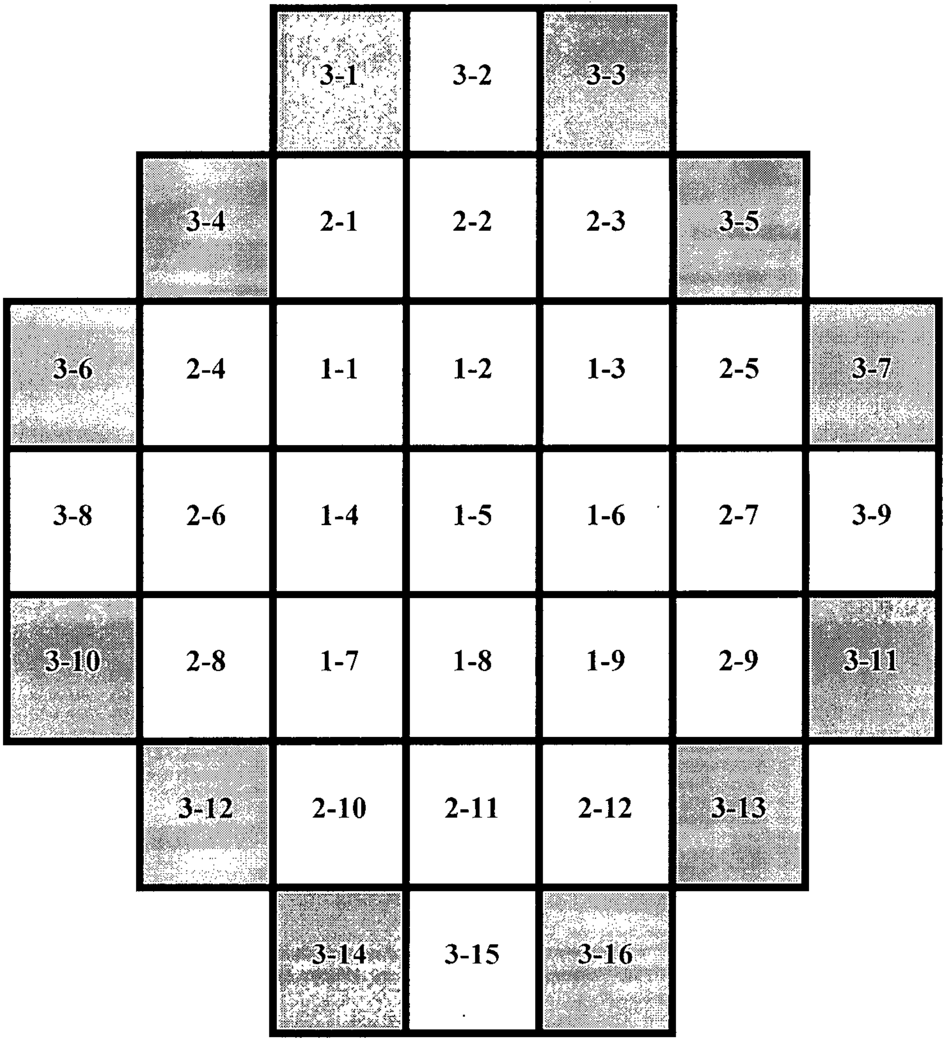
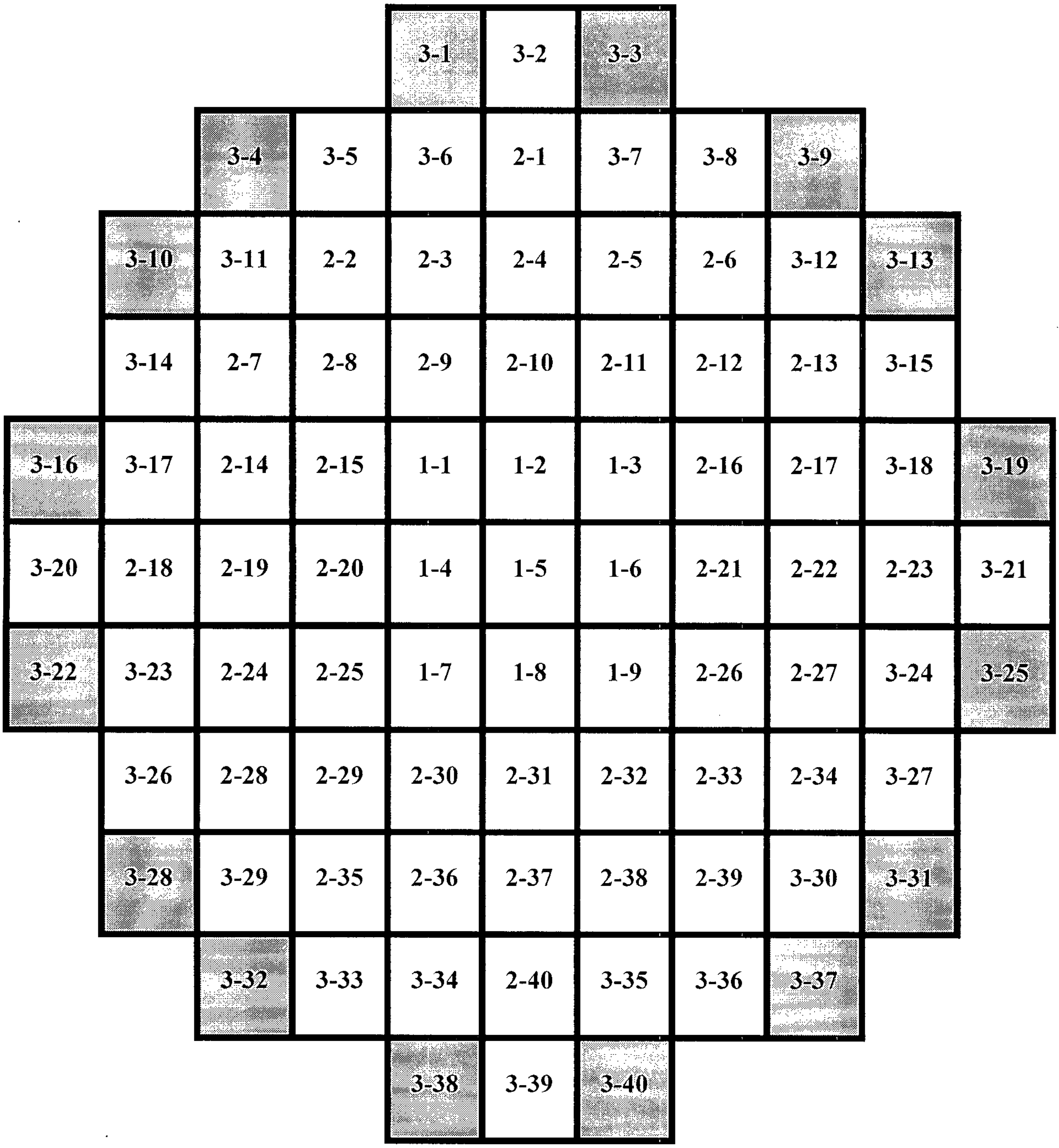


Figure 2.1.1 Location of DFCs for Damaged Fuel or Fuel Debris
in the MPC-37(Shaded Cells)



				3-1	3-2	3-3				
		3-4	3-5	3-6	2-1	3-7	3-8	3-9		
	3-10	3-11	2-2	2-3	2-4	2-5	2-6	3-12	3-13	
	3-14	2-7	2-8	2-9	2-10	2-11	2-12	2-13	3-15	
3-16	3-17	2-14	2-15	1-1	1-2	1-3	2-16	2-17	3-18	3-19
3-20	2-18	2-19	2-20	1-4	1-5	1-6	2-21	2-22	2-23	3-21
3-22	3-23	2-24	2-25	1-7	1-8	1-9	2-26	2-27	3-24	3-25
	3-26	2-28	2-29	2-30	2-31	2-32	2-33	2-34	3-27	
	3-28	3-29	2-35	2-36	2-37	2-38	2-39	3-30	3-31	
		3-32	3-33	3-34	2-40	3-35	3-36	3-37		
				3-38	3-39	3-40				

Figure 2.1.2 Location of DFCs for Damaged Fuel or Fuel Debris in the MPC-89 (Shaded Cells)

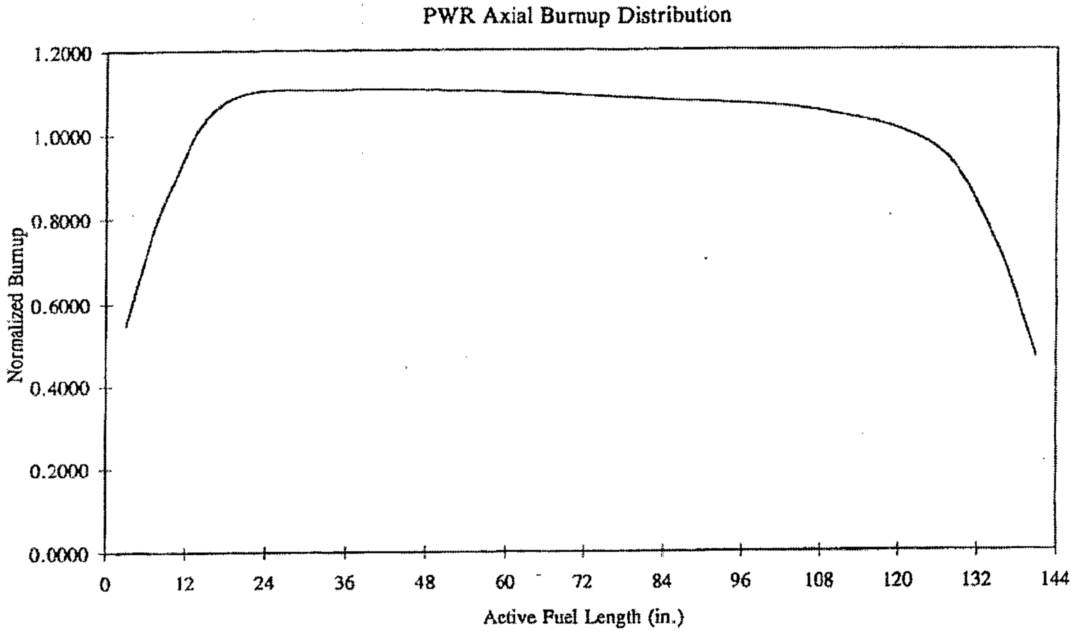


Figure 2.1.3 PWR Axial Burnup Profile with Normalized Distribution

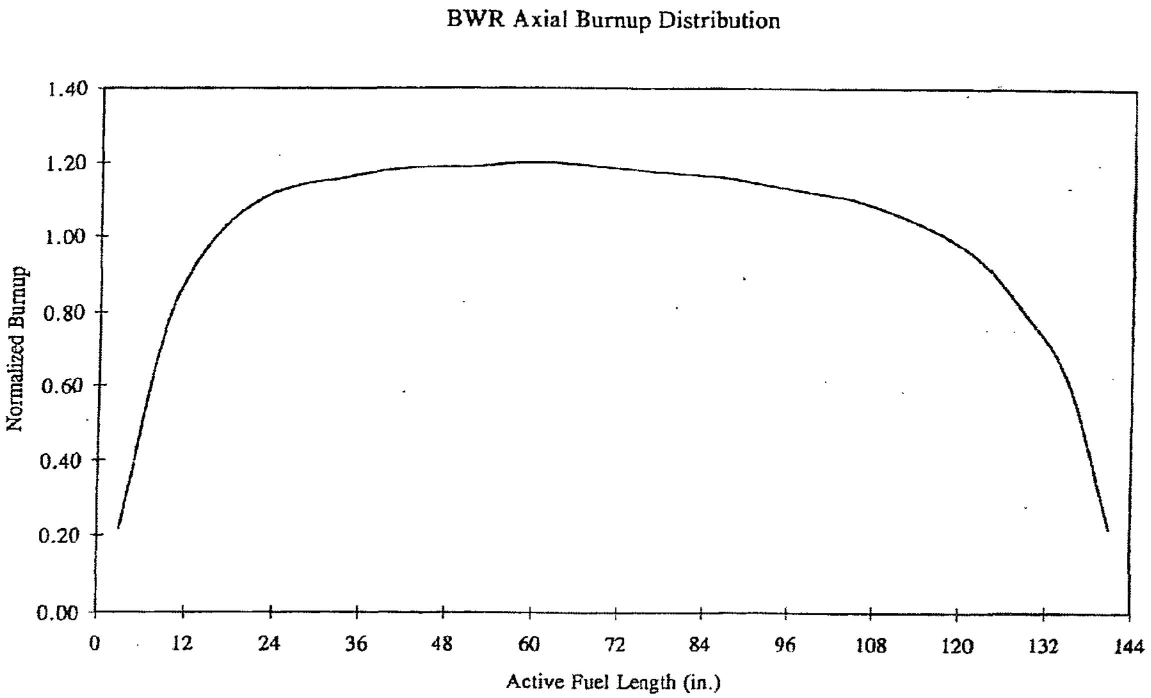


Figure 2.1.4 BWR Axial Burnup Profile with Normalized Distribution

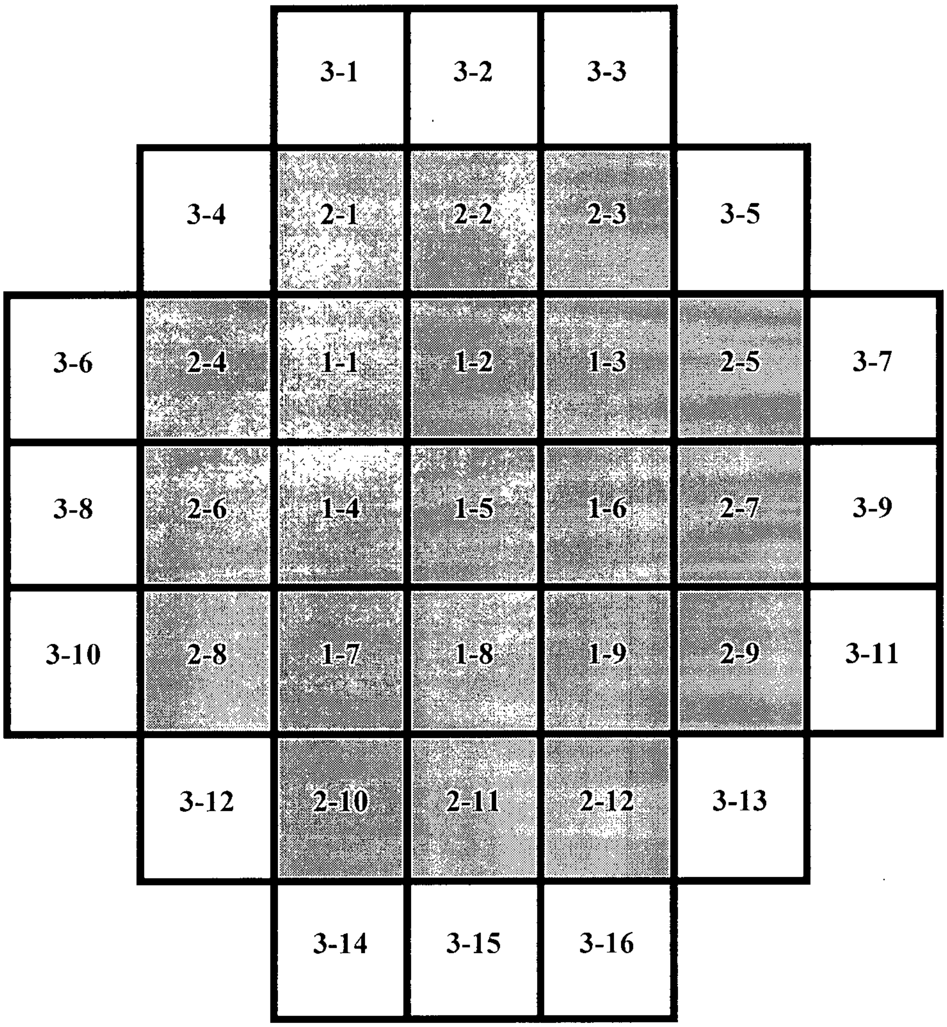


Figure 2.1.5: Location of NSAs, APSRs, RCCAs, CEAs, and CRAs in the MPC-37 (Shaded Cells)

Withheld in Accordance with 10 CFR 2.390

Figure 2.1.6: Damaged Fuel Container (Typical)

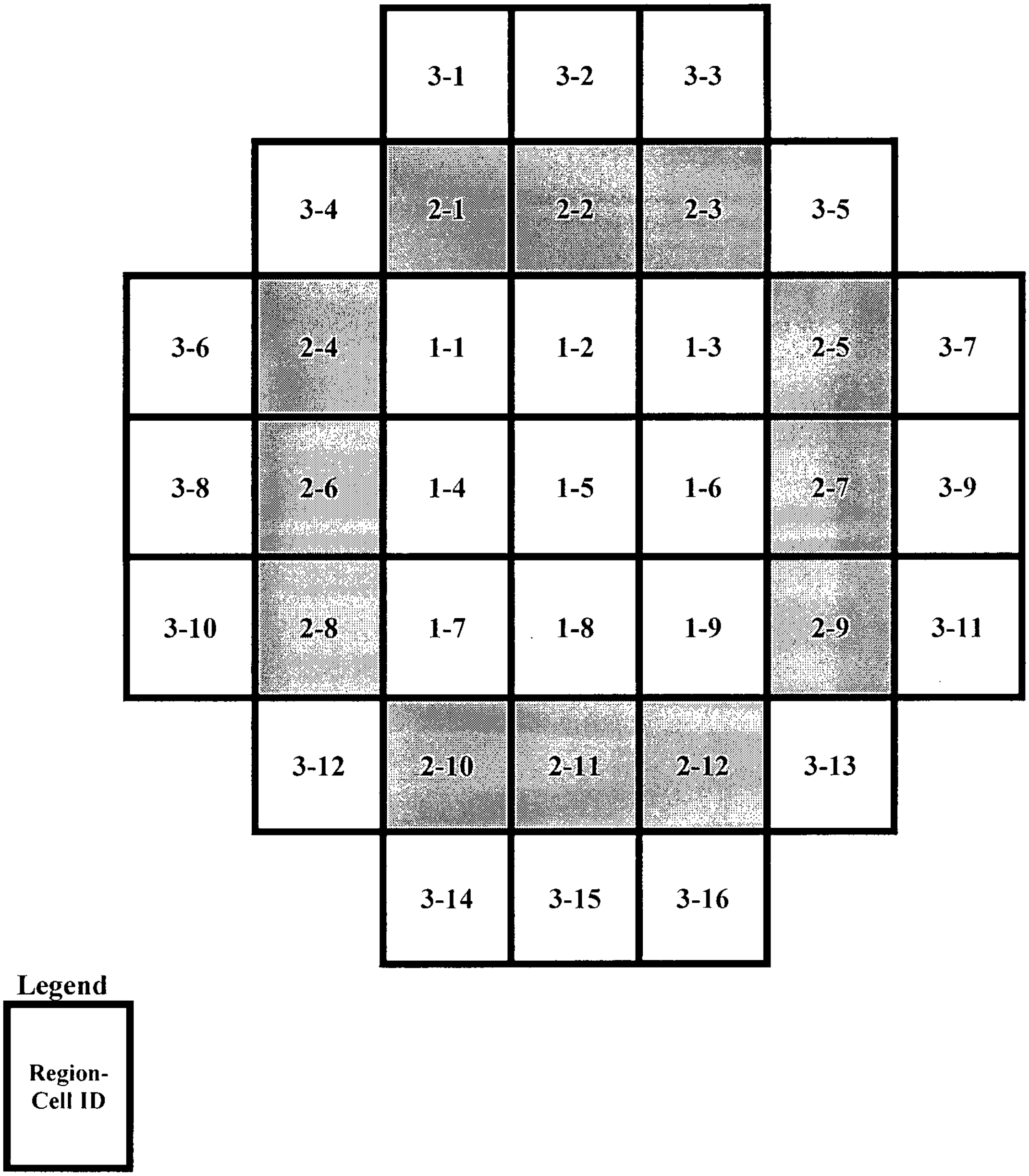
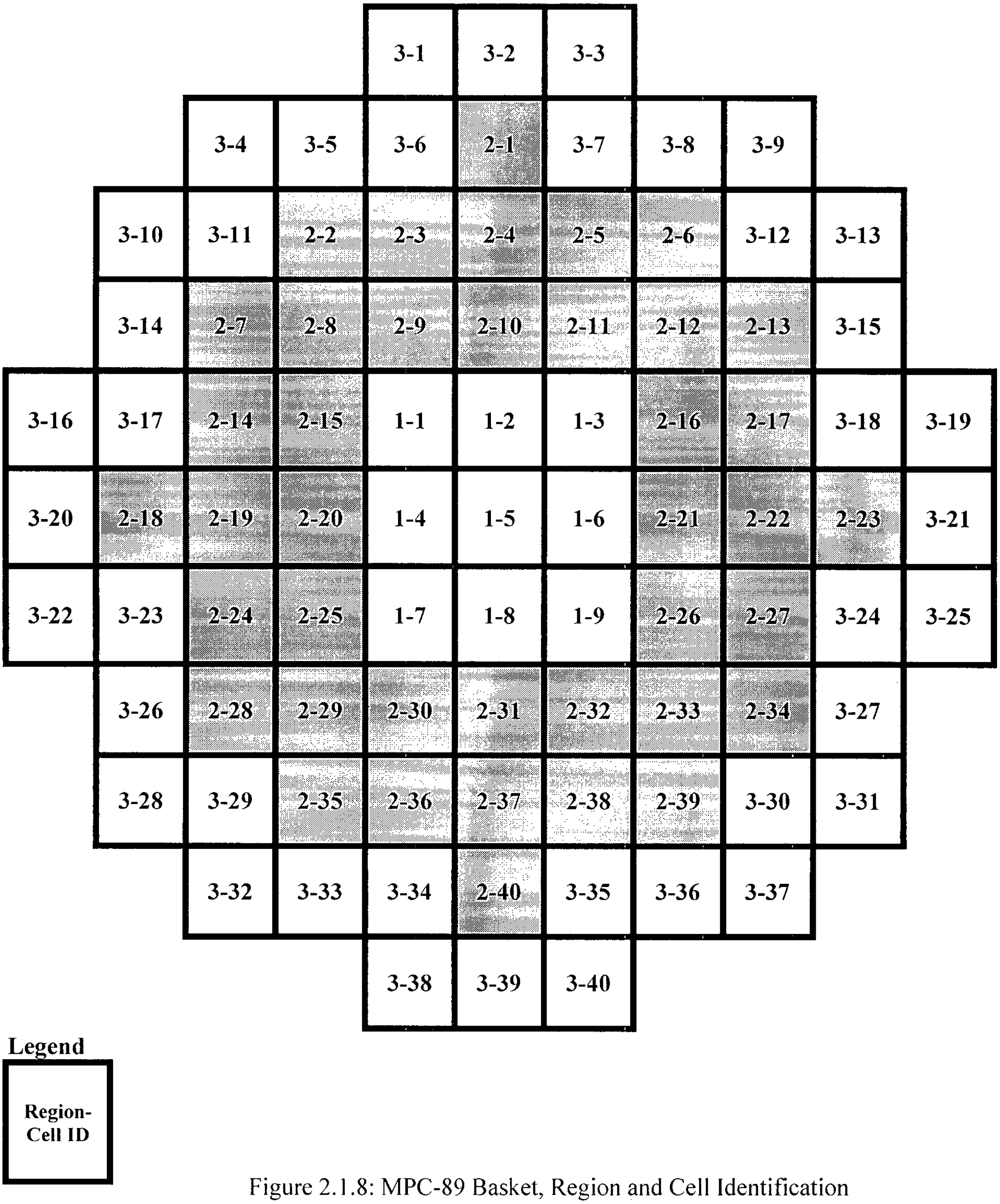


Figure 2.1.7: MPC-37 Basket, Region and Cell Identification



				3-1	3-2	3-3				
		3-4	3-5	3-6	2-1	3-7	3-8	3-9		
	3-10	3-11	2-2	2-3	2-4	2-5	2-6	3-12	3-13	
	3-14	2-7	2-8	2-9	2-10	2-11	2-12	2-13	3-15	
3-16	3-17	2-14	2-15	1-1	1-2	1-3	2-16	2-17	3-18	3-19
3-20	2-18	2-19	2-20	1-4	1-5	1-6	2-21	2-22	2-23	3-21
3-22	3-23	2-24	2-25	1-7	1-8	1-9	2-26	2-27	3-24	3-25
	3-26	2-28	2-29	2-30	2-31	2-32	2-33	2-34	3-27	
	3-28	3-29	2-35	2-36	2-37	2-38	2-39	3-30	3-31	
		3-32	3-33	3-34	2-40	3-35	3-36	3-37		
				3-38	3-39	3-40				

Legend

Region-Cell ID

Figure 2.1.8: MPC-89 Basket, Region and Cell Identification

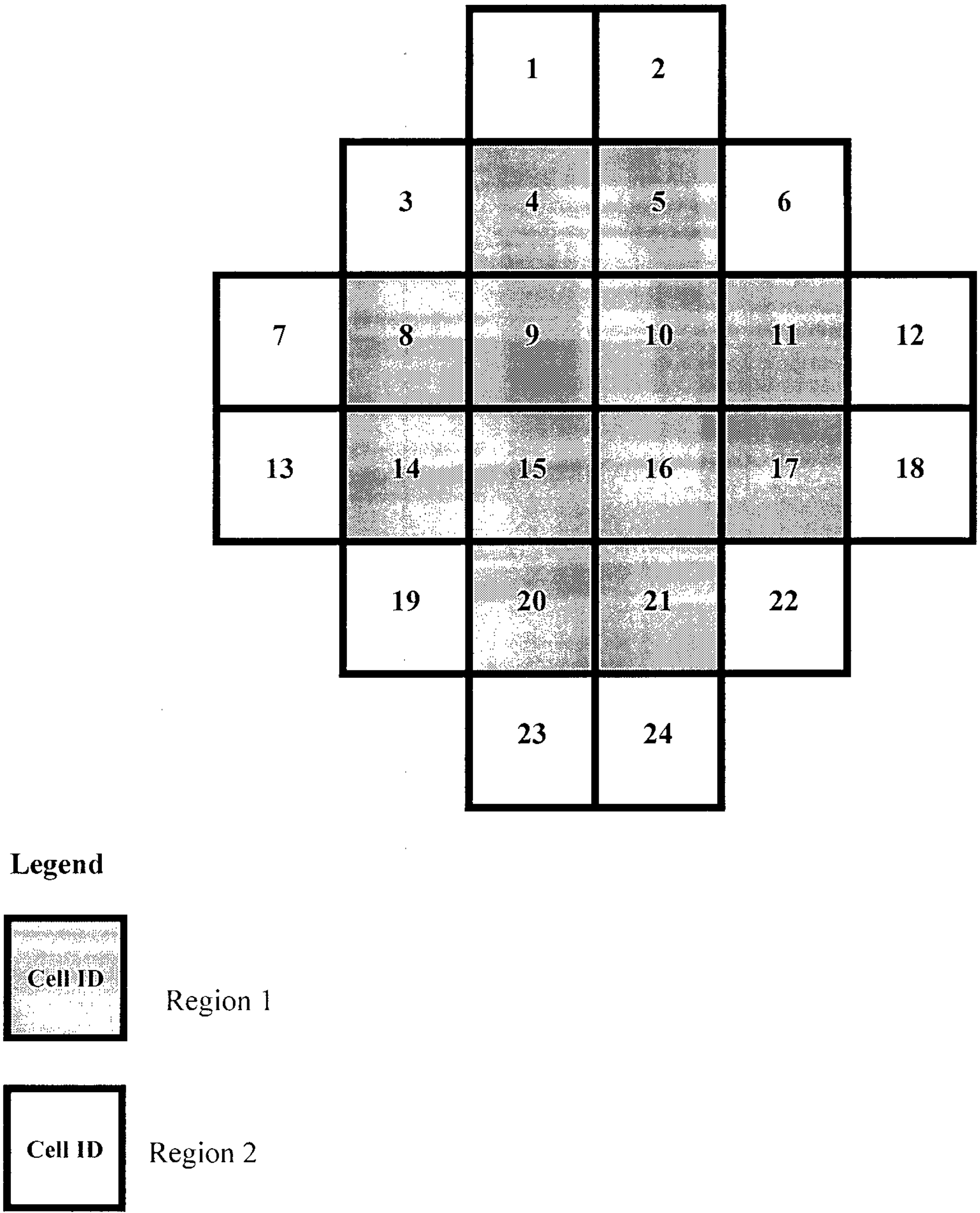


Figure 2.1.9: MPC-24/24E/24EF Cell Identification

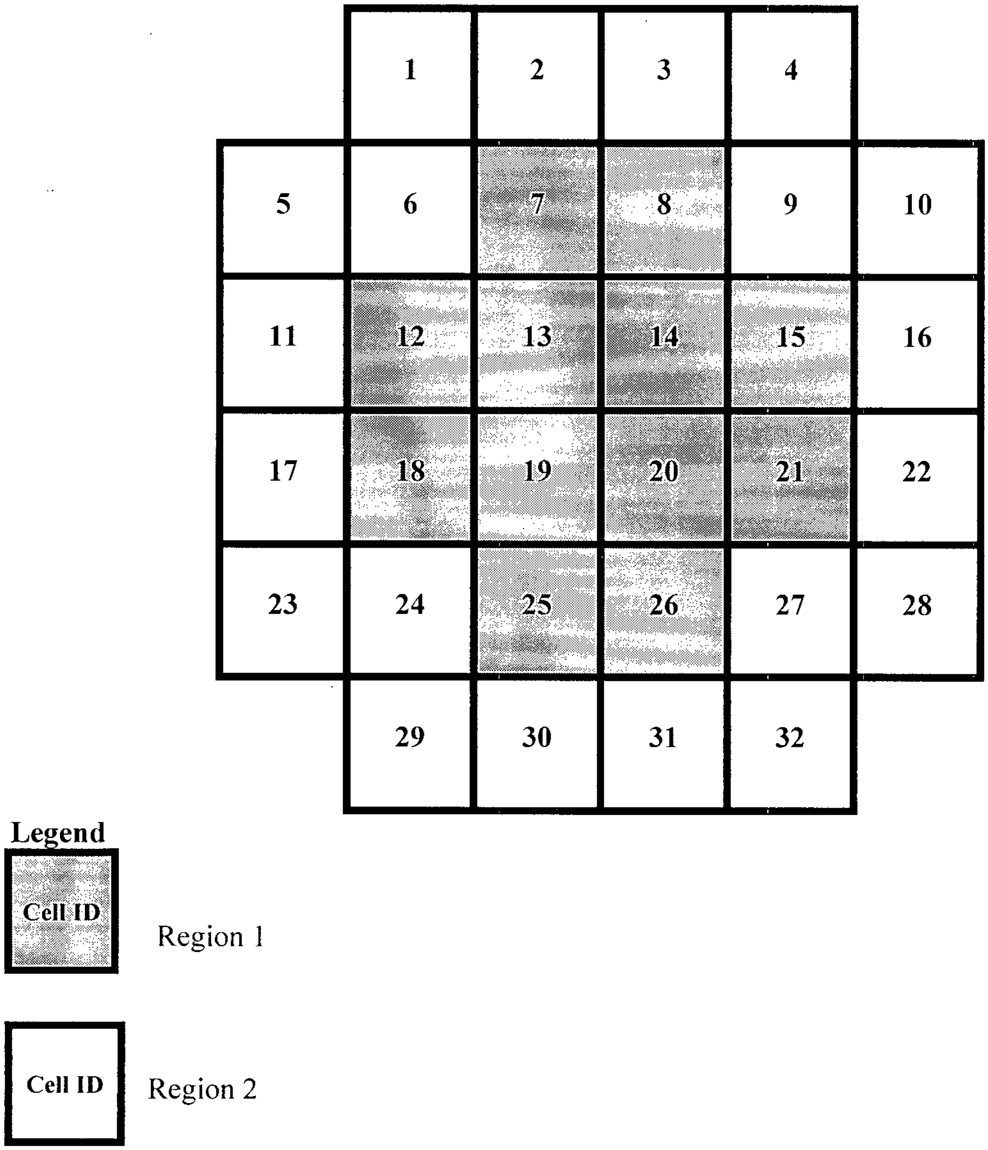


Figure 2.1.10: MPC-32/32F Cell Identification

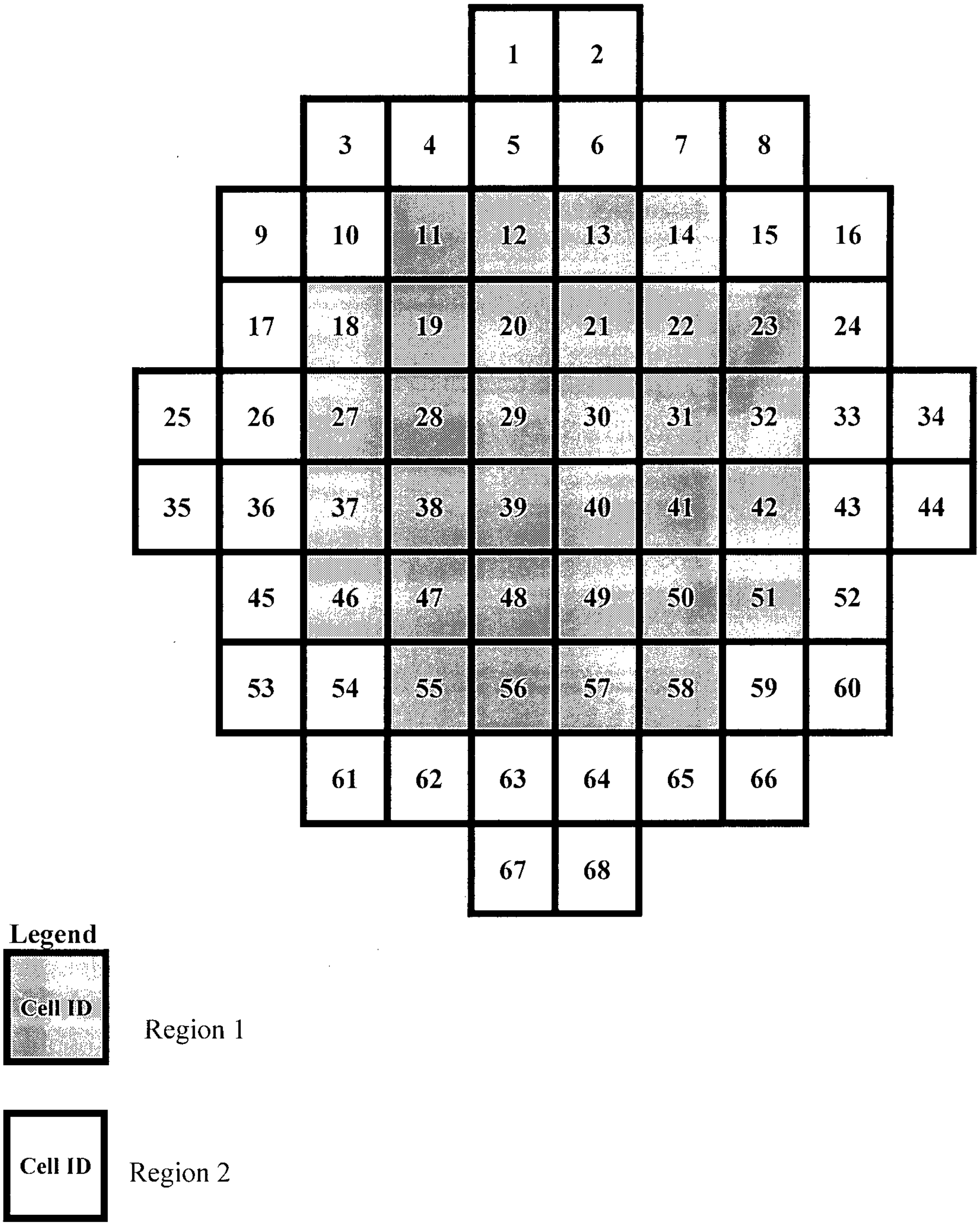


Figure 2.1.11: MPC-68/68F/68FF/68M Cell Identification

2.2 HI-STORM UMAX VVM COMPONENTS AND ISFSI STRUCTURES

The VVM is engineered for below-grade storage of the MPCs 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. A discussion of measures to ameliorate corrosion of VVM components is presented in Chapter 8.

The structural limit criteria imposed on the VVM Components are specified to comply with the provisions of 10CFR72, with an embedded large margin of safety. Table 2.4.1 provides the principal acceptance 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 2.6.2 along with their maximum permissible temperature for different conditions of storage.

The ISFSI Structures in a HI-STORM UMAX ISFSI are:

a. The Support Foundation Pad (SFP)

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 2.3.2 and the licensing drawing in Section 1.5.

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

- Dead load (from the ISFSI pad, the loaded VVM, and the mass of soil above the SFP).
- Live load (from the loaded vertical cask transporter bearing on the ISFSI pad).
- 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).
- Long-term settlement.

The load combinations for the HI-STORM UMAX structural analysis of the SFP pursuant to ACI-318(2005) are provided in Table 2.4.3.

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 [2.4.3].

In the structural qualification of the SFP, the loading from the seismic event is computed using the dynamic elastic modulus corresponding to the minimum shear wave velocity of the subgrade layers specified in Table 2.3.2.

b. The ISFSI Pad

The ISFSI Pad girdles the Container Shell and extends to the underside of the Container Flange to form a rain water-resistant interface, and has a slight slope to direct water away from the CEC. The principal functions of the ISFSI pad 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 ISFSI storm drain system. An expansion joint between the CEC and the ISFSI pad is incorporated to permit differential movement between the two. 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 in the Licensing drawing, but there are several equivalent proven sealant materials commercially available that are suitable for this application.

The minimum structural design requirements on the ISFSI pad are provided in Table 2.3.2 and the licensing drawing in Section 1.5. The applicable loads on the ISFSI pad are:

- Dead load (Self weight)
- Live load (Weight of a loaded cask transporter)
- Seismic Load (Inertia load from the concrete pad and the transporter under the ISFSI's DBE event)

The applicable load combinations for the structural analysis of the ISFSI pad pursuant to ACI-318(2005) are provided in Table 2.4.3.

Note that the ISFSI pad is not expected to settle relative to the SFP over their Design Life due to the use of CLSM [2.2.1] or lean concrete to refill the space between the SFP and the ISFSI pad (i.e., Space A in Figure 2.4.4).

The design of the ISFSI pad together with the lateral subgrade must also satisfy the allowable bearing capacity requirement of ACI 360R-06 [2.6.5] for slabs on grade. In particular, the total load imparted by the ISFSI pad 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.

c. Enclosure Wall (optional)

The Enclosure Wall, if used to sequester the substrate under the ISFSI pad from the surrounding subgrade, serves to render each VVM group autonomous and, at sites with elevated water table and serves as a means to prevent water intrusion in the VVM subgrade space. The Enclosure Wall does not have a structural function. In other words, as shown in Chapter 3, the Enclosure Wall is not needed to maintain the physical stability of the subgrade under the ISFSI pad under a Design Basis Earthquake in the limiting condition where the adjacent space has been excavated down to the SFP for construction purposes. Likewise it is shown in Chapter 3 that a Design Basis Missile will not reach any CEC in the ISFSI if the missile were to strike laterally through the excavated space adjacent to the ISFSI.

d. Lateral Subgrade and Under-grade

The soil lateral to the CECs (termed Space A in this FSAR) is required to be removed and replaced with a Self-hardening Engineered Subgrade (SES) such as CLSM or lean concrete which imparts enhanced structural characteristics to the ISFSI pad support system improving its ability to support the Cask transporter during MPC transfer operations. The minimum average density and the minimum shear wave velocity in the lateral subgrade surrounding the VVMs have been specified in Table 2.3.2.

The Under-grade's minimum properties have also been specified in Table 2.3.2. A structurally inadequate under-grade may be strengthened by suitably engineered pilings.

2.3 SERVICE CONDITIONS AND APPLICABLE LOADS

2.3.1 Service Conditions

The categories of loads applicable to the HI-STORM UMAX VVM are identified below.

> Normal Condition: dead weight, handling of the Closure Lid, soil overburden pressure from subgrade, live load due to cask transporter movement, long-term settlement and snow loads.
>
> Off-Normal Condition: elevated ambient temperature, wind, partial blockage of air inlets, and off-normal pressure.
>
> Extreme Environmental Phenomena and Accident Condition: extreme ambient temperature, handling accidents, fire, tornado, flood, earthquake, explosion, lightning, complete (assumed) blockage of all inlet ducts, burial under debris, and 100% fuel rod rupture.
>
> Short-term Operations: Short-term operation includes those normal operational evolutions necessary to support fuel loading or unloading activities. These include, but are not limited to MPC cavity drying, helium backfill, MPC transfer, and on-site handling of a loaded HI-TRAC VW transfer cask. The peak cladding temperature in the MPC must meet the ISG-11 Rev. 3 limit for short-term operations

Of the above loadings, lightning is considered to be innocuous to the HI-STORM UMAX ISFSI because of its underground configuration and is therefore not considered as a loading that merits safety evaluation.

As can be seen from the above, the loads that are most significant to the storage system's structures and components are either structural or thermal in origin. Accordingly, they are discussed in the two discrete sections in the following Sections 2.4 and 2.5. The design basis magnitudes of the above loads, as applicable to the HI-STORM VVM, are provided in Tables 2.3.1 and 2.3.2. The loads applicable to the MPC and HI-TRAC VM are defined in Tables 2.2.6, 2.2.7, 2.2.13 and 3.1.1 of the HI-STORM FW FSAR.

2.3.2 Loadings Applicable to Normal Conditions of Storage

2.3.2.1 Pressure

The MPC internal pressure is dependent on the initial volume of cover gas (helium), the volume of fill gas in the fuel rods, the fraction of fission gas released from the fuel matrix, the number of fuel rods assumed to have ruptured, and temperature.

The normal condition MPC internal design pressure bounds the cumulative effects of the maximum fill gas volume, normal environmental ambient temperatures, the maximum MPC heat load, and an assumed 1% of the fuel rods ruptured with 100% of the fill gas and 30% of the significant radioactive gases (e.g., H^3, Kr, and Xe) released in accordance with NUREG-1536.

For the storage of damaged fuel assemblies or fuel debris in a damaged fuel container (DFC), it shall be conservatively assumed that 100% of the fuel rods are ruptured with 100% of the rod fill gas and 30% of the significant radioactive gases (e.g., H^3, Kr, and Xe) liberated. For PWR assemblies stored with non-fuel hardware, 100% of the gases in the non-fuel hardware (e.g., BPRAs) shall be assumed to be released. The accident condition design pressure shall envelop the case of 100% of the fuel rods ruptured.

The MPC internal and external pressures under the normal condition of storage must remain below the respective limits in docket number 72-1032. For convenience of reference, the maximum allowable internal and external pressures common to all MPCs in Table 1.2.1 are provided in Table 2.3.5.

The HI-TRAC transfer cask is not capable of retaining internal pressure due to its open design. Therefore, no analysis is required for the internal pressure loading in HI-TRAC VW transfer cask. However, the HI-TRAC transfer cask water jacket may experience an internal vapor pressure due to the heat-up of the water contained in the water jacket. Analysis is performed in Chapter 3 of the HI-STORM FW FSAR to demonstrate that the water jacket can withstand the design pressure in Table 2.3.5 without a structural failure and that the water jacket design pressure will not be exceeded. To provide an additional layer of safety, a pressure relief device is used to ensure that the water jacket design pressure will not be exceeded.

The HI-STORM UMAX VVM is not capable of retaining internal pressure due to its open design, and therefore no analysis is required or provided for the VVM internal pressure.

2.3.2.2 Environmental Temperatures and Pressures

To evaluate the long-term effects of ambient temperatures on the HI-STORM UMAX System, an upper bound value on the annual average ambient temperature for the continental United States is used. The annual average temperature is termed as normal ambient temperature for storage. The normal ambient temperature specified in Table 2.3.6 is bounding for all reactor sites in the contiguous United States. The normal ambient temperature set forth in Table 2.3.6 is intended to ensure that it is greater than the annual average of ambient temperature at any location in the continental United States. In the northern region of the U.S., the design basis normal ambient temperature will be exceeded only for brief periods, whereas in the southern U.S, it may be straddled daily in summer months. In as much as the sole effect of the normal temperature is on the computed fuel cladding temperature to establish long-term fuel integrity, it should not lie below the time averaged yearly mean for the ISFSI site. Previously licensed cask systems have employed lower normal temperatures (viz., 75° F in Docket 72-1007) by utilizing national meteorological data.

Likewise, within the thermal analysis, a conservatively assumed soil temperature of the value specified in Table 2.3.6 is utilized to bound the annual average soil temperatures for the continental United States. The 1987 ASHRAE Handbook (HVAC Systems and Applications) reports average earth temperatures, from 0 to 10 feet below grade, throughout the continental United States. The highest reported annual average value for the continental United States is 77°F for Key West, Florida. Therefore, this value is specified in Table 2.3.6 as the bounding soil temperature.

Confirmation of the site-specific annual average ambient temperature and soil temperature is to be performed by the licensee, in accordance with 10CFR72.212. Insolation based on 10CFR71.71 input averaged over 24 hours shall be used as the additional heat input under the normal and off-normal conditions of storage.

The ambient pressure shall be assumed to be 760mm of Hg coincident with the normal condition temperature, whose bounding value is provided in Table 2.3.6. For sites located substantially above sea level (elevation > 1500 feet), it will be necessary to perform a site specific evaluation of the peak cladding temperature using the site specific ambient temperature (maximum average annual temperature based on 40 year meteorological data for the site). ISG 11, Revision 3 [2.4.6] temperature limits will be applicable.

All of the above requirements are consistent with those in the HI-STORM 100 and HI-STORM FW FSARs.

2.3.2.3 Design Temperatures

The ASME Boiler and Pressure Vessel Code (ASME Code) requires that the value of the vessel design temperature be established with appropriate consideration for the effect of heat generation internal or external to the vessel. The decay heat load from the spent nuclear fuel is the internal heat generation source for the HI-STORM UMAX System. The ASME Code (Section III, Paragraph NCA-2142) requires the design temperature to be set at or above the maximum through thickness mean metal temperature of the pressure part under normal service (Level A) condition. Consistent with the terminology of NUREG-1536, this temperature is referred to as the Design Temperature for Normal Conditions. Conservative calculations of the steady-state temperature field in the HI-STORM UMAX System, under assumed environmental normal temperatures with the maximum decay heat load shall remain below the maximum permissible temperatures set down in Table 2.3.7. Unless otherwise stated, the maximum permissible temperatures in Table 2.3.7 are thru-wall thickness average values and are intended to insure that the storage system meets the safety criteria applicable to the specific operating condition.

Maintaining fuel rod cladding integrity is a principal design consideration. The fuel rod peak cladding temperature (PCT) limits for all operating conditions shall meet the limits set forth in ISG-11, Revision 3 [2.4.6].

2.3.2.4 Snow and Ice

The HI-STORM UMAX System must be capable of withstanding pressure loads due to snow and ice. Section 7.0 of ANSI/ASCE 7-05 [2.2.2] provides empirical formulas and tables to compute the effective design pressure on the VVM due to the accumulation of snow for the contiguous U.S. and Alaska. Typical calculated values for heated structures such as the HI-STORM UMAX System range from 50 to 70 pounds per square foot. For conservatism, the snow pressure load provided in Table 2.3.1 is set to bound the ANSI/ASCE 7-05 recommendation.

2.3.2.5 Dead Weight

The HI-STORM UMAX System must withstand the static loads due to the weights of each of its components, including the weight of the HI-TRAC VW with the loaded MPC stacked on top the VVM during the MPC transfer.

2.3.2.6 Handling Evolutions

The HI-STORM UMAX System must withstand loads experienced during routine handling. Normal handling includes:

i. Vertical lifting of HI-STORM UMAX Enclosure Lid.
ii. Vertical lifting and handling of the HI-TRAC VW transfer cask containing a loaded MPC.
iii. Lifting of a loaded MPC.

The dead load of the lifted component is increased by 15% in the stress qualification analyses (to meet ANSI N14.6 guidance) to account for dynamic effects from lifting operations as suggested in CMAA #70 [2.3.3].

2.3.3 Loadings Applicable to Off -Normal Conditions of Storage

As the HI-STORM UMAX System is passive, loss of power and instrumentation failures are not defined as off-normal conditions. The off-normal service conditions are defined in this subsection.

A discussion of the effects of each off-normal condition and the corrective action for each off-normal condition is provided in Chapter 12.

2.3.3.1 Pressure

The HI-STORM UMAX System must withstand loads due to off-normal pressure. The off-normal condition for the MPC internal design pressure bounds the cumulative effects of the maximum fill gas volume, normal environmental ambient temperatures, the maximum MPC heat load, and an assumed 10% of the fuel rods ruptured with 100% of the fill gas and 30% of the significant radioactive gases (e.g., H^3, Kr, and Xe) released as suggested in NUREG-1536.

2.3.3.2 Environmental Temperatures

The HI-STORM UMAX System must withstand off-normal environmental temperatures. The off-normal environmental temperatures are specified in Table 2.3.6. For conservatism the lower bound temperature is assumed to occur with no solar loads and the upper bound temperature occurs with steady-state insolation. Each bounding temperature is assumed to persist for a sufficient duration to allow the system to reach steady-state temperatures.

Limits on the peaks in the time-varying ambient temperature at an ISFSI site are recognized in the FSAR in the specification of the off-normal temperatures. The lower bound off-normal temperature is defined as the minimum of the 72-hour average of the ambient temperature at an ISFSI site. Likewise, the upper bound off-normal temperature is defined by the maximum of 72-hour average of the ambient temperature. The lower and upper bound off-normal temperatures listed in Table 2.3.6 are intended to cover all ISFSI sites in the continental U.S. The 72-hour average of temperature used in the definition of the off-normal temperature recognizes the considerable thermal inertia of the HI-STORM UMAX storage system which essentially flattens the effect of daily temperature variations on the internals of the MPC.

2.3.3.3 Design Temperatures

In addition to the normal condition design temperatures, which apply to long-term storage and short-term operating conditions, an off-normal/accident condition temperature pursuant to the provisions of NUREG-1536 and Regulatory Guide 3.61 is also defined. This is the temperature which may exist during a transient event (examples of such an instance is the blockage of the VVM inlet vents or the fire accident). The off-normal/ accident condition temperatures of Table 2.3.7 are selected to bound the maximum (maximum in time and space) value of the thru-thickness average temperature of the structural or non-structural part, as applicable, during the transient event. These enveloping values, therefore, will bound the maximum temperature reached anywhere in the part, excluding skin effects, during or immediately after, a transient event.

The off-normal/accident condition temperatures for stainless steel and carbon steel components are chosen such that the material's ultimate tensile strength does not fall below 30% of its room temperature value, based on published data [2.4.8 and 2.4.13]. This ensures that the material will not be subject to significant creep rates during these short duration transient events.

2.3.3.4 Leakage of One Seal

The MPC enclosure vessel (in any MPC model listed in Table 1.2.1) does not contain gaskets or seals: All confinement boundary closure locations are welded. Because the material of construction (austenitic stainless steel) is known from extensive industrial experience to lend to high integrity, high ductility and high fracture strength welds, the MPC enclosure vessel welds provide a secure barrier against leakage.

The confinement boundary is defined by the MPC shell, MPC baseplate, MPC lid, port cover plates, closure ring, and associated welds. Most confinement boundary welds are inspected by radiography or ultrasonic examination. Field welds are examined by the liquid penetrant method on the root (if more than one weld pass is required) and final weld passes. In addition to multi-pass liquid penetrant examination, the MPC lid-to-shell weld is pressure tested. The vent and drain port cover plates are also subject to proven non-destructive evaluations for leak detection such as liquid penetrant examination. These inspection and testing techniques are performed to verify the integrity of the confinement boundary.

The HI-STORM UMAX VVM does not serve a confinement function: It does not feature any safety significant seals. Therefore, leakage of one seal is not evaluated for its consequence to the storage system.

2.3.3.5 Malfunction of FHD

The FHD system is a forced helium circulation device used to effectuate moisture removal from loaded MPCs. For circulating helium, the FHD system is equipped with active components requiring external power for normal operation.

Initiating events of FHD malfunction are: (i) a loss of external power to the FHD System and (ii) an active component trip. In both cases a stoppage of forced helium circulation occurs and heat dissipation in the MPC transitions to natural convection cooling.

Although the FHD System is monitored during its operation, stoppage of FHD operations does not require actions to restore forced cooling for adequate heat dissipation. This is because the condition of natural convection cooling evaluated in Section 4.6 of HI-STORM FW FSAR shows that the fuel temperatures remain below off-normal limits. An FHD malfunction is detected by operator response to control panel visual displays and alarms.

2.3.4 Extreme Environmental Phenomena and Accident Conditions

The loadings corresponding to the extreme environmental phenomena and accident events, collectively referred to as Faulted States, are discussed as a part of load combinations.

2.3.4.1 Partial Blockage of MPC Basket Flow Holes

The MPC is designed to prevent reduction of thermosiphon action due to partial blockage of the MPC basket flow holes by fuel cladding failure, fuel debris and crud. The HI-STORM UMAX System maintains the SNF in an inert environment with fuel rod cladding temperatures below accepted values (Table 2.3.7). Therefore, there is no credible mechanism for gross fuel cladding degradation of fuel classified as undamaged during storage in the HI-STORM UMAX. Fuel classified as damaged fuel or fuel debris are placed in damaged fuel containers. The damaged fuel container is equipped with mesh screens which ensure that the damaged fuel and fuel debris will not escape to block the MPC basket flow holes. The MPC is loaded once for long-term storage and, therefore, buildup of crud in the MPC due to numerous loadings is precluded. Using crud quantities for fuel assemblies reported in an Empire State Electric Energy Research Corporation Report [2.2.3] determines a layer of crud of conservative depth that is assumed to partially block the MPC basket flow holes. The crud depth is listed in Table 2.2.8 of the HI-STORM FW FSAR. The flow holes in the bottom of the fuel basket are designed (as can be seen on the licensing drawings) to ensure that this amount of crud does not block the internal helium circulation.

2.3.4.2 Confinement Boundary Leakage

None of the postulated environmental phenomenon or accident conditions identified will cause failure of the confinement boundary. Section 7.1 of the HI-STORM FW FSAR provides the rationale to treat leakage of the radiological contents from the MPC as a non-credible event.

2.3.4.3 Handling Accident

A handling accident in the Part 72 jurisdiction is precluded by the requirements and provisions specified in the HI-STORM FW FSAR. The loaded HI-TRAC VW and MPCs will be lifted in the Part 72 operations jurisdiction in accordance with written and Q.A. validated procedures and shall use special lifting devices which comply with ANSI N14.6-1993 [2.2.2]. Also, the lifting and handling equipment (typically the cask transporter) is required to have a built-in redundancy against uncontrolled lowering of the load. Further, the HI-TRAC VW is a vertically deployed system, and the handling evolutions in *short term operations*, as discussed in Chapter 9, do not involve downending of the loaded cask to the horizontal configuration (or upending from the horizontal state) at any time. In particular, the loaded MPC shall be lowered into the HI-STORM UMAX VVM or raised from it using the HI-TRAC VW transfer cask and a MPC lifting system designed in accordance with ANSI N14.6. Therefore, analysis of a handling accident event involving a HI-TRAC VW or MPC is not required.

2.3.4.4 Non-Mechanistic Tip-Over

Because the HI-STORM UMAX VVM is situated underground and cannot be moved, a tip-over event is not a credible accident for this design.

2.3.4.5 Tornado

The HI-STORM UMAX System must withstand pressures, wind loads, and missiles generated by a tornado. The prescribed design basis tornado and wind loads for the HI-STORM FW System are consistent with NRC Regulatory Guide 1.76 [2.4.9], ANSI 57.9 [2.4.10], and ASCE 7-05 [2.4.11]. Table 2.3.4 provides the wind speeds and pressure drops applicable to the HI-STORM UMAX System.

The continued integrity of the MPC confinement boundary, within the HI-TRAC VW transfer cask, under impact from tornado-generated missiles in conjunction with the wind loadings is demonstrated in Chapter 3 of the HI-STORM FW FSAR.

2.3.5 Short-Term Operations

Short-term operations and their safety considerations are discussed in Chapter 9.

Table 2.3.1

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	60 yrs	-
Service Life	100 yrs	-
Licensed Life	40 years	10CFR72.42(a) & 10CFR72.236(g)
	Structural:	
Design & Fabrication Codes: Foundation Pad and ISFSI 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 2.6	10CFR72.24(c)(4)
VVM Closure Lid Dead Weight:	Section 3.2	R.G. 3.61
Design Internal Pressure	Atmospheric	Ventilated Module
	Thermal:	
Design Basis Heat Load	Governed by ISG-11, Rev. 3	The permissible heat load is limited by the requirement that the temperature of the fuel cladding and the internal pressure in the MPC do not exceed allowable limits under all thermally significant loadings listed in Section 2.5.
Maximum Design Temperatures:		
Closure Lid Concrete		
Through-Thickness Section Average (Normal)	Table 2.3.7	ACI 318(2005)
Through-Thickness Section Average (Off-Normal and Accident)	Table 2.3.7	ACI 318(2005)
Structural Steel	Table 2.3.7	ASME Code, Section II, Part D
Divider Shell Thermal Insulation	Heat transfer resistance per Table 4.2.7. Must be stable under long-term normal and short-term accident conditions.	N/A
	Confinement:	
	N/A, Provided by MPC	10CFR72.128(a)(3) and 10CFR72.236(d) & (e)
	Retrievability:	
Normal/Off-Normal	Retrieval of the contents.	10CFR72.122(f), (h), (1), & (l)
Accident	Retrieval of the canister	ISG-3
	Criticality:	

Table 2.3.1

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
	Provided by MPC	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	10CFR72.104 and 10CFR72.212
	Ensure dose rates on and around the VVM during MPC transfer and lid installation operations are ALARA	10CFR20
Accident or Conditions of Extreme Environmental Phenomena	Meet controlled area boundary dose limits in regulations for all accidents	10CFR72.106
Design Bases:		
Spent Fuel Specification	N/A: Governed by the MPC's CoC with heat load adjusted per Section 2.1	10CFR72.236(a)
Normal Design Event Conditions:		
Ambient Outside Temperature:	-	-
Max. Yearly Average	Table 2.3.6	ANSI/ANS 57.9
Live Load[†]:		
Loaded HI-TRAC and Mating Device	Table 3.2.1	R.G. 3.61
Dry Loaded MPC	Table 3.2.1	R.G. 3.61
Cask Transporter	Table 3.2.1	-
Handling:		-
VVM Closure Lid Lift Points	Section 3.4	NUREG-0612 ANSI N14.6
Minimum Permissible Temperature During Closure Lid Handling Operations	10°F	ANSI/ANS 57.9
Snow and Ice Load	100 lb/ft^2	ASCE 7-88
Wet/Dry Loading	Dry	-
Storage Orientation	Vertical	-
Off-Normal Design Event Conditions:		
Ambient Temperature:		-
Minimum	Table 2.3.6	
Maximum	Table 2.3.6	
Partial Blockage of Air Inlets	50% blockage of air inlet	-

[†] Bounding weights.

Table 2.3.1

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
Design Basis Accident Events and Conditions:		
Drop Cases:		
End Drop	Not credible	In-ground VVM cannot be lifted
Tip-over	Not credible	In-ground VVM is constrained from tip over by ISFSI interfacing structures
Fire:	-	-
Amount of Fuel	50 Gallons	10CFR72.122(c)
Temperature	1475°F	10CFR72.122(c)
Fuel Rod Rupture	Chapter 4	-
Air Flow Blockage	100% blockage of air inlet flow area	10CFR72.128(a)(4)
Explosive Overpressure External Differential Pressure	10 psi steady state	10CFR72.128(a)(4)
Extreme Environmental Phenomenon Events and Conditions:		
Flood:		-
Height	125 ft	R.G. 1.59
Velocity	N/A	In-ground VVM is not subject to tip-over or sliding. Loads on the Closure Lid are bounded by missile impact loads.
Max. Earthquake	Table 2.3.2	10CFR72.102(f)
Tornado:	Table 2.3.4	-
Tornado-Borne Missiles:		
i. Automobile	Ensure shielding, fuel subcriticality and MPC retrievability and confinement	NUREG-1536
Weight	Table 2.3.3	NUREG-0800
Velocity	Table 2.3.3	NUREG-0800
ii. Rigid Solid Steel Cylinder (intermediate tornado missile)	Ensure shielding, fuel subcriticality and MPC retrievability and confinement	NUREG-1536
Weight	Table 2.3.3	NUREG-0800
Velocity	Table 2.3.3	NUREG-0800
iii. Steel Sphere	Section 2.4	NUREG-1536 In-ground VVM has no penetrations that provide line-of-sight to MPC
Weight	Table 2.3.3	NUREG-0800
Velocity	Table 2.3.3	NUREG-0800
Extreme Environmental Temp.	Table 2.3.6 (3-Day Average for the ISFSI Site)	-

Table 2.3.2

DESIGN DATA FOR HI-STORM UMAX ISFSI

	Type	**Value (minimum or nominal, as applicable)**	**Comment**
1.	ISFSI Pad and SFP concrete density concrete compressive strength rebar yield strength concrete cover on rebar	• 150 lb/ft^3 reference dry density • 4,500 psi minimum concrete compressive strength @ ≤ 28 days • 60,000 psi minimum rebar yield strength • minimum concrete cover on rebar per subsection 7.7.1 of ACI-318(05)	See Licensing Drawings in Section 1.5 for details on concrete pad thickness. Grade 60 Rebar. Rebar is #11@9" (each face, each direction) Compressive strength, allowable bearing stress and reference dry density values for ISFSI structures are also applicable to the plain concrete used in the UMAX Closure Lid
2.	Depth averaged density of subgrade in Space A (see Figure 2.4.4)	120 lb/ft^3 minimum	Required for shielding and structural analysis
3.	Depth averaged density of subgrade in Space B (see Figure 2.4.4)	110 lb/ft^3 minimum	Required for shielding analysis.
4.	Depth averaged density of subgrade in Space C (see Figure 2.4.4)	120 lb/ft^3 nominal	Not required for shielding.
5.	Depth averaged density of subgrade in Space D (see Figure 2.4.4)	120 lb/ft^3 nominal	This space will typically contain native soil. Not required for shielding.
6.	Strain compatible effective shear wave velocity in Space A, V	1300 ft/sec minimum	This space will typically contain CLSM or lean concrete.
7.	Strain compatible effective shear wave velocity in Space B, V	450 ft/sec minimum	This space will typically contain native soil.
8.	Strain compatible effective shear wave velocity in Space C, V	485 ft/sec minimum	This space may be remediated with vertical reinforcement such as pilings to enhance V.

Table 2.3.2

DESIGN DATA FOR HI-STORM UMAX ISFSI

	Type	Value (minimum or nominal, as applicable)	Comment
9.	Strain compatible effective shear wave velocity in Space D, V (Figure 2.4.4)	485 ft/sec minimum	This space will typically contain native soil.
10.	Design Basis Earthquake	Top of the Grade (Ground surface) spectra per Figure 2.4.1 with horizontal ZPA, a_H and vertical ZPA, a_V scaled as follows: $a_H = 1.0g$ $a_V = 0.75g$ and foundation surface pad spectra per Figure 2.4.2 with horizontal ZPA, a_H and vertical ZPA, a_V of: $a_H = 0.93g$ $a_V = 0.71g$	Horizontal and vertical spectra shown in Figures 2.4.1 and 2.4.2 are based on 5% damping. Following the Newmark 100-40-40 response combination technique [2.6.7] endorsed by the Regulatory Guide 1.92 [2.4.7], 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 1.214 g's (=1.0×0.93g's + 0.4×0.71 g's), respectively.
11.	Permissible long-term settlement of the SFP	0.2 inch maximum	Used as the input value in the strength qualification of the SFP.
12	Density of plain concrete in the Closure Lid (nominal)	150 lb/cubic feet	Used in shielding calculations
13	Reference compressive strength of plain concrete in the Closure Lid	4,000 psi	Used in analysis of mechanical loadings on the Closure Lid
14	Minimum compressive strength of SES in Space A (see Figure 2.4.4)	1,000 psi	Used in tornado missile impact analysis and SSI analysis

Table 2.3.3

TORNADO-GENERATED MISSILES

Missile Description	**Mass (kg)**	**Velocity (mph)**
Automobile	1800	126
Rigid solid steel cylinder (8 in. diameter)	125	126
Solid sphere (1 in. diameter)	0.22	126

Table 2.3.4

CHARACTERISTICS OF REFERENCE TORNADO

Condition	**Value**
Rotational wind speed (mph)	290
Translational speed (mph)	70
Maximum wind speed (mph)	360
Pressure drop (psi)	3.0

Table 2.3.5

DESIGN (MAXIMUM ALLOWABLE) PRESSURES

Pressure Location	**Condition**	**Pressure (psig)**
MPC Internal Pressure	Normal	100
	Off-Normal/Short-Term	110 (MPC-24, MPC-32 and MPC-68) 120 (MPC-37 and MPC-89)
	Accident	200
MPC External Pressure	Normal	(0) Ambient
	Off-Normal/Short-Term	(0) Ambient
	Accident	55
HI-TRAC Water Jacket Internal Pressure	Accident	65

Table 2.3.6

ENVIRONMENTAL TEMPERATURES

Condition	Temperature (°F)	Comments
Normal Ambient Temperature (Bounding Annual Average from the contiguous United States)	80	
Normal Soil Temperature (Bounding Annual Average from the contiguous United States)	77	
Off-Normal Ambient Temperature (3-Day Average)	-40 (min) and 100 (max)	-40°F with no insolation 100°F with insolation
Extreme Accident Level Ambient (3-Day Average)	125	125°F with insolation
Short-Term Operations	0 (min.) 90 (max.)	The lower bound limit is specified in the technical specifications. The upper bound limit is a 3-day daily average with insolation and can be increased for a specific site if justified by the appropriate thermal analysis.

Table 2.3.7

DESIGN TEMPERATURES

Component	Normal & Mechanical Accident Condition Design Temperature Limits (^{0}F) (Note 1)	Off-Normal and Accident Condition Temperature Limits (^{0}F) (Note 2)
MPC shell	650	1058
MPC basket	752	1058 (Note 5)
MPC basket shims	752	1058
MPC lid	752	1058
MPC closure ring	752	1058
MPC baseplate	752	1058
CEC shell	650	1058
CEC Flange	650	1058
Fuel Cladding	752 (Storage) 752 or 1058 (Short Term Operations) (Note 6)	1058 (Note 3)
Closure Lid concrete(section average)	350	600 (Note 4)
Closure Lid Top and Bottom Plate	650	1058
Remainder of VVM steel structure	650	1058
Divider Shell	650	1058
Insulation	650	1058
HI-TRAC VW inner shell	500	700
HI-TRAC VW bottom lid	350	700
HI-TRAC VW top flange	400	650
HI-TRAC VW bottom lid seals	350	N/A
HI-TRAC VW bottom lid bolts	350	800
HI-TRAC VW bottom flange	350	700
HI-TRAC VW radial neutron shield	311	N/A
HI-TRAC VW radial lead gamma shield	350	600

Note1: Column 2 temperature limits apply to normal conditions of storage and to accident conditions that do not involve a thermally adverse condition such as seismic loading.

Note 2: For extreme environmental phenomena and accident conditions which involve heating of the steel structures and no mechanical loading (such as the blocked air duct accident, fire and burial-under-debris), the maximum permissible temperature is set equal to the permissible fuel cladding temperature(see Note 3 for MBF) at which the VVM structure will remain physically stable .

Note 3: Short term operations include MPC drying and onsite transport. The 1058°F temperature limit applies to MPCs containing all moderate burnup fuel. The limit for MPCs containing one or more high burnup fuel assemblies is 752°F.

Note 4: The VVM closure lid concrete, the primary function of which is shielding, will maintain its structural, thermal and shielding properties provided that the temperature limits prescribed.

The Portland Cement Association (PCA) Bulletin ST32 [2.3.1] provides a comprehensive assay of high temperature effects on concrete, stating, "Under certain conditions such as reinforced concrete chimneys, it (concrete) has been successfully used for temperatures of 600 deg. F (315.5°C). Where there is no load, such as chimney linings, it has been successfully used for temperature up to 1000 deg. F (537.8°C)".

The hydrogen loss from closure lid concrete due to high temperature is small because the closure lid concrete is completely enclosed by steel plate.

Note 5: The MPC basket contains stainless steel and Metamic (MPC-24, MPC-32 and MPC-68) or Metamic-HT (MPC-68M, MPC-37 and MPC-89). The neutron absorber material used in MPC baskets for criticality control (Metamic or Metamic-HT) are manufactured with B_4C and aluminum. B_4C is a refractory material that is unaffected by high temperature and aluminum is solid at temperatures in excess of 1200°F [2.3.2]. For conservatism, neutron absorbers temperatures under off-normal and accident conditions are limited to 1058°F.

Note 6: Short term operations include MPC drying and onsite transport. The 1058°F temperature limit applies to MPCs containing all moderate burnup fuel. The limit for MPCs containing one or more high burnup fuel assemblies is 752°F.

Table 2.3.8

MPC CONFINEMENT BOUNDARY STRESS INTENSITY LIMITS FOR DIFFERENT LOADING CONDITIONS (ELASTIC ANALYSIS PER NB-3220)[†]

Stress Category	Design	Level A	Level D[††]
Primary Membrane, P_m	S_m	S_m	A MIN ($2.4S_m$, $.7S_u$)
Local Membrane, P_L	$1.5S_m$	$1.5S_m$	150% of P_m Limit
Membrane plus Primary Bending	$1.5S_m$	$1.5S_m$	150% of P_m Limit
Primary Membrane plus Primary Bending	$1.5S_m$	N/A	150% of P_m Limit
Membrane plus Primary Bending plus Secondary	N/A	$3S_m$	N/A
Average Shear Stress[††††]	$0.6S_m$	$0.6S_m$	$0.42S_u$

[†] Stress combinations including F (peak stress) apply to fatigue evaluations only.

[††] Governed by Appendix F, Paragraph F-1331 of the ASME Code, Section III.

[††††] Governed by NB-3227.2 or F-1331.1(d).

Table 2.3.9 STRUCTURAL DESIGN CRITERIA FOR THE FUEL BASKET	
PARAMETER	**VALUE**
Minimum service temperature	-40°F
Maximum total (lateral) deflection in the active fuel region - dimensionless	0.005

2.4 STRUCTURALLY SIGNIFICANT LOAD COMBINATIONS AND ACCEPTANCE CRITERIA

Where appropriate, for each loading type, a bounding value is selected in this FSAR to impute an additional margin for the associated loading events. Such bounding loads are referred to as Design Basis Loads (DBL) in this FSAR. For example, the Design Basis External Pressure on the MPC, set down in Table 2.3.1, is a DBL, as it grossly exceeds any credible external pressure that may be postulated for an ISFSI site.

The Design Basis structural loads and their combinations applicable to normal, off-normal and accident conditions for the HI-STORM UMAX system are considered in this section and summarized in Tables 2.4.1 and 2.4.3. The qualifying analyses are presented in Chapter 3.

Each loading case in Table 2.4.1 is distinct in respect of the sub-component of the VVM that it affects most significantly. The acceptance criteria for the storage system, pursuant to NUREG-1536, consist of demonstrating that:

a. The radiation shielding in the storage system does not degrade under normal and off-normal conditions of storage.

b. The system does not deform under credible loading conditions in a manner that would jeopardize the subcritical state of the storage system or ready retrievability of the MPC.

c. The MPC maintains confinement of radiological matter. 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 VVM, including unloading if necessary, and loss of function must be readily discernible ,i.e., apparent or detectable.

The above overarching acceptance criteria are further particularized in a more conservative form for each applicable loading case explicitly listed in Table 2.4.1 in the following sections.

2.4.1 Load Case 01: Dead Load plus Design Basis Explosion Pressure

The HI-STORM UMAX system must withstand the pressure pulse due to a design basis explosion event. The effect of overpressure due to an explosion near the VVM acting concurrently with the dead load of the system is defined as Load Case 01 and analyzed in Chapter 3. The overpressure design value applied to the Closure Lid outer surface (see Table 2.3.1) 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 shall be evaluated under the provisions of 10CFR72.212.

The explosion load is stated in Table 2.3.1 in terms of an equivalent static pressure. The affected sub-components are:

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

a. 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. Level D stress limits are applicable to this load case based on applicable metal service temperatures. The explosion pressure also envelops other normal condition mechanical loads such as snow and flood. Load Case 01, therefore, is a bounding load combination that conservatively subsumes other loading types. Acceptance criteria for this load case are provided in Table 2.4.1. Level A stress limits are applicable based on reference metal temperatures that bound all mechanical loading scenarios (Table 2.4.1) when this case is used as an enveloping evaluation for any normal condition.

2.4.2 Load Case 02: Design Basis Missile Loadings

The HI-STORM UMAX 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 prescribed design basis tornado and wind loads for the HI-STORM UMAX System are consistent with NRC Regulatory Guide 1.76 [2.4.9], ANSI 57.9 [2.4.10] and ASCE 7.05 [2.4.11]. Design Basis Missiles are summarized in Table 2.3.3. The HI-STORM UMAX 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 UMAX 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 2.3.3. 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 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 UMAX system is not analyzed.

When subject to a tornado missile strike, the Closure Lid must not be dislodged creating a direct line of sight from the top of the MPC to the outside (see Table 2.4.1). 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.

2.4.3 Load Case 03: Design Basis Seismic Event and Long-Term Settlement

The DBE and Long-Term Settlement are treated together under Load Case 03 because they are both germane to the qualification of the two pads (SFP and the ISFSI Pad).

a. Design Basis Seismic Event

As required by 10CFR72.102(f), the Design Basis Earthquake for the ISFSI must be specified. For the HI-STORM UMAX 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 2.3.2). For purposes of the generic seismic analysis in this FSAR, the Design Basis Earthquake for the HI-STORM UMAX system is defined by two sets of response spectra specified at the ISFSI pad top surface elevation and at the SFP bottom surface elevation, as shown in Figures 2.4.1 and 2.4.2, respectively. 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 soil seismic response analyses performed using a lower-bound soil shear wave velocity profile (see Figure 2.4.3). This lower bound profile was established in [2.4.1] 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) as specified in Table 2.3.2. 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 2.3.2.

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 of the native soils in Table 2.3.2) to define the structural characteristics of the soil layers above and below the SFP elevation. 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 Chapter 3. The response spectrum plots shown in Figure 2.4.1 and 2.4.2 are the results of the LS-DYNA soil 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 Chapter 3.

The combination of weak soil properties and strong earthquake, as specified in Table 2.3.2 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 HI-STORM UMAX system is performed conservatively based on the lower bound support from the sub-grade and the under-grade. Thus, the HI-STORM UMAX 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 HI-STORM UMAX ISFSI site will be exempt from a detailed SSI analysis if the soil seismic response analysis for the site (using SHAKE or similar program) can demonstrate that the following two criteria are met:

- The site's response spectra at both ISFSI pad and SFP elevations are enveloped by the Design Basis Earthquake response spectra shown in Figures 2.4.1 and 2.4.2 at their applicable elevations, respectively;
- The soil properties of the candidate site are greater than the minimum values specified in Table 2.3.2.

In order to satisfy the first criterion, the site must perform a soil seismic response analysis using SHAKE or a similar program. The site's response spectra at both the ISFSI pad and SFP elevations must be bounded by the Design Basis Earthquake response spectra in Figures 2.4.1 and 2.4.2.

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:

Scenario A: The site's response spectra are not completely enveloped by the respective Design Basis Earthquake response spectra in Figures 2.4.1 and 2.4.2. However, the site's overall earthquake strength, represented by the resultant ZPA (see Table 2.3.2 for definition) is bounded by that of the Design Basis Earthquake at both ISFSI pad 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 2.4.4, 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 HI-STORM UMAX system would exhibit a greater safety margin against the earthquake loading at the stiffer subgrade/under-grade 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 2.4.4) is less than the required minimum value specified in Table 2.3.2.

Typically, Spaces B and D (in Figure 2.4.4) 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 these 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 2.4.1 and 2.4.2).

The site-specific safety analysis, if required, shall follow the methodology set down in Chapter 3. 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 Paragraph 3.3.3.2 of ASCE 4-98 [2.4.3]. Uncertainties in SSI analysis for a candidate HI-STORM UMAX

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:

a. Compliance of the VVM Components to the applicable stress/deformation limits specified in Table 2.4.2.

b. Strength compliance of the ISFSI reinforced concrete structures under ACI-318(2005) load combinations listed in Table 2.4.3.

The Design Basis Seismic Event (also referred to as the Design Basis Earthquake (DBE)) is classified as an extreme environmental phenomenon. As such the Level D service condition limits are applicable to the VVM components, such as the MPC Enclosure Vessel, MPC Guides and the MPC shell (Table 2.4.2).

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 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.

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

b. Long-Term Settlement

At an ISFSI site, depending on the density of the subgrade, there may be a small mismatch between the weight of the excavated native soil above the SFP and the total weight of loaded VVMs and the refilled subgrade, leading to a minor amount of long-term settlement of the SFP. The limiting allowable value of the SFP long-term settlement has been specified in Table 2.3.2

for a conservative stress analysis of the pad under the load combinations of Table 2.4.3. The effect of long-term settlement on the SFP shall be considered as a concurrent load with Dead load. On the other hand, the ISFSI pad is founded on the refilled Self-hardening Engineered Subgrade (i.e., CLSM or lean concrete), which is known to be immune from long term settlement due to its own weight and the dead weight of the ISFSI pad.

2.4.4 Load Case 04: Design Basis Handling and Impact Events

Because the VVM is situated underground and cannot be moved, drop and tip-over events are not credible accidents for this design. The Closure Lid, as can be inferred from the Licensing Drawings, cannot strike the MPC lid if it were to undergo a free fall due to geometry constraints. 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 HI-TRAC 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).

The design of the lifting equipment must meet single failure proof criteria to preclude a safety related load handling event during emplacement or removal of the Closure Lid while the CEC contains a loaded MPC. 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 [2.6.1] 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.

Lift locations for the CEC are expected to be used for lifting only during construction, and possibly during 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, and the site decommissioning plan, as applicable.

2.4.5 Load Case 05: Design Basis Fire Event

The potential of a fire accident near an ISFSI pad is considered to be rendered extremely remote by ensuring that there are no significant combustible materials in the area. The only credible concern is related to a transport vehicle fuel tank fire engulfing the loaded HI-STORM module during the MPC transfer operations or loaded HI-TRAC transfer cask while it is being moved to the ISFSI.

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 modules in docket numbers 72-1014 and 72-1032. As is the case for aboveground VVMs, 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, the spilled fuel will collect and burn over the ISFSI pad, also referred to as Top-of-Grade. Therefore, the location of fuel combustion will be physically removed from the CEC. Also, the natural grade in the ISFSI pad 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 MPCs.

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 the Closure Lid suffers structural failure or instability.

Therefore, 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.

Finally, it is necessary to demonstrate that the internal pressure in the stored MPC will not exceed the accident condition design pressure during or after the fire event.

2.4.6 Load Case 06: Live Load on VVM During MPC Transfer

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.

The acceptance criterion for this load case, like all other load cases, is provided in Table 2.4.1.

2.4.7 Load Case 7: Design Basis Flood

The HI-STORM UMAX System is engineered to be flood resistant. Furthermore, the potential water ingress passages are elevated in the HI-STORM UMAX (in contrast to the pad level inlet ducts in typical ventilated VVMs) to prevent intrusion of floodwater in the MPC storage cavities. However, all HI-STORM MPCs are designed to withstand 125 feet of water submergence (Table 2.4.1). The VVM will clearly withstand this static head of water above the surface of the ISFSI because all structural members are either 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 Chapter 1, because heat removal is enhanced by the floodwater. Submergence of the CEC up to the level of the Container Flange will not result in a significant hydrostatic pressure; therefore, collapse of the CEC or potential for significant stresses is not a concern. Furthermore, the uplift force on the CEC due to buoyancy is less than the downward force due to the system's dead weight; therefore, uplift of the CEC is not a concern.

The analysis of the CEC for submergence under 125 feet of water is presented in Chapter 3.The qualification of the MPC under the Design Basis Flood is documented in the FSAR that supports the CoC of the MPC.

Table 2.4.1
LOAD CASES AND ACCEPTANCE CRITERIA

Load Case I.D.	Bounding Loading	Affected Sub-Component	Applicable Data		Acceptance Criterion
			Magnitude of Loading	Reference Coincident Metal Temperature (Deg. F)	
01	Normal operation condition; dead load plus design basis explosion pressure	• Container Shell structure • Closure Lid	Section 3.2 (dead weight);Table 2.3.1 (pressure)	150 350	Primary stresses do not exceed applicable Level A stress limits of ASME Subsection NF for dead weight only (or Level D limits with explosion)
02	Design basis missile	Closure Lid	Table 2.3.3	350	Closure Lid does not collapse, is not dislodged from the cavity, and is not perforated by the missile.
03	Design basis earthquake	Container Shell	Figure 2.4.1 and 2.4.2	150	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 2.4.2
04	Closure lid handling	Lid Lift Lugs; all metal structure in Lid	1.15 x Closure Lid Weight (From Table 3.2.1)	200	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.
05	Design basis fire	Closure Lid	Section 2.4.5	800	The Closure Lid structure does not collapse under its dead weight due to elevated metal temperatures.

Table 2.4.1

LOAD CASES AND ACCEPTANCE CRITERIA

Load Case I.D.	**Bounding Loading**	**Affected Sub-Component**	**Applicable Data**		**Acceptance Criterion**
			Magnitude of Loading	**Reference Coincident Metal Temperature (Deg. F)**	
06	VVM loaded by the overhead transfer cask and Mating Device during the transfer operation	Container Shell	-	150	Service A stress limit for NF Class 3 plate and shell structure and buckling stress limits for the VVM shell must be met.
07	Design Basis Flood	Container Shell	125 feet of water head	150	The hoop stress in the Container Shell shall be below the minimum material yield strength without taking credit for the action of the surrounding subgrade.

Note 1. Structural loads and acceptance criteria for each load case are further explained in Section 2.4.

Note 2: Materials of construction are identified in Table 2.6.2.

Note 3: Design attributes of the VVM are explained in Chapter 1 and details are presented in the drawings in Section 1.5.

Note 4: The limiting value of coincident metal temperature is used to establish material properties and allowable stress (or stress intensity) when applicable.

Note 5: Load cases applicable to MPC and HI-TRAC VW are presented in Tables 2.2.6, 2.2.7, 2.2.13 and 3.1.1 of the HI-STORM FW FSAR.

Table 2.4.2

ACCEPTANCE CRITERIA FOR THE HI-STORM UMAX VVM AND INTERNALS UNDER EXTREME ENVIRONMENTAL CONDITIONS

Component	**Calculated Value**	**Allowable Limit**
CEC Container Shell	Radial gap between Divider Shell and the MPC after the seismic event	Nominal Gap between the MPC and the Divider 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 Top Lid 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 [2.4.12].

Table 2.4.3

LOAD COMBINATIONS FOR THE ISFSI PAD AND SUPPORT FOUNDATION PAD PER ACI-318 (2005)

Load Combination Case	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.

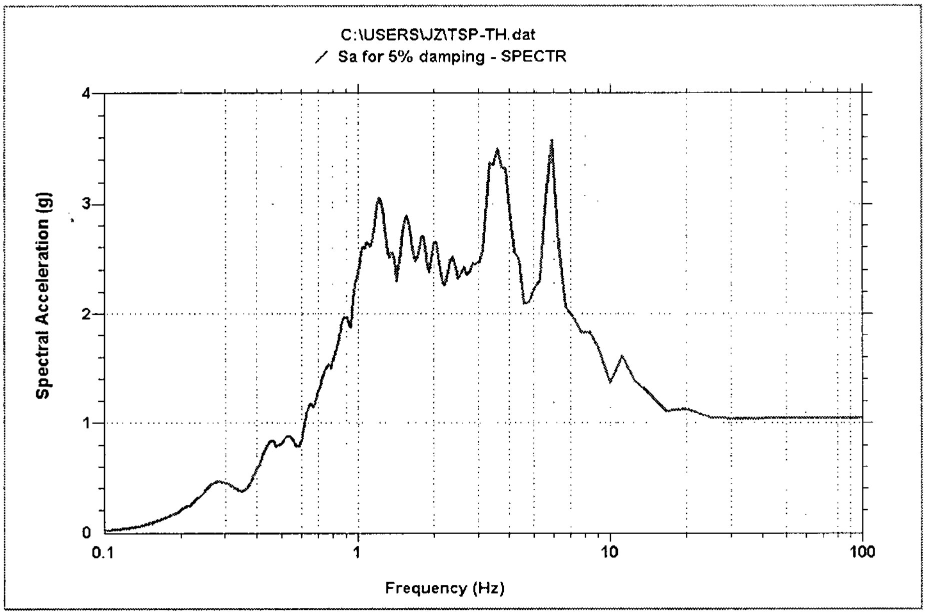
L: Live Load

E: DBE for the Site

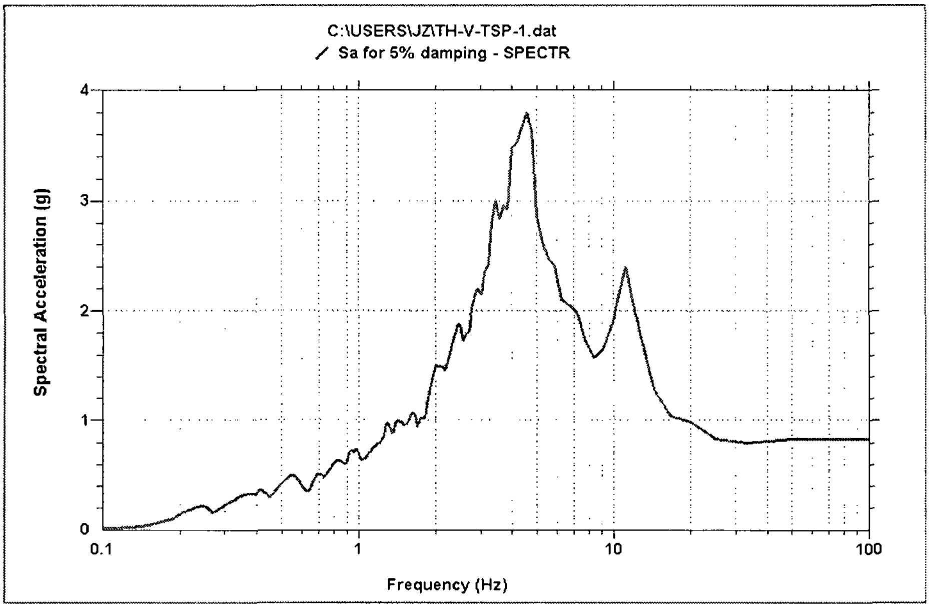
Table 2.4.4

SHAKE PARAMETRIC STUDY OF THE EFFECT OF SUBGRADE PROPERTIES ON SOIL RESPONSES AT HI-STORM UMAX ISFSI TOP & BOTTOM ELEVATIONS

Elevation & Direction	**Acceleration Response**	**Value (g's)**	
		Lower Bound Shear Wave Velocity Profile (see Figure 2.4.3)	**Upper Bound Shear Wave Velocity Profile (see Figure 2.4.3)**
ISFSI pad Top Surface Horizontal Direction	ZPA	1.008	0.897
	Peak	3.851	4.040
SFP Bottom Surface Horizontal Direction	ZPA	0.930	0.795
	Peak	3.519	3.762
ISFSI pad Top Surface Vertical Direction	ZPA	0.751	0.539
	Peak	3.912	2.377
SFP Bottom Surface Vertical Direction	ZPA	0.706	0.516
	Peak	3.573	2.286



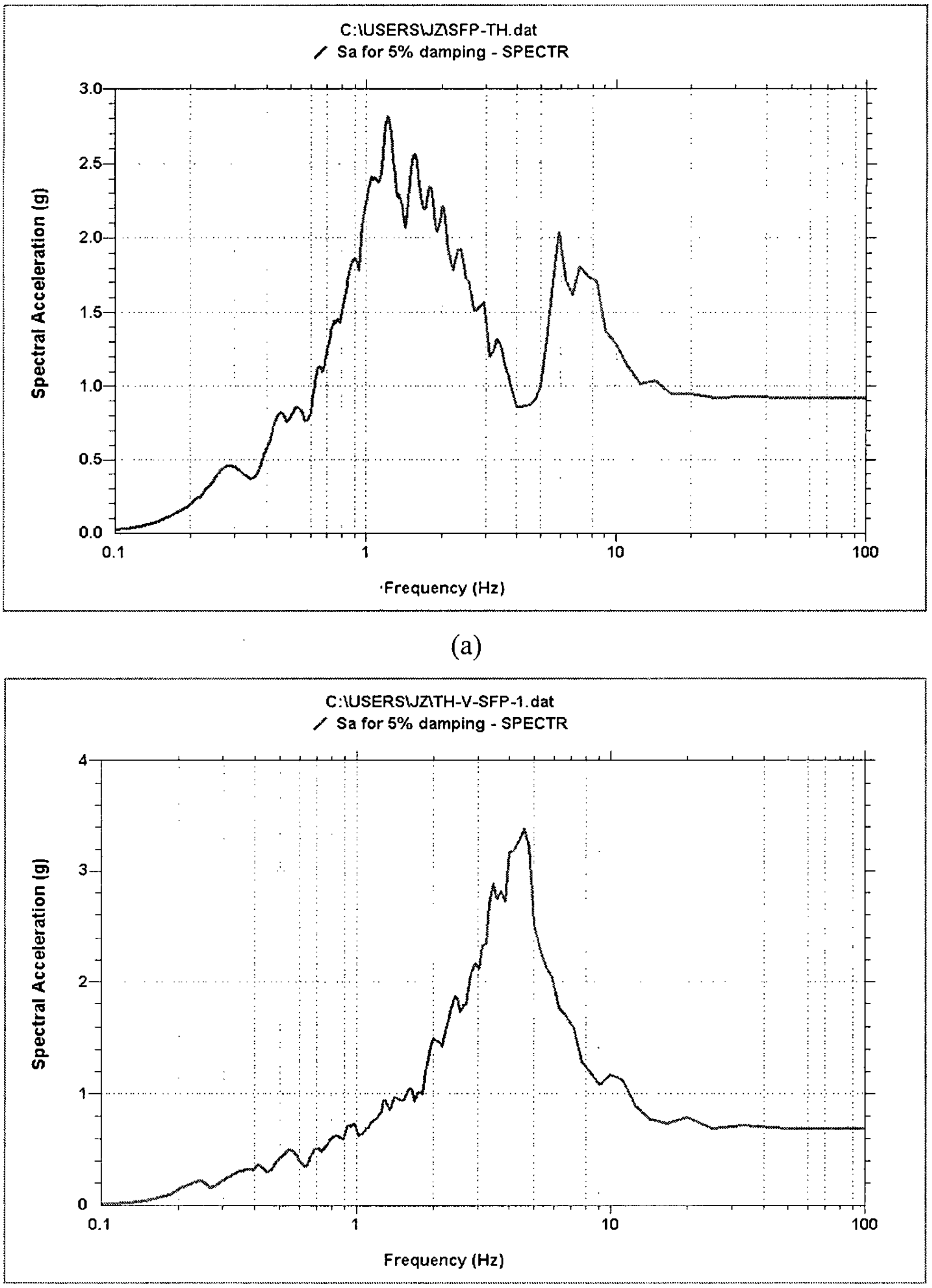
(a)



(b)

FIGURE 2.4.1: DESIGN BASIS SPECTRUM AT THE GROUND SURFACE (TOP OF ISFSI PAD) ELEVATION

(a) HORIZONTAL DIRECTION; (b) VERTICAL DIRECTION



(a)

(b)

FIGURE 2.4.2: DESIGN BASIS SPECTRUM AT THE HI-STORM UMAX FOUNDATION SURFACE (BOTTOM OF SFP) ELEVATION

(a) HORIZONTAL DIRECTION; (b) VERTICAL DIRECTION

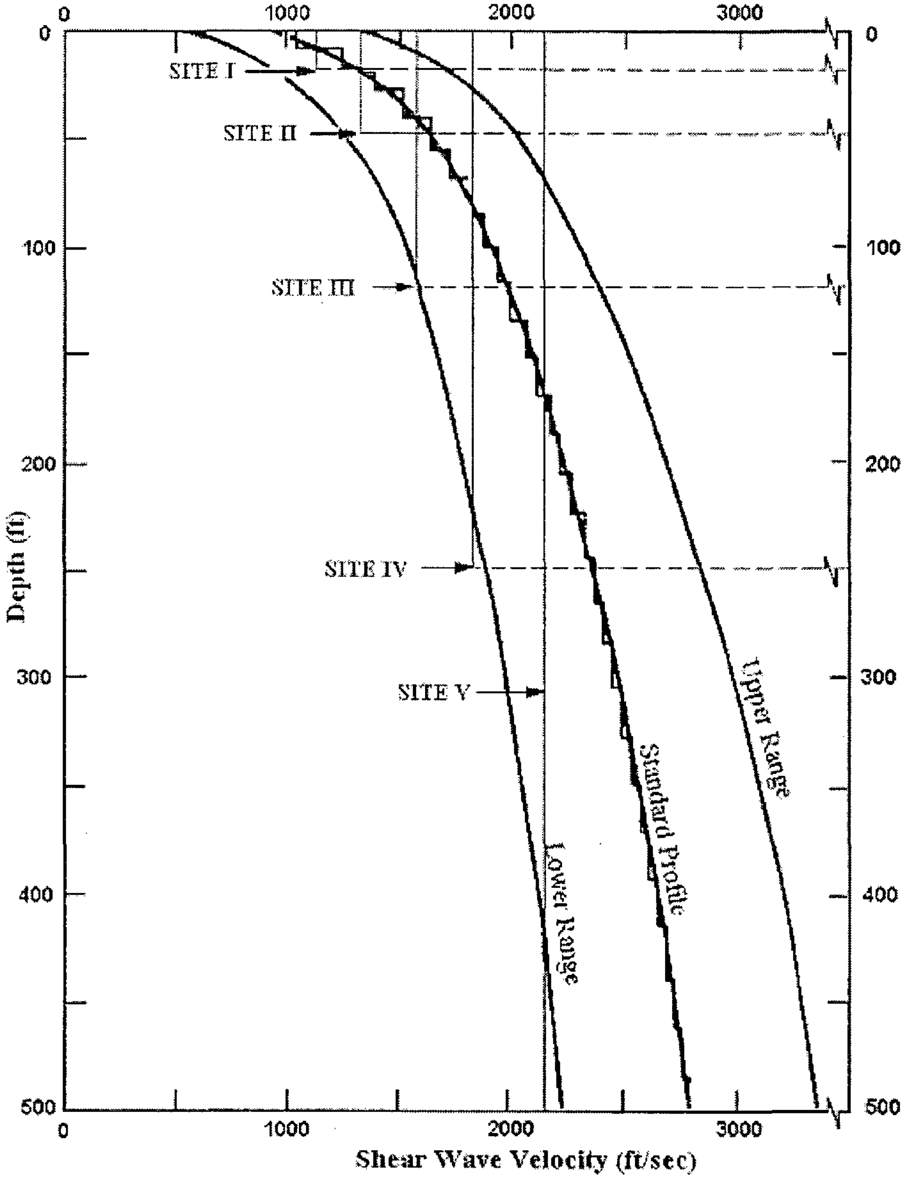


FIGURE 2.4.3: TYPICAL SHEAR WAVE VELOCITY PROFILES FOR NUCLEAR POWER PLANT SITES (REPRODUCED FROM FIGURE I-1 OF [2.4.1]

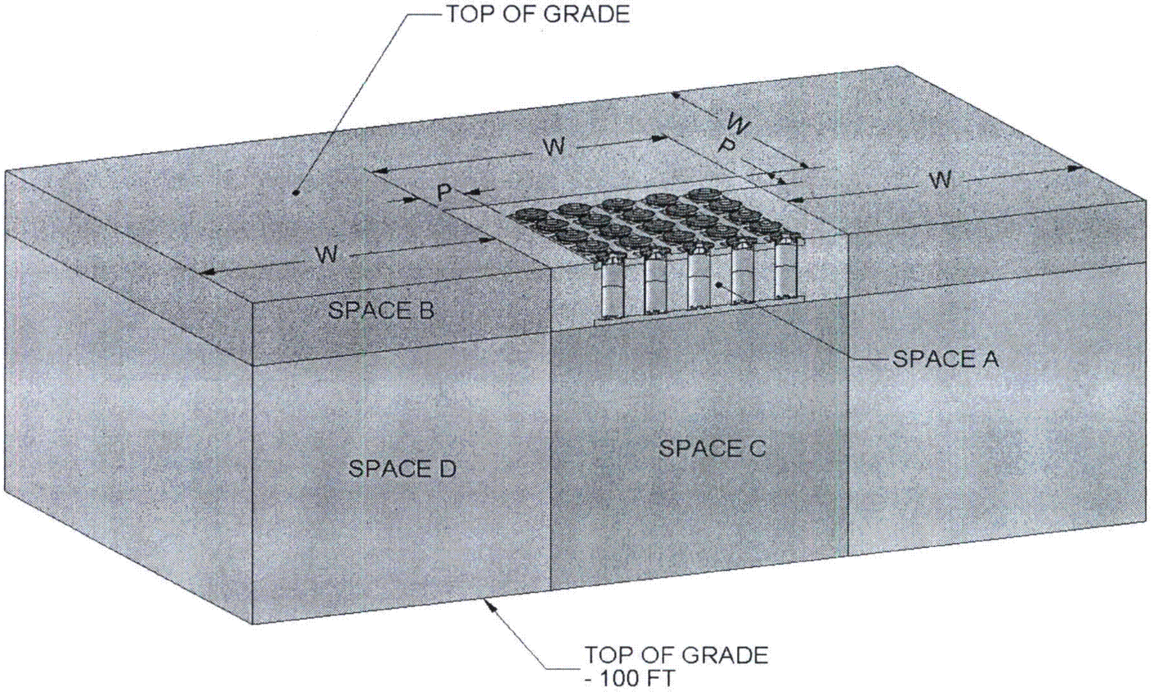


FIGURE 2.4.4: SUB-GRADE AND UNDER-GRADE SPACE NOMENCLATURE

Note: Space A is the lateral subgrade space in and around the VVMs which is refilled with CLSM or lean concrete after the construction of the SFP. 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 under-grade below the SFP. Space D is the under-grade surrounding Space C. P is the distance to the Enclosure wall.

2.5 THERMALLY SIGNIFICANT LOADS AND ACCEPTANCE CRITERIA

The analyses summarized in this chapter focus on the governing canisters out of the population of MPCs listed in Table 1.2.1. This chapter, however, supports the certification of only MPC-37 and MPC-89 at this time. The analyses reported for smaller canisters are for reference purposes only.

The thermal design and operation of the HI-STORM UMAX System shall meet the intent of the review guidance contained in ISG-11, Revision 3 [2.4.6]. Specifically, the ISG-11 provisions that are explicitly invoked and satisfied are:

a. The thermal acceptance criteria for all commercial spent fuel (CSF) authorized by the USNRC for operation in a commercial reactor are unified into one set of requirements.

b. The maximum value of the calculated temperature for all CSF under long-term normal conditions of storage must remain below 400°C (752°F). For short-term operations, including canister drying, helium backfill, and on-site cask transport operations, the fuel cladding temperature must not exceed 400°C (752°F) for high burn-up fuel (HBF) and 570°C (1058°F) for moderate burn-up fuel.

c. The maximum fuel cladding temperature as a result of an off-normal or accident event must not exceed 570°C (1058°F).

d. For HBF, operating restrictions are imposed to limit the maximum temperature excursion during short-term operations to 65°C (117°F) and the number of excursions to less than 10.

As stated in Chapter 1, the MPC models designated for storage in the HI-STORM UMAX system are previously certified for use in the HI-STORM FW overpack. For storage in HI-STORM UMAX, additional restriction in the heat load is applicable for certain MPCs and fuel types. Section 2.1 provides the Design Basis Heat Load for storage in HI-STORM UMAX as a function of the certified Design Basis heat load for the MPC in the " FW" docket..

The normal condition design temperatures for the materials used in the HI-STORM UMAX system are provided in Table 2.3.7.

Thermally significant loads are characterized by the absence of any significant mechanical loading and are principally applicable to the integrity of the stored fuel. The safety analyses for thermal loadings are contained in Chapter 4. The acceptance criteria for the fuel cladding temperature summarized above, are from ISG 11 Rev 3. The following thermal condition scenarios are applicable to HI-STORM UMAX:

- Normal Ambient Temperature

The HI-STORM UMAX System is analyzed for the same maximum yearly average ambient air temperature as that used for the HI-STORM FW systems (Table 2.3.6) which apply to long-term storage and short-term normal operating conditions (e.g., MPC drying operations and onsite transport operations). Pursuant to NUREG -1536, a certain population of the fuel rods in the MPC is also assumed to have become depressurized due to cladding failure. This normal operating condition temperature bounds all locations in the continental United States.

- Elevated Ambient Air Temperature

The HI-STORM UMAX System must be able to reject the design basis heat load under short-term conditions of elevated ambient air temperature designated as an Off-normal condition pursuant to NUREG-1536.

- Partial Blockage of Inlet Air Plenum

Pursuant to NUREG-1536, 50% of the inlet ducts are assumed to be blocked under an off normal storage condition.

The HI-STORM UMAX System must withstand 50% blockage of the inlet air flow plenum without exceeding allowable temperature and pressure limits specified for the off-normal condition.

- 100% Blockage of Air Inlets by Debris

The HI-STORM UMAX is assumed to be subject to a complete blockage of the inlet ducts. This is assumed to occur as a postulated accident event. Chapter 4 contains the appropriate thermal analysis which serves to establish the ISFSI surveillance program in the CoC for the system.

- 100% Fuel Rod Rupture

The 100% rod rupture event is a *non-mechanistic* postulate intended to define a bounding scenario of rise in the MPC internal pressure. The HI-STORM UMAX System must withstand loads due to 100% fuel rod rupture. For conservatism, 100% of the fuel rods are assumed to rupture with 100% of the fill gas and 30% of the significant radioactive gases (e.g., H^3, Kr, and Xe) released in accordance with NUREG-1536. All of the fill gas contained in non-fuel hardware, such as burnable poison rod assemblies (BPRAs), is also assumed to be released concomitantly.

The acceptance criterion for this loading event is that the accident condition MPC Design Pressure (Table 2.3.5) is not exceeded.

- Wind

Wind is a common environmental condition which is characterized by varying magnitude and direction at all terrestrial locations. Because wind is an ever changing condition, steady state conditions cannot be expected to be reached in the HI-STORM UMAX storage system which has a substantial thermal inertia. However, it is necessary to ensure that the heat rejection function of the system is not significantly impaired by wind. To make this determination, the thermal performance of the system is quantified under a sustained wind (assumed to be of sufficient duration so that steady state conditions are reached) at typical velocities of in the range of 0 to 10 MPH. Sustained wind in a fixed direction for an extended period is not a plausible environmental occurrence event. Because in NUREG-1536, this condition is not specified as one requiring evaluation, this evaluation performed in this FSAR, exceeds the scope specified in NUREG-1536.

- Burial Under Debris

The HI-STORM UMAX vent screens are engineered to prevent accumulation of dust and debris. Siting of the ISFSI pad shall ensure that the storage location is not located over shifting soil.

However, it may be possible for wind borne debris or debris from a collapsing structure in the vicinity of the ISFSI to block the inlet plenum. If burial of an extensive portion of the VVM is a credible event for an ISFSI, then a thermal analysis to analyze the effect of such an accident condition shall be performed for the site using the analysis methodology presented in Chapter 4. The duration of the burial-under-debris scenario will be based on the ISFSI owner's emergency preparedness program. The following acceptance criteria apply to the burial-under-debris accident event:

The fuel cladding temperature shall not exceed the ISG-11, Revision 3 [2.4.6] temperature limits.

The internal pressure in the MPC cavity shall not exceed the accident condition design pressure limit in Table 2.3.5.

The burial-under-debris analysis will be performed if applicable, for the site-specific conditions and heat loads.

- Extreme Environmental Temperature

The HI-STORM UMAX System must withstand extreme environmental temperatures. The extreme accident level temperature is specified in Table 2.3.6. The extreme accident level temperature is assumed to occur with steady-state insolation. This temperature is assumed to persist for a sufficient duration to allow the system to reach steady-state temperatures. As is standard for ventilated systems, extreme environmental temperature is a 3-day average for the ISFSI site.

- Design Basis Fire

The possibility of a fire accident near an ISFSI site is considered to be extremely remote due to the absence of significant combustible materials. The only credible concern is related to a transport vehicle fuel tank fire engulfing the loaded HI-STORM UMAX VVM or loaded HI-TRAC VW transfer cask while it is being moved to the ISFSI.

The HI-TRAC and HI-STORM UMAX VVM must withstand temperatures due to a fire event. The HI-STORM UMAX fire accidents for storage are conservatively postulated to be the result of the spillage and ignition of 50 gallons of combustible transporter fuel (identical to the HI-STORM 100 docket). The HI-STORM UMAX lid external surfaces are considered to receive an incident radiation and forced convection heat flux from the fire. The temperature of fire is assumed to be 1475° F in accordance with 10CFR71.73.

The HI-STORM UMAX System must withstand fire accident without exceeding allowable temperature and pressure limits specified for the accident condition.

- Flood

A potentially severe flood event could happen during the storage period. In that event, the water could enter the inlet ducts and block portion or the entire cooling air flow passageway at the bottom of the cavity, which reduces the air flow ventilating through VVM and causes an elevation of the fuel cladding temperature and system component temperatures.

Chapter 4 contains the appropriate thermal analysis which serves to establish the ISFSI surveillance program in the CoC for the system.

- Jacket Water Loss

The fuel cladding and MPC boundary integrity should be evaluated under a postulated (non-mechanistic) complete loss of water from the HI-TRAC VW water jacket. The HI-TRAC VW must withstand the jacket water loss accident without exceeding allowable temperature and pressure limits specified for the accident condition.

2.5.1 The Forced Helium Dehydrator

The Forced Helium Dehydrator (FHD) is a HI-STORM system ancillary used to remove the remaining moisture in the MPC cavity after all of the water that can practically be removed through the drain line using a hydraulic pump or an inert gas has been expelled in the water blow-down operation. The FHD system is required to be used for MPCs loaded with one or more high burnup fuel assemblies and generating greater than threshold heat loads defined in Chapter 4. The FHD method of moisture removal is optional for all other MPCs.

Expelling the water from the MPC using a conventional pump or a water displacement method using inert gas would remove practically all of the contained water except for the small quantity remaining on the MPC baseplate below the bottom of the drain line and an even smaller adherent amount wetting the internal surfaces. A skid-mounted, closed loop dehydration system will be used to remove the residual water from the MPC such that the partial pressure of the trace quantity of water vapor in the MPC cavity gas is brought down to ≤ 3 torr. The FHD system, engineered for this purpose, utilizes helium gas as the working substance. In comparison to the classical vacuum drying process, the FHD maintains the fuel cladding at a relatively low temperature (substantially below the permissible cladding temperature in ISG-11 Rev 3) which insures that the pressure inside the cladding and hence its hoop stress remains at a moderate level. The design features of the FHD are described in an array of USPTO-issued patents available in the open literature as follows:

- Patent Number 7,096,600B2, Forced Helium Dehydrator, dated August 29, 2006
- Patent Number 7,210,247B2, Forced Gas Flow Canister Dehydration, dated May 1, 2007
- Patent Number 7,707,741B2, Dew Point Temperature Based Canister Dehydration, dated May 4, 2010
- Patent Number 8,067,659B2, Method of Removing Radioactive Materials from Submerged State and/or Preparing Spent Nuclear Fuel for Dry Storage, dated November 29, 2011
- Patent Number 8,266,823B2, Method and Apparatus for Dehydrating High Level Waste Based on Dew Point Temperature Measurements, dated September 18, 2012

2.5.1.1 FHD Design Criteria

The Design of the FHD has been standardized for all HI-STORM/HI-STAR MPCs using the design criteria set forth in the following which have remained unchanged since their first adoption in the HI-STORM 100 FSAR over a decade ago. These design criteria are intended to ensure that design and operation of the FHD system will remove bulk moisture and lower the partial pressure of the residual vapor in the MPC cavity to ≤ 3 torr if the circulating gas reaches the specified temperature or dew point value and duration criteria. The FHD system is designed to ensure that during normal operation (i.e., excluding startup and shutdown ramps) the following criteria are met:

i. The temperature of helium gas in the MPC shall be at least 15°F higher than the saturation temperature at coincident pressure. The operating pressure shall be selected to maximize the mass flow rate within the constraints of the pressure rating of the associated pressure parts.

ii. The recirculation rate of helium shall be sufficiently high (minimum hourly throughput equal to ten times the nominal helium mass backfilled into the MPC for fuel storage operations) so as to produce a turbulated flow regime in the MPC cavity.

iii. The partial pressure of the water vapor in the MPC cavity will not exceed 3 torr. This limit will be met if the gas temperature at the de-moisturizer outlet is verified by measurement to remain $\leq 21°F$ for ≥ 30 minutes or if the dew point of the gas exiting the MPC is verified by measurement to remain $\leq 22.9°F$ for ≥ 30 minutes.

The design of the FHD ancillary and the thermal- hydraulic simulations to insure that it would meet the above design criteria were carried out at the time of its introduction in the HI-STORM 100 system in 2001. A Holtec proprietary report titled "Forced Helium Dehydrator Sourcebook" Holtec Report HI-2022966 documents the design and confirmatory analyses on the FHD. As required by the HI-STORM 100 FSAR (in its Appendix 2.B), the first FHD manufactured and deployed in MPC drying was subjected to acceptance testing. Since then, over 20 nuclear units have opted for the FHD method of drying. Like all ancillaries, the entire body of information on the design, manufacturing and testing of the FHDs is maintained for archival reference in Holtec's quality assurance system. The FHD has been designated not-important-to-safety (NITS) because its malfunction cannot precipitate a rise in the stored fuel's reactivity, cause increase in the cladding temperature above design limits, cause a significantly elevated dose rate to the crew or lead to release of radioactive matter to the environment. Instrumentation used to ensure that the licensed conditions for operation are met is calibrated by vendors who are on the Holtec Approved Vendors List for Important-to-Safety and Safety Related equipment.

2.6 MATERIALS, 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 VVMs. 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 2.6.1.

The ASME Boiler and Pressure Vessel Code (ASME Code) Section III, Subsection NF Class 3 [2.6.1], is the applicable code to determine stress limits for the metallic structural components of the VVM when required by the acceptance criteria listed in Tables 2.4.1 and 2.4.2. The permitted material types for long-term use are listed in Table 2.6.2. Manufacturing requirements are set down in licensing and design drawings.

Section III Subsection NB of the ASME Boiler and Pressure Vessel Code [2.6.8], is the governing code for the structural design of the MPC. The alternatives to the ASME Code, Section III Subsection NB, applicable to the MPC in Docket Nos. 72-1032 are also applicable to the MPC in the HI-STORM UMAX System, as documented in Table 2.6.5.

The stress limits of ASME Section III Subsection NF [2.6.10] are applied to the HI-TRAC structural parts where the applicable loading is designated as a code service condition.

The fuel basket, made of Metamic-HT, is subject to the requirements in Appendix 1.B of HI-STORM FW FSAR and is designed to a specific (lateral) deformation limit of its walls under accident conditions of loading (credible and non-mechanistic) (see Table 2.2.11 of HI-STORM FW FSAR). The basis for the lateral deflection limit in the active fuel region, θ, is provided in [2.6.9].

ACI-318(2005) [2.6.2] is the applicable reference code to establish applicable limits on unreinforced concrete (in the Closure Lid), which is subject to secondary structural loadings. Chapter 8 contains the design, construction, and testing criteria applicable to the plain concrete in the VVM's Closure Lid. The load combinations applicable to the ISFSI pad and the Enclosure Wall, pursuant to ACI-318(05) are summarized in Table 2.4.3 Applicable sections of ACI-318(2005) should be used in the design of the ISFSI pad and the SFP. Reference [2.6.5] should be used as a secondary guidance document in designing the ISFSI pad. The applicable provisions of [2.6.6] are invoked as an aid in defining the subgrade space that should be modeled in the soil/structure interaction simulation.

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 in evaluating the suitability of a candidate ISFSI location.

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 UMAX VVM, using the guidelines of NUREG-CR/6407 [2.6.4], are provided in the Licensing drawing package.

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 s would meet the intent of §72.24(c), §72.120(a) and §72.236(b). As required by Holtec's QA Program docketed with the NRC (Docket Number 71-0784), 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 structures (such as the SFP), 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.

Table 2.6.1

REFERENCE ASME CODE PARAGRAPHS FOR VVM PRIMARY LOAD BEARING PARTS

	Item	**Code Paragraph [2.6.1]**	**Explanation and Applicability**
1.	Definition of primary and secondary members	NF-1215	-
2.	Jurisdictional boundary	NF-1133	The VVM's jurisdictional boundary is defined by the bottom surface of the SFP, the top surface of the ISFSI pad and the SES side surfaces.
3.	Certification of material(structural)	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 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

Table 2.6.1

REFERENCE ASME CODE PARAGRAPHS FOR VVM PRIMARY LOAD BEARING PARTS

	Item	**Code Paragraph [2.6.1]**	**Explanation and Applicability**
			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	-

Table 2.6.2

PRINCIPAL MATERIALS, THEIR FUNCTION & ITS CATEGORIES FOR VVM

Item	Primary Function	Part	ITS Category	Material
1.	Shielding	Closure Lid Concrete	C	Shielding Concrete
2.	Shielding	Closure Lid Steel	C	ASTM A516, Gr. 70, A515 Gr. 70 or equivalent
3.	Structural	Container Shell, Bottom Plate and Container Flange	C	ASTM A516, Gr. 70, A515 Gr. 70 or equivalent
4.	Thermal	Insulation	C	Commercial
5.	Thermal	Inlet/Outlet Vent Screens and associated hardware	NITS	Carbon steel, stainless steel, aluminum, polymeric fabric or commercial
6.	Thermal	Outlet Vent Cover and associated hardware	NITS	Carbon steel, stainless steel, aluminum or commercial
7.	Rain Protection	Vent Flue	NITS	Aluminum
8.	Structural	MPC Bearing Pad	C	Carbon Steel (with stainless steel liners)
9.	Shielding and Physical Protection	ISFSI Pad	C	Reinforced Concrete Per ACI-318 (2005)
10.	Shielding and Physical Protection	ISFSI Pad Subgrade Surrounding the VVMs	C	Self-hardening Engineered Subgrade (SES)
11.	Structural Support	Support Foundation Pad (SFP)	C	Reinforced Concrete per ACI-318 (2005)
12.	Barrier against water ingress in the ISFSI space and/or as the "form" for SES placement	Enclosure wall (optional)	NITS	Concrete or another form of moisture resistant barrier

Table 2.6.3

CRITICAL CHARACTERISTICS OF MATERIALS REQUIRED FOR SAFETY EVALUATION OF STORAGE AND TRANSPORT SYSTEMS

Item	**Property**	**Type (Note 1)**	**Purpose**	**Bounding Acceptable Limit**
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.	Insulation Thermal conductivity (maximum averaged value in the range of ambient to maximum service temperature, t_{max})	T	To reduce the transmission of decay heat from the MPC to the down-coming cool air in the annular gap between divider shell and container shell	Max.
8.	Thermal conductivities for basket (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.
9.	Minimum Emissivity	T	To ensure that the thermal calculations are performed conservatively	Min.
10.	Specific Gravity	S (and R)	To compute weight of the component (and shielding effectiveness)	Max. (and Min.)
11.	Thermal Expansion Coefficient	T (and S)	To compute the change in basket dimension due to temperature (and thermal stresses)	Min. (and Max.)
12.	Boron-10 Content	R	To control reactivity	Min.

Note 1: **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

Table 2.6.4

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.
	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.
	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 2.6.5

LIST OF ASME CODE ALTERNATIVES FOR MULTI-PURPOSE CANISTERS (MPCS)

MPC Enclosure Vessel	Subsection NCA	General Requirements. Requires preparation of a Design Specification, Design Report, Overpressure Protection Report, Certification of Construction Report, Data Report, and other administrative controls for an ASME Code stamped vessel.	Because the MPC is not an ASME Code stamped vessel, none of the specifications, reports, certificates, or other general requirements specified by NCA are required. In lieu of a Design Specification and Design Report, the HI-STORM FSAR includes the design criteria, service conditions, and load combinations for the design and operation of the MPCs as well as the results of the stress analyses to demonstrate that applicable Code stress limits are met. Additionally, the fabricator is not required to have an ASME-certified QA program. All important-to-safety activities are governed by the NRC-approved Holtec QA program. Because the cask components are not certified to the Code, the terms "Certificate Holder" and "Inspector" are not germane to the manufacturing of NRC-certified cask components. To eliminate ambiguity, the responsibilities assigned to the Certificate Holder in the Code, as applicable, shall be interpreted to apply to the NRC Certificate of Compliance (CoC) holder (and by extension, to the component fabricator) if the requirement must be fulfilled. The Code term "Inspector" means the QA/QC personnel of the CoC holder and its vendors assigned to oversee and inspect the manufacturing process.

Table 2.6.5

LIST OF ASME CODE ALTERNATIVES FOR MULTI-PURPOSE CANISTERS (MPCS)

MPC Enclosure Vessel	NB-1100	Statement of requirements for Code stamping of components.	MPC Enclosure Vessel is designed and will be fabricated in accordance with ASME Code, Section III, Subsection NB to the maximum practical extent, but Code stamping is not required.
MPC basket supports and lift lugs	NB-1130	NB-1132.2(d) requires that the first connecting weld of a non-pressure retaining structural attachment to a component shall be considered part of the component unless the weld is more than 2t from the pressure retaining portion of the component, where t is the nominal thickness of the pressure retaining material. NB-1132.2(e) requires that the first connecting weld of a welded nonstructural attachment to a component shall conform to NB-4430 if the connecting weld is within 2t from the pressure retaining portion of the component.	The lugs that are used exclusively for lifting an empty MPC are welded to the inside of the pressure-retaining MPC shell, but are not designed in accordance with Subsection NB. The lug-to-Enclosure Vessel Weld is required to meet the stress limits of Reg. Guide 3.61 in lieu of Subsection NB of the Code.
MPC Enclosure Vessel	NB-2000	Requires materials to be supplied by ASME-approved material supplier.	Materials will be supplied by Holtec approved suppliers with Certified Material Test Reports (CMTRs) in accordance with NB-2000 requirements.

Table 2.6.5

LIST OF ASME CODE ALTERNATIVES FOR MULTI-PURPOSE CANISTERS (MPCS)

MPC Enclosure Vessel	NB-3100 NF-3100	Provides requirements for determining design loading conditions, such as pressure, temperature, and mechanical loads.	These requirements are subsumed by the HI-STORM FW FSAR, serving as the Design Specification, which establishes the service conditions and load combinations for the storage system.
MPC Enclosure Vessel	NB-4120	NB-4121.2 and NF-4121.2 provide requirements for repetition of tensile or impact tests for material subjected to heat treatment during fabrication or installation.	In-shop operations of short duration that apply heat to a component, such as plasma cutting of plate stock, welding, machining, and coating are not, unless explicitly stated by the Code, defined as heat treatment operations.
MPC Enclosure Vessel	NB-4220	Requires certain forming tolerances to be met for cylindrical, conical, or spherical shells of a vessel.	The cylindricity measurements on the rolled shells are not specifically recorded in the shop travelers, as would be the case for a Code-stamped pressure vessel. Rather, the requirements on inter-component clearances (such as the MPC-to-transfer cask) are guaranteed through fixture-controlled manufacturing. The fabrication specification and shop procedures ensure that all dimensional design objectives, including inter-component annular clearances are satisfied. The dimensions required to be met in fabrication are chosen to meet the functional requirements of the dry storage components. Thus, although the post-forming Code cylindricity requirements are not evaluated for compliance directly, they are indirectly satisfied (actually exceeded) in the final manufactured components.

Table 2.6.5

LIST OF ASME CODE ALTERNATIVES FOR MULTI-PURPOSE CANISTERS (MPCS)

MPC Enclosure Vessel	NB-4122	Implies that with the exception of studs, bolts, nuts and heat exchanger tubes, CMTRs must be traceable to a specific piece of material in a component.	MPCs are built in lots. Material traceability on raw materials to a heat number and corresponding CMTR is maintained by Holtec through markings on the raw material. Where material is cut or processed, markings are transferred accordingly to assure traceability. As materials are assembled into the lot of MPCs being manufactured, documentation is maintained to identify the heat numbers of materials being used for that item in the multiple MPCs being manufactured under that lot. A specific item within a specific MPC will have a number of heat numbers identified as possibly being used for the item in that particular MPC of which one or more of those heat numbers (and corresponding CMTRS) will have actually been used. All of the heat numbers identified will comply with the requirements for the particular item.
MPC Lid and Closure Ring Welds	NB-4243	Full penetration welds required for Category C Joints (flat head to main shell per NB-3352.3)	MPC lid and closure ring are not full penetration welds. They are welded independently to provide a redundant seal.
MPC Closure Ring, Vent and Drain Cover Plate Welds	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required.	Root (if more than one weld pass is required) and final liquid penetrant examination to be performed in accordance with NB-5245. The closure ring provides independent redundant closure for vent and drain cover plates. Vent and drain port cover plate welds are helium leakage tested.
MPC Lid to	NB-5230	Radiographic (RT) or	Only progressive liquid penetrant

Table 2.6.5

LIST OF ASME CODE ALTERNATIVES FOR MULTI-PURPOSE CANISTERS (MPCS)

Shell Weld		ultrasonic (UT) examination required.	(PT) examination is permitted. PT examination will include the root and final weld layers and each approx. 3/8" of weld depth.
MPC Enclosure Vessel and Lid	NB-6111	All completed pressure retaining systems shall be pressure tested.	The MPC vessel is seal welded in the field following fuel assembly loading. The MPC vessel shall then be pressure tested as defined in Chapter 10. Accessibility for leakage inspections preclude a Code compliant pressure test. All MPC enclosure vessel welds (except closure ring and vent/drain cover plate) are inspected by volumetric examination. MPC shell and shell to baseplate welds are subject to a fabrication helium leak test prior to loading. The MPC lid-to-shell weld shall be verified by progressive PT examination. PT must include the root and final layers and each approximately 3/8 inch of weld depth. The inspection results, including relevant findings (indications) shall be made a permanent part of the user's records by video, photographic, of other means which provide an equivalent record of weld integrity. The video or photographic records should be taken during the final interpretation period described in ASME Section V, Article 6, T-676. The vent/drain cover plate and the closure ring welds are confirmed by liquid penetrant examination. The inspection of the weld must be performed by qualified personnel and shall meet the acceptance

Table 2.6.5
LIST OF ASME CODE ALTERNATIVES FOR MULTI-PURPOSE CANISTERS (MPCS)

			requirements of ASME Code Section III, NB-5350.
MPC Enclosure Vessel	NB-7000	Vessels are required to have overpressure protection.	No overpressure protection is provided. Function of MPC enclosure vessel is to contain radioactive contents under normal, off-normal, and accident conditions of storage. MPC vessel is designed to withstand maximum internal pressure considering 100% fuel rod failure and maximum accident temperatures.
MPC Enclosure Vessel	NB-8000	States requirements for nameplates, stamping and reports per NCA-8000.	The HI-STORM FW System is to be marked and identified in accordance with 10CFR71 and 10CFR72 requirements. Code stamping is not required. QA data package to be in accordance with Holtec approved QA program.

2.7 SAFETY PROTECTION SYSTEMS

2.7.1 General

The HI-STORM UMAX System is engineered to provide for the safe long-term storage of spent nuclear fuel (SNF). The HI-STORM UMAX will withstand all normal, off-normal, and postulated accident conditions without release of radioactive material or excessive radiation exposure to workers or members of the public. Special considerations in the design have been made to ensure long-term integrity and confinement of the stored SNF throughout all cask normal and off-normal operating conditions and its retrievability for further processing or ultimate disposal in accordance with 10 CFR 72.122(l) and ISG-2 [2.7.1].

The HI-STORM UMAX 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.

2.7.2 Protection by Multiple Confinement Barriers and Systems

a. Confinement Barriers and Systems

The confinement of the spent fuel is provided by the MPC's Enclosure Vessel. .

Contamination on the outside of the MPC from the fuel pool water is minimized by preventing contact, removing the contaminated water, and decontamination. An inflatable seal in the annular gap between the MPC and HI-TRAC, and the elastomer seal in the HI-TRAC bottom lid (see Chapter 9 of the HI-STORM FW FSAR) prevent the fuel pool water from contacting the exterior of the MPC and interior of the HI-TRAC VW while submerged for fuel loading.

The MPC is a seal welded enclosure which provides the confinement boundary. The MPC confinement boundary is defined by the MPC baseplate, MPC shell, MPC lid, closure ring, port cover plates, and associated welds.

The MPC confinement boundary has been designed to withstand any postulated off-normal operations, accident conditions, or external natural phenomena. Redundant closure of the MPC is provided by the MPC closure ring welds which provide a second barrier to the release of radioactive material from the MPC internal cavity. Therefore, no monitoring system for the confinement boundary is required.

Confinement is discussed further in Chapter 7 of FW FSAR. MPC field weld examinations, helium leakage testing of the port cover plate welds, and pressure testing are performed to verify the confinement function. Fabrication inspections and tests are also performed, as discussed in Chapter 10 of the HI-STORM FW FSAR, to verify the integrity of the confinement boundary.

b. Cask Cooling

To ensure that an effective passive heat removal capability exists for long-term satisfactory performance, several thermal design features are incorporated in the storage system. They are as follows:

The MPC fuel basket is formed by a honeycomb structure of Metamic-HT plates which allows the unimpeded conduction of heat from the center of the basket to the periphery. The MPC cavity is equipped with the capability to circulate helium internally by natural buoyancy effects and transport heat from the interior region of the canister to the peripheral region (Holtec Patent 5,898,747).

The MPC confinement boundary ensures that the inert gas (helium) atmosphere inside the MPC is maintained during normal, off-normal, and accident conditions of storage and transfer. The MPC confinement boundary maintains the helium confinement atmosphere below the design temperatures and pressures stated in Table 2.3.7 and Table 2.3.5, respectively.

The MPC thermal design maintains the fuel rod cladding temperatures below the ISG-11 limits such that fuel cladding does not experience degradation during the long term storage period.

The HI-STORM UMAX is optimally designed, with multiple cooling passages and suitably sized flow annuli, which maximize air flow by ensuring a turbulent flow regime at Design Basis heat loads.

As shown in the licensing drawing package, cooling air to each MPC storage cavity is provided by four independent ducts. Thus, there is a significant level of redundancy in the cooling air delivery system for the HI-STORM UMAX.

As can be observed from the licensing drawings, the air inlet locations are separated from the outlet vent by a significant lateral and vertical distance. This design feature ensures that there is minimal mixing of cold and heated air in the storage system. Calculations summarized in Chapter 4 show that the heat rejection performance of the system is stable under varying wind speed.

2.7.3 Protection by Equipment and Instrumentation Selection

a. Equipment

The HI-STORM UMAX System may include use of ancillary or support equipment for ISFSI implementation. Ancillary equipment and structures utilized at the HI-STORM UMAX ISFSI may be broken down into two broad categories, namely Important-to-Safety (ITS) ancillary equipment and Not Important to Safety (NITS) ancillary equipment. NUREG/CR-6407 provides guidance for the determination of a component's safety classification [2.6.4].

The only ancillary equipment used in conjunction with the MPC loading at an ISFSI consists of the Mating Device (a patented design, see Table 1.3.2) and the load handling device such as the cask transporter.

The MPC transfer is carried out by actuating the Mating Device and moving the MPC vertically to the cylindrical cavity of the recipient VVM cavity. The mating device is actuated by removing the bottom lid of the HI-TRAC transfer cask. The device utilized to lift the HI-TRAC transfer cask to place it on the VVM and to vertically transfer the MPC may be of stationary or mobile type, but it must have redundant drop protection features. The cask transporter can serve as the load handling device.

b. Instrumentation

As a consequence of the passive nature of the HI-STORM UMAX System, Important-to-Safety instrumentation is not necessary. No instrumentation is required or provided for HI-STORM UMAX storage operations, other than normal security service instruments and dosimeters.

However, in lieu of performing the periodic inspection of the HI-STORM UMAX VVM vent screens, temperature elements may be installed inside the VVM outlet duct and below the bottom of outlet screen to continuously monitor the air temperature. If the temperature elements and associated temperature monitoring instrumentation are used as the sole means of surveillance then they shall be designated as Important-to-Safety.

2.8 NUCLEAR CRITICALITY SAFETY

The criticality safety criteria stipulates that the effective neutron multiplication factor, k_{eff}, including statistical uncertainties and biases, is less than 0.95 for all postulated arrangements of fuel within the cask under all credible conditions.

2.8.1 Control Methods for Prevention of Criticality

The control methods and design features used to prevent criticality for all MPC configurations are the following:

- Fuel basket constructed of neutron absorbing material with no potential of detachment, delamination or degradation in long term inert environment of the MPC.
- Favorable geometry provided by the MPC fuel basket.
- A high B-10 concentration (50% greater than the concentration used in the existing state-of-the art designs certified under 10CFR72) leads to a lower reactivity level under all operating scenarios.

Administrative controls shall be used to ensure that fuel placed in the HI-STORM UMAX System meets the requirements described in Chapters 2. All appropriate criticality analyses are presented in Chapter 6 of the HI-STORM FW FSAR.

2.8.2 Error Contingency Criteria

Provision for error contingency is built into the criticality analyses performed in Chapter 6. Because biases and uncertainties are explicitly evaluated in the analysis, it is not necessary to introduce additional contingency for error.

2.8.3 Verification Analyses

In Chapter 6 of the HI-STORM FW FSAR, critical experiments are selected which reflect the design configurations. These critical experiments are evaluated using the same calculation methods, and a suitable bias is incorporated in the reactivity calculation.

2.9 RADIOLOGICAL PROTECTION

a. Access Control

As required by 10CFR72, uncontrolled access to the ISFSI is prevented through physical protection means. A security fence surrounded by a physical barrier fence with an appropriate locking and monitoring system is a standard approach to limit access if the ISFSI is located outside the controlled area. The details of the access control systems and procedures, including division of the site into radiation protection areas, will be developed by the licensee (user) of the ISFSI utilizing the HI-STORM UMAX System.

b. Shielding

The objective of shielding is to assure that radiation dose rates at key locations are as low as practical in order to maintain occupational doses to operating personnel As Low As Reasonably Achievable (ALARA) and to meet the requirements of 10 CFR 72.104 and 10 CFR 72.106 for dose at the controlled area boundary (see Table 2.9.1).

The HI-STORM UMAX is designed to limit dose rates in accordance with 10CFR72.104 and 10CFR72.106 which provide radiation dose limits for any real individual located at or beyond the nearest boundary of the controlled area. The individual must not receive doses in excess of the limits given in Table 2.9.1 for normal, off-normal, and accident conditions.

Three locations are of particular interest in the storage mode:

- immediate vicinity of the cask
- restricted area boundary
- controlled area (site) boundary

Dose rates in the immediate vicinity of the loaded VVM are important in consideration of occupational exposure. Conservative evaluations of dose rate have been performed and are described in Chapter 5 based on Reference PWR fuel.

Consistent with 10 CFR 72, there is no single dose rate limit established for the HI-STORM UMAX System. Compliance with the regulatory limits on occupational and controlled area doses is performance-based, as demonstrated by dose monitoring performed by each cask user.

Design objective dose rates for the HI-STORM UMAX system are presented in Table 2.9.2.

Because of the passive nature of the HI-STORM UMAX System, human activity related to the system after deployment in storage is infrequent and of short duration. Personnel exposures due to operational and maintenance activities are discussed in Chapter 11, wherein measures to reduce occupational dose are also discussed. The estimated occupational doses for personnel provided in Chapter 11 comply with the requirements of 10CFR20. As discussed in Chapter 11, the HI-STORM UMAX System has been configured to minimize both the site boundary dose in storage and occupational dose during short-term operations to the maximum extent possible.

The analyses and discussions presented in Chapters 5, 9, and 11 demonstrate that the HI-STORM UMAX System is capable of meeting the radiation dose limits set down in Table 2.9.1.

c. Radiological Alarm System

The HI-STORM UMAX does not require a radiological alarm system. There are no credible events that could result in release of radioactive materials from the system. Furthermore, direct radiation exposure from the ISFSI is subject to monitoring by the plant's existing dose monitoring system.

Table 2.9.1 RADIOLOGICAL SITE BOUNDARY REQUIREMENTS	
MINIMUM DISTANCE TO BOUNDARY OF CONTROLLED AREA (m)	100
NORMAL AND OFF-NORMAL CONDITIONS:	
-Whole Body (mrem/yr)	25
-Thyroid (mrem/yr)	75
-Any Other Critical Organ (mrem/yr)	25
DESIGN BASIS ACCIDENT:	
-TEDE (rem)	5
-DDE + CDE to any individual organ or tissue (other than lens of the eye) (rem)	50
-Lens dose equivalent (rem)	15
-Shallow dose equivalent to skin or any extremity (rem)	50

Table 2.9.2

DESIGN OBJECTIVE DOSE RATES FOR HI-STORM UMAX

Area of Interest	Dose Rate (mrem/hr)
Inlet Vents	80
Inlet Plenum Region	150
Outlet Vent	60

2.10 FIRE AND EXPLOSION PROTECTION

There are no combustible or explosive materials associated with the HI-STORM UMAX System. Combustible materials will not be stored within the HI-STORM UMAX ISFSI. However, for conservatism, a hypothetical fire accident has been analyzed in Chapter 4 as a bounding condition for HI-STORM UMAX System. The evaluation of the HI-STORM UMAX System fire accident is discussed in Chapter 12.

Explosive material will not be stored within an ISFSI. Small overpressures may result from accidents involving explosive materials which are stored or transported in the vicinity of the site. Explosion as an accident loading condition has been considered in Chapter 12.

2.11 DECOMMISSIONING CONSIDERATIONS

Efficient decommissioning of the ISFSI is a paramount objective of the HI-STORM UMAX System. The HI-STORM UMAX System is ideally configured to facilitate rapid, safe, and economical decommissioning of the storage site. As discussed below, Holtec International has taken appropriate steps to ensure that the necessary equipment designs and certifications shall be available to the user of the HI-STORM UMAX System to expeditiously decommission the ISFSI at the end of the storage facility's required service life.

Towards that end, the loaded MPC has been designed with the objective to transport it in a HI-STAR 190 transportation cask (Figure 2.11.1) Since the loaded MPC is a self-contained Waste Package, no further handling of the SNF stored in the MPC will be required prior to transport to a licensed centralized storage facility or repository.

The MPC which holds the SNF assemblies is engineered to be suitable as a waste package for permanent internment in a deep Mined Geological Disposal System (MGDS). The materials of construction permitted for the MPC are known to be highly resistant to severe environmental conditions. No carbon steel, paint, or coatings are used or permitted in the MPC in areas where they could be exposed to spent fuel pool water or the ambient environment. Therefore, the SNF assemblies stored in the MPC do not need to be removed. However, to ensure a practical, feasible method to defuel the MPC, the top of the MPC is equipped with sufficient gamma shielding and markings locating the drain and vent locations to enable semiautomatic (or remotely actuated) severing of the MPC closure ring to provide access to the MPC vent and drain. The circumferential welds of the MPC closure lid can be removed by semiautomatic or remotely actuated means, providing access to the SNF.

Likewise, the VVM consists of steel and concrete rendering it suitable for permanent burial. Alternatively, the MPC can be removed from the VVM, and the latter reused for storage of other MPCs. In either case, the VVM would be expected to have no interior or exterior radioactive surface contamination. Any neutron activation of the steel and concrete is expected to be extremely small, and the assembly would qualify as Class A waste in a stable form based on definitions and requirements in 10CFR61.55. As such, the material would be suitable for burial in a near-surface disposal site as Low Specific Activity (LSA) material.

If the SNF needs to be removed from the MPC before it is placed into the MGDS, the MPC interior metal surfaces can be decontaminated using existing mechanical or chemical methods to allow for its disposal. This will be facilitated by the smooth metal surfaces designed to minimize crud traps. After the surface contamination is removed, the MPC radioactivity will be diminished significantly, allowing near-surface burial or secondary applications at the licensee's facility.

The HI-STORM UMAX ISFSI will contain MPCs that are readily removable from their storage cavities. The ISFSI will be decommissioned only after all MPCs have been removed from the storage cavities. Removing the Divider Shell does not require any weld removal or unfastening of bolts. 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. 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 off. In the aggregate, it is estimated that less material will need to be disposed off to decommission a VVM ISFSI in comparison to an ISFSI containing aboveground VVMs.

Finally, the activation estimate in Table 2.4.1 of [2.6.3] for the aboveground VVM inner shell is adopted herein (conservatively) for the VVM steel shell enclosure.

Due to the design of the HI-STORM UMAX System, no residual contamination is expected to be left behind on the concrete ISFSI pad. The base pad, fence, and peripheral utility structures will require no decontamination or special handling after the last VVM is removed.

The long-lived radio-nuclides produced by the irradiation of the HI-STORM UMAX System components are listed in Table 2.11.1. The activation of the HI-STORM UMAX components shall be limited to a cumulative activity of 10 Ci per cubic meter before decommissioning and disposal of the activated item can be carried out.

Table 2.11.1

PRINCIPAL LONG-LIVED ISOTOPES PRODUCED DURING IRRADIATION OF THE HI-STORM UMAX COMPONENTS

Nuclide	MPC Stainless Steel	HI-STORM Steel	HI-STORM Concrete
^{54}Mn	X	X	X
^{55}Fe	X	X	X
^{59}Ni	X	-	-
^{60}Co	X	-	-
^{63}Ni	X	-	-
^{39}Ar	-	-	X
^{41}Ca	-	-	X

Withheld in Accordance with 10 CFR 2.390

Figure 2.11.1: HI-STAR 190 Transportation Overpack and MPC Shown in Exploded, Cut-Away View

2.12 REGULATORY COMPLIANCE

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

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);

A clear identification of VVM structural parts subject to a fully articulated design subject to certification under 10CFR72 and of interfacing structures;

The required set of limiting critical characteristics of interfacing ISFSI Structures to ensure that the VVM will render its intended function under all design basis scenarios of operation; and

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.

It is noted that the requirements of 10CFR72 do not preclude the use of an underground storage system such as the HI-STORM UMAX. The underground VVM design, 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.

2.13 REFERENCES

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CHAPTER 3: STRUCTURAL EVALUATION[1]

3.0 OVERVIEW

In this chapter, the structural safety evaluation of the HI-STORM UMAX Vertical Ventilated Module (VVM) system is performed pursuant to the guidelines of NUREG-1536. The organization of technical information in this chapter mirrors the format and content of Regulatory Guide 3.61 to the extent applicable. The objective of the structural analyses is to ensure that the integrity of the HI-STORM UMAX system is maintained under the normal, off-normal and extreme environmental conditions and accident events listed in Chapter 2. The design basis information contained in the previous two chapters and in this chapter provides the necessary data to permit all needed structural evaluations for demonstrating compliance with the requirements of 10CFR72.24. To facilitate regulatory review, the assumptions and conservatisms inherent in the analyses are identified along with a concise description of the analytical methods, models, and acceptance criteria. A summary of the system's ability to maintain its structural integrity under other effects that may contribute to structural failure, such as fatigue, buckling, and non-ductile fracture is also provided. (An evaluation of the suitability of the materials used in the HI-STORM UMAX VVM system under both slow acting (degenerative) and fast acting (precipitous) loads is presented in Chapter 8.)

The VVM, consisting of the CEC and the Closure Lid, serves as the storage space for the loaded MPC. The CEC is a weldment of the Container Shell, Container Flange, Bottom Plate, Lower MPC Guides, and MPC Bearing Pads. The Closure Lid is a weldment of structural steel encasing plain concrete and arranged to provide an appropriate outlet passage for the heated air issuing from the storage cavity. An insulated Divider Shell with Upper MPC Guides is situated within the CEC and restrained by the Lower MPC Guides at the bottom and by the Container Flange at the top. These individual components are collectively referred to as VVM Components. Interfacing structures that surround and support the VVM, as well as proximate structures, which are collectively referred to as ISFSI Structures, are explained in Chapter 2. Section 1.2 contains a complete description of the VVM components and ISFSI Structures (accompanied by appropriate figures) and their respective functions within the HI-STORM UMAX ISFSI. The essential design details of both the VVM Components and the ISFSI Structures are set down in the Licensing Drawing in Section 1.5. The design basis loadings for the facility are provided in Chapter 2. The applicable codes, standards, and practices governing the structural analysis of the HI-STORM UMAX module, as well as the design criteria, are also presented in Chapter 2. Throughout this chapter, 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, which are 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)

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[1] The analyses summarized in this chapter focus on the governing canisters out of the population of MPCs listed in Table 1.2.1. Specifically, this chapter supports the certification of only MPC-37 and MPC-89 at this time. The analyses reported for smaller canisters are for reference purposes only.

developed under the factored load combination.

The following information germane to safety factors is important to understanding the safety case presented in this chapter:

1. All safety factors are dimensionless.

2. The minimum permissible value of any safety factor to support a positive safety conclusion is 1.0. However, to permit an occasional 10CFR72.48 evaluation that may be required, the HI-STORM UMAX system is designed to ensure that all safety factors in the initial design basis calculations are at least 1.1.

The objective of the structural analyses is to ensure that the integrity of the HI-STORM UMAX system is maintained under all credible loadings under normal, off-normal and extreme environmental conditions as well all credible accident events. Specifically, the design basis information contained in the previous two chapters and in this chapter provides the necessary data to permit all needed structural evaluations for demonstrating compliance with the requirements of 10CFR72.236(a), (b), (d) (e), (f), (g), and (1). To facilitate regulatory review, the assumptions and conservatisms inherent in the analyses are identified along with a concise description of the analytical methods, models, and acceptance criteria. The information presented herein is intended to comply with the guidelines of NUREG-1536 and ISG-21 pertaining to use of finite element codes.

In particular, every Computational Modeling Software (CMS) deployed to perform the structural analyses is identified and its implementation appropriately justified as suggested in ISG-21. The information on benchmarking and validation of each Computational Modeling Software is also provided (in Subsection 3.6.2).

Where appropriate, the structural analyses have been performed using classical strength materials solution. Such calculations are presented in this FSAR in transparent detail.

Finally, the input data and analyses using Computational Modeling Software (CMS) are described in sufficient detail to enable an independent evaluation of safety conclusions reached in this chapter.

The MPC and HI-TRAC are categorized as "interfacing components" in this FSAR because they have been licensed in their host docket (i.e., docket number 72-1032 for HI-STORM FW). Nevertheless, it is necessary to demonstrate in this FSAR that the loads exerted on an interfacing component do not exceed its licensing basis in its docket number 72-1032. For example, the MPC structural integrity has been evaluated in this chapter to ensure that the rattling motion of the MPC inside the VVM storage cavity during the DBE event will not produce a breach in the confinement boundary or subject the MPC to lateral decelerations in excess of the value for which it was qualified in docket number 72-1032.

However, it should be noted without ambiguity that the HI-STORM UMAX system has been designed such that, with the exception of the earthquake induced impact load on its Confinement Boundary, *the MPC stored in HI-STORM UMAX will always be subject to a less severe loading than what would be obtained in the above-ground HI-STORM systems under an identical environmental condition. In particular, the thermal calculations documented in Chapter 4 show that the internal temperature and pressure in the MPC, under the Design Basis heat load and environmental condition specified in Chapter 2 herein, are always less in HI-STORM UMAX than that computed for its storage in the above-ground HI-STORM FW overpack in docket number 72-1032. Furthermore, the following restrictions apply:*

1. *The content conditions for an MPC to be stored in HI-STORM UMAX must not exceed the technical specification for HI-STORM UMAX.*
2. *The design specifications for the MPC (and the HI-TRAC cask used to load the MPC that are identified in its licensing basis FSAR) will apply at all times during loading and storage of the MPC. Such specifications include Design Basis external pressure and any acceptable radiation dose limits.*

Table 3.1.1 provides the acceptance criteria that apply to the MPCs listed in Table 1.2.1.

Technical descriptions and safety analyses in this chapter, especially pertaining to the components common to the HI-STORM FW and the HI-STORM UMAX systems are referenced in this FSAR, as necessary to the HI-STORM FW FSAR. To facilitate convenient access to the referenced material, the latest edition of the HI-STORM FW FSAR has been placed in this docket and a list of HI-STORM FW FSAR sections germane to this chapter is provided in a tabular form below.

HI-STORM FW FSAR MATERIAL ADOPTED IN THIS FSAR BY REFERENCE [2]		
Location of UMAX FSAR	**Subject of the reference**	**Location in HI-STORM FW FSAR, Revision 1**
Subsection 3.1.3	Structural Qualifications of MPC	Subsections 3.4.3 and 3.4.4
Subsection 3.1.3	Structural Qualifications of HI-TRAC	Subsections 3.4.3 and 3.4.4
Subsection 3.4.4	MPC Qualified for accident conditions of storage	Subsection 3.4.4
Subsection 3.4.4	Stress Analysis for MPCs and HI-TRAC under normal handling conditions	Subsection 3.4.3

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[2] For convenience of reference, the specific revision of the HI-STORM FW FSAR that is referenced in the safety analysis herein is placed in this docket. Updated versions of the HI-STORM FW FSAR shall be placed in this docket as necessary so as to ensure that the safety analyses on the "UMAX" docket (72-1040) remain aligned with the material referenced in the HI-STORM FW FSAR.

3.1 STRUCTURAL DESIGN

3.1.1 Overview

This chapter presents the structural evaluation of the VVM Components for the applicable load cases summarized in Chapter 2 (Table 2.4.1). In Section 3.4, 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) [2.6.2] (see Table 2.4.3). Summary tables of bounding safety factors are provided for governing load combination for the ISFSI Structures. The Licensing Drawing for the HI-STORM UMAX VVM is provided in Section 1.5. Section 2.6 provides a summary 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 depicted in sufficient detail in the Licensing Drawing to enable the safety analyses summarized in this chapter to be performed. The applicable Design Basis Earthquake is defined by the response spectra shown in Figures 2.4.1 and 2.4.2.

3.1.2 Design Criteria and Applicable Loads

Consistent with the provisions of NUREG-1536, the central objective of the structural analysis presented in this chapter is to ensure that the HI-STORM UMAX system possesses sufficient structural capacity to withstand normal and off-normal loads and the worst case loads under extreme environmental phenomenon or accident events. Withstanding such loadings implies that the HI-STORM UMAX system must successfully preclude the following:

- unacceptable risk of criticality
- unacceptable release of radioactive materials
- unacceptable radiation levels
- impairment of ready retrievability of the SNF

The above design objectives for the HI-STORM UMAX system can be particularized for individual components as follows:

- The objective of the structural analysis of the MPC is to demonstrate that:

  i. Confinement of radioactive material is maintained under normal, off-normal, accident conditions, and natural phenomenon events.

  ii. The MPC basket does not deform under credible loading conditions such that the subcriticality or retrievability of the SNF is jeopardized.

  As stated previously in Section 3.0, the certification of a new MPC design is not envisaged for this docket. Any MPC that is to be stored in HI-STORM UMAX must have been certified in another docket.

Furthermore, the design of the HI-STORM UMAX VVM has been configured such that it maintains the steady state stresses acting on the MPC at a lower (equal) level than those that would develop at the design basis heat load during storage in the above-ground HI-STORM FW overpack in docket number 72-1032. Among the environmental loadings, the case of earthquakes warrants special attention because the manner of support provided to the MPC in HI-STORM UMAX is quite different from the above ground overpacks. To ensure that the MPC design continues to meet the above safety goals under the earthquake event, acceptance criteria for the MPC in Table 3.1.1 have been provided.

- The objectives of the structural analysis of the storage modules are to demonstrate that:

  i. Large energetic missiles such as tornado-generated missiles (see Subsection 2.4.2) do not compromise the integrity of the MPC Confinement Boundary.

  ii. The radiation shielding remains properly positioned in the case of any normal, off-normal, or natural phenomenon or accident event.

  iii. The flow path for the cooling airflow shall remain available under normal and off-normal conditions of storage and after an extreme environmental phenomenon or an accident event.

  iv. The loads arising from normal, off-normal, and accident level conditions exerted on the contained MPC do not violate the structural design criteria of the MPC.

  v. No geometry changes occur under any normal, off-normal, and accident level conditions of storage that preclude ready retrievability of the contained MPC.

  vi. The inter-cask transfer of a loaded MPC can be carried out without exceeding the structural capacity of the HI-STORM UMAX module.

Design (and acceptance) criteria for the HI-STORM UMAX VVM components and the ISFSI structures are summarized in Tables 2.3.1 and 2.3.2. The acceptance criteria for the MPC are provided in Table 3.1.1.

3.1.2.1 Applicable Loadings

Individual loads, applicable to the HI-STORM UMAX System, are defined in Sections 2.4 and 2.5.

3.1.2.2 Design Basis Loads and Load Combinations

i. Design Basis Loads and Load Combinations for VVM Components

Load combinations are developed by assembling the individual loads that may act concurrently, and possibly, synergistically. Load cases and design basis loads applicable to the VVM Components are summarized in Table 2.4.1. Those load cases in Table 2.4.1 which involve an "interfacing component" (namely the stored MPC and the HI-TRAC transfer cask) are analyzed with an appropriate model of the interfacing component included in the simulation of the storage system. For example, the evaluation of the design basis earthquake (DBE) loading includes the MPC. Results of the analyses carried out under the Design Basis Loads are compared with their respective allowable limits and/or functional performance criteria, as applicable.

ii. Design Basis Loads and Load Combinations for ISFSI Structures

The HI-STORM UMAX ISFSI consists of plate-type reinforced concrete structures whose minimum section strength properties are defined by Table 2.3.2 and the Licensing Drawings. The ISFSI is supported by the subgrade underneath the SFP, which may include pilings, if required, to meet the effective shear wave velocity in Table 2.3.2. Table 2.4.3 contains load combinations applicable to the ISFSI Structures (reinforced concrete structures) in the HI-STORM UMAX ISFSI. The individual 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 2.4.3). The method to incorporate the effect of long-term settlement of the subgrade underneath the SFP (also referred to as the "undergrade"), described in Section 3.4, 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 equivalent (degraded) elastic properties of the subgrade underneath the SFP are utilized to account for the effect of long-term settlement. The Dead load on the SFP from the weight of the loaded VVMs nearly equals the weight of the earth removed. Therefore, the long-term settlement of the SFP is expected to be quite small. The ISFSI pad will not settle relative to the SFP over its service life since it's supported by the Self-hardening Engineered Subgrade (SES).

b. Live load from the loaded transporter acts directly on the ISFSI pad. This load also adds to the overall load on the SFP (L in Table 2.4.3). The load from the loaded transporter is the sole live load applicable to the ISFSI structures.

c. Seismic load is computed using the methodology presented in Subsection 3.4.4. This load, denoted as E in Table 2.4.3, 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 transient in nature.

3.1.2.3 Allowables

The important-to-safety components of the HI-STORM UMAX system are identified on the drawings in Section 1.5. Allowable stresses, as appropriate, are tabulated for these components for all service conditions.

Relationships for allowable stresses and stress intensities for NB [3.1.4] and NF [3.1.5] components are provided in Tables 3.1.11 and 3.1.12, respectively. Tables 3.1.2 through 3.1.8 contain numerical values of the stresses/stress intensities for all MPC and VVM load bearing Code materials as a function of temperature.

In all tables the terms S, S_m, S_y, and S_u, respectively, denote the design stress, design stress intensity, minimum yield strength, and the ultimate strength. Property values at intermediate temperatures that are not reported in the ASME Code are obtained by linear interpolation. Property values are not extrapolated beyond the limits of the Code in any structural calculation.

Additional terms relevant to the stress analysis of the HI-STORM UMAX system extracted from the ASME Code (see Figure NB-3222-1, for example) are listed in Table 3.1.10.

3.1.2.4 Brittle Fracture

HI-STORM UMAX utilizes the same material types as HI-STORM 100 (Docket number 72-1014) and HI-STORM FW (docket number 72-1032). In addition, the material thicknesses used in HI-STORM UMAX do not exceed those in the previously certified HI-STORM modules. Furthermore, in comparison to its above ground counterparts, the lowest material temperatures in the HI-STORM UMAX shell, because of its underground configuration, will not be as severely affected by the cold ambient temperatures in winter months. Therefore, the safety considerations for brittle fracture for the HI-STORM UMAX structural steel materials are informed (and bounded) by those previously used in the above-ground HI-STORM modules (see also Section 8.4). Table 3.1.9 reproduces the applicable fracture toughness test requirements for the HI-STORM UMAX VVM from the HI-STORM FW FSAR.

3.1.2.5 Fatigue

Fatigue is a consequence of a cyclic state of stress applied on a metal part. Failure from fatigue occurs if the combination of amplitude of the cyclic stress, σ_a, and the number of cycles, n_f, reaches a threshold value at which failure occurs. ASME Code, Section III, Subsection NCA provides the σ_a-n_f curves for a number of material types. At $n_f = 10^6$, the required σ_a is referred to as the "Endurance Limit". The Endurance Limit for stainless steel (the material used in the MPC) according to the ASME Code, Section III, Div. 1, Appendices, Table I.9.2, is approximately 28 ksi.

The causative factors for fatigue expenditure in a non-active system (i.e., no moving parts) such as the HI-STORM UMAX system may be:

i. rapid temperature changes
ii. significant pressure changes

The HI-STORM UMAX system is exposed to the fluctuating thermal state of the ambient environment. Effect of wind and relative humidity also play a role in affecting the temperature of the cask components. However, the most significant effects are the large thermal inertia of the system and the relatively low heat transfer coefficients that act to smooth out the daily temperature cycles.

As a result, the amplitude of the cyclic stresses, to the extent that they are developed, remains orders of magnitude below the cask material's Endurance Limit.

The second causative factor, namely, pressure pulsation, is limited to the only pressure vessel in the system – the MPC. Pressure produces several types of stresses in the MPC (see Table 3.1.10); all of which are equally effective in causing fatigue expenditure in the metal. However, the amplitude of stress from the pressure cycling (due to the changes in the ambient conditions) is quite small and well below the Endurance Limit of the stainless steel material.

Therefore, failure from fatigue is not a credible concern for the HI-STORM UMAX system components.

3.1.2.6 Buckling

Buckling is caused by compressive stress acting on a slender section. In the HI-STORM UMAX system, the steel weldment in the overpack is not slender; its height-to-diameter ratio being less than 2. There is no source of compressive stress except from the self-weight of the shell and the overpack weight of the HI-TRAC transfer cask in the stacked condition, which produces a modest state of compressive stress. The state of a small compressive stress combined with a low slenderness ratio makes the HI-STORM UMAX VVM safe from the buckling mode of failure.

The only instance of a significant in-plane load on a HI-STORM UMAX part is the impact load exerted on the MPC Guides by the lateral rattling of the MPC under the DBE event. Calculations have been performed and summarized in this FSAR that demonstrate that the MPC Guides will not buckle.

3.1.2.7 Consideration of Manufacturing and Material Deviations

Departure from the assumed values of material properties in the safety analyses can, in certain cases, adversely affect the computed safety margins. Likewise, deviations in manufacturing that inevitably occur in custom fabrication of capital equipment may detract from the safety factors reported in this chapter. In what follows, the method and measures adopted to ensure that deviations in material properties or in the fabricated hardware will not undermine the structural safety conclusions are summarized.

It is noted that the yield and ultimate strengths of materials used in the manufacturing of the HI-STORM UMAX components will typically be greater than that assumed in the structural analyses because the ASME Code mandates all Code materials meet the minimum certified property values set down in the Code tables. Holtec International requires the material supplier to provide a Certified Mill Test Report in the format specified in the Code to ensure compliance of all physical properties of the supplied material with the specified Code minimums.

The above measures make the probability of an actual material strength property to be falling below the assumed value in the structural analysis in this chapter to be non-credible. On the contrary, Holtec's manufacturing experience suggests that the actual properties are likely to be uniformly and substantially greater than the assumed values.

A similarly conservative approach is used to ensure that the fabrication processes do not degrade the computed safety margins. Towards this end, the fabrication documents (drawings, travelers and shop procedures) implement a number of pro-active measures to prevent all known sources of development of a strength-adverse condition, such as:

i. All welding procedures are qualified to yield better physical properties than the Code minimums. All essential variables that affect weld quality are tightly controlled.

ii. Only those craftsmen who have passed the welding skill criteria implemented in the shop are permitted to weld.

iii. A rigorous weld material quality over-check program is employed to ensure that every weld wire spool meets its respective Code specification.

iv. All structural welds are specified as minimums: In practice, most exceed the specified minimums significantly. All primary structural welds are subject to Q.C. over-check and sign-off.

In the event of a deviation that may depress the computed safety margin, a non-conformance report is prepared by the manufacturer and subject to a safety analysis by Holtec International's corporate engineering using the same methodology as that described in this FSAR. The item is accepted only if the safety evaluation musters part 72.48 acceptance criteria. A complete documentation of the life cycle of the NCR is archived in the Company's Permanent Filing System and shared with the designated system user.

The above processes and measures have been in place at the Holtec Manufacturing Division to ensure that an unacceptable reduction in the safety factors due to variation in material properties and manufacturing processes does not occur. The Company's nuclear manufacturing experience over the past 25 years corroborates the effectiveness of the above measures.

3.1.3 Stress Analysis Models and Computer Codes

To evaluate the effect of loads on the HI-STORM UMAX system components, finite element models for stress and deformation analysis are developed. The essential attributes of the finite element models for the HI-STORM UMAX VVM and the MPC, developed for Design Basis earthquake induced impact analyses, are presented in this subsection. All finite element models are three-dimensional and are prepared to the level of discretization appropriate to the problem to be solved. The models are developed using ANSYS and LS-DYNA general purpose codes, which are described in Subsection 3.6.2.

Pursuant to ISG-21, the description of the computational model for each component addresses the following areas:

- Description of the model, its key attributes and its conservative aspects
- Types of finite elements used and the rationale for their selection
- Material properties and applicable temperature ranges
- Modeling simplifications and their underlying logic

In subsequent subsections, where the finite element models are deployed to analyze the different load cases, the presentation includes the consideration of:

- Geometric compliance of the simulation with the physics of the problem
- Boundary conditions
- Effect of tolerances on the results
- Convergence (numerical) of the solutions reported in this FSAR

The input files prepared to implement the finite element solutions as well as detailed results are archived in the Calculation Package [3.4.1] within the Company's Configuration Control System. Essential portions of the results for each loading case necessary to draw safety conclusions are extracted from the Calculation Packages and reported in this FSAR. Specifically, the results summarized from the finite element solutions in this chapter are self-contained to enable an independent assessment of the system's safety. Input data is provided in tabular form as suggested in ISG-21. For consistency, the following units are employed to document input data throughout this chapter:

- Time: second
- Mass: pound

Four commercial computer programs, all with a well-established history of usage in the nuclear industry, have been utilized to perform structural and mechanical analyses documented in this submittal. These codes are described in Subsection 3.6.2.

3.1.3.1 HI-STORM UMAX VVM

The physical geometry and materials of construction of the HI-STORM UMAX modules are provided in Chapter 1 including the drawings in Section 1.5. The HI-STORM UMAX VVM finite element model is developed for the seismic Soil Structure Interaction (SSI) analysis of the standard 5×5 VVM array (see Figure 1.0.1), which is fully loaded with the tallest and heaviest MPC allowed to be stored in this underground storage system. The key attributes of the HI-STORM UMAX VVM LS-DYNA finite element model are:

i. Shell elements are used to model the divider shell and CEC except for the CEC base plate and MPC pedestals, which are modeled using thick shell and solid elements, respectively. The VVM lid model is conservatively simplified as a rigid solid body to maximize the contact force at the lid/CEC interface. The bounding MPC stored in the VVM is conservatively represented by a rigid cylinder to yield bounding stresses in the VVM structural members and bounding loads for the ISFSI structural components.

ii. Based on the experience gained in developing the HI-STORM 100U (docket number 72-1014) VVM model, the HI-STORM UMAX VVM model is meshed sufficiently fine to capture the primary stresses developed under the Design Basis Earthquake condition.

iii. Except for the divider shell, CEC baseplate and MPC pedestal, which are conservatively assumed to behave linear elastically to maximize the predicted impact loads under the seismic condition, the VVM steel members are represented by their applicable nonlinear elastic-plastic true stress-strain relationships, which can be found directly from [3.1.2] or derived from engineering stress-strain data. The methodology used for obtaining a true stress-strain curve from a set of engineering stress-strain data (e.g., strength properties from [3.3.2]) is provided in [3.1.6], which utilizes the following power law relation to represent the flow curve of metal in the plastic deformation region:

$$\sigma = K\varepsilon^{n}$$

where n is the strain-hardening exponent and K is the strength coefficient. Table 3.1.14 provides the values of K and n used to model the behavior of the structural materials in LS-DYNA.

The key input data of the VVM model is listed in Table 3.1.13.

3.1.3.2 Multi-Purpose Canister (MPC)

The structural qualification of the MPCs is documented in the HI-STORM FW FSAR. The finite element model of the MPC is needed, however, for two reasons:

i. To determine the structural consequences of the impact of the MPC's "hard points", namely the Top Lid and the Baseplate locations, with the radial guides welded to the CEC under the DBE.

ii. To ensure that the maximum deceleration sustained by each MPC due to their impact with the Guides is less than its licensing basis (see Table 3.1.1).

The LS-DYNA finite element model of the MPC is essentially identical to that developed for the non-mechanistic tipover analysis for HI-STORM FW (docket number 72-1032). The contents of the MPC, i.e., fuel assemblies, fuel basket and basket shims, are explicitly modeled to account for the interaction between the MPC shell and the MPC contents. Moreover, the MPC model employs a refined element grid in the impact regions of the canister. Additional attributes of the finite element model are:

i. The MPC shell and fuel basket are modeled using LS-DYNA thick shell elements while the MPC lid, baseplate and each fuel assembly are modeled using solid elements. The MPC lid-to-shell weld is also explicitly modeled using solid elements. The finite element discretization of the MPC is sufficiently detailed to accurately articulate the primary membrane and bending stresses as well as the secondary stresses at locations of impact.

ii. The material properties of the MPC components are taken based on the calculated bounding temperatures under normal storage condition. The fuel basket is divided into four regions based on the temperature distribution of the basket in order to use more realistic material properties for the finite element analysis; the same approach was used in the HI-STORM FW tipover analysis.

iii. Except for the fuel assembly model, which is assumed to behave linear elastically, all other MPC structural members are characterized by the true stress-strain relationship of the material to accurately determine the actual plastic deformation in the MPC enclosure vessel for the confinement evaluation of the MPC under impact condition.

The key input data of the MPC enclosure vessel model is listed in Table 3.1.15.

3.1.3.3 HI-TRAC Transfer Cask

The structural qualification of the transfer casks is contained in the HI-STORM FW FSAR. There are no new loads that arise from the operations described in Chapter 9. Therefore, no additional analysis of the transfer cask is performed in this chapter. In the LS-DYNA SSI analysis, the loaded HI-TRAC, along with the transfer cask transporter, is represented as a rigid body in the finite element model for conservatism.

Table 3.1.1

ACCEPTANCE CRITERIA FOR MPCs FOR DEPLOYMENT IN HI-STORM UMAX

	ITEM	Limiting Value	**Source**
1.	Maximum permissible deceleration under seismic or mechanical loading condition	45 g's	Section 3.4 of the HI-STORM FW FSAR
2.	Maximum local plastic strain in the confinement boundary shell	0.1	Reference [3.1.3]

Table 3.1.2

DESIGN AND LEVEL A: ALLOWABLE STRESS

Reference Code: ASME NF
Material: A36
Service Conditions: Design and Normal
Item: Stress

Temp. (Deg. F)	**Classification and Value (ksi)**		
	S	**Membrane Stress**	**Membrane plus Bending Stress**
-20 to 650	16.6	16.6	24.9
700	15.6	15.6	23.4

Notes:

1. S = Maximum allowable stress values from Table 1A of ASME Code, Section II, Part D.
2. Stress classification per Paragraph NF-3260.

Table 3.1.3

LEVEL B: ALLOWABLE STRESS

Reference Code:	ASME NF
Material:	A36
Service Conditions:	Off-Normal
Item:	Stress

Temp. (Deg. F)	**Classification and Value (ksi)**	
	Membrane Stress	**Membrane plus Bending Stress**
-20 to 650	22.1	33.1
700	20.7	31.1

Table 3.1.4

DESIGN AND LEVEL A: ALLOWABLE STRESS

Code: ASME NF
Material: A516 (A515) Grade 70, A350-LF3 (A350-LF2)
Service Conditions: Design and Normal
Item: Allowable Stress

Temp. (Deg. F)	Classification and Value (ksi)		
	S	Membrane Stress	Membrane plus Bending Stress
-20 to 400	20.0	20.0	30.0
500	19.6	19.6	29.4
600	18.4	18.4	27.6
650	17.8	17.8	26.7
700	17.2	17.2	25.8
800	12.0	12.0	18.0

Notes:

1. S = Maximum allowable stress values from Table 1A of ASME Code, Section II, Part D.
2. Stress classification per Paragraph NF-3260.
3. Maximum allowable stress values are the lowest of all values for the candidate materials (A516 (A515) Grade 70, A350-LF3 (A350-LF2)) at corresponding temperature. Calculations can be performed using the allowable stress values from this table or using the values directly taken from the ASME code [3.1.4] for a specific candidate material.

Table 3.1.5

LEVEL B: ALLOWABLE STRESS

Code: ASME NF
Material: A516 (A515) Grade 70, A350-LF3 (A350-LF2)
Service Conditions: Off-Normal
Item: Allowable Stress

Temp. (Deg. F)	**Classification and Value (ksi)**	
	Membrane Stress	**Membrane plus Bending Stress**
-20 to 400	26.6	39.9
500	26.1	39.1
600	24.5	36.7
650	23.7	35.5
700	22.9	34.3

Notes:

1. Maximum allowable stress values are the lowest of all values for the candidate materials (A516 (A515) Grade 70, A350-LF3 (A350-LF2)) at corresponding temperature. Calculations can be performed using the allowable stress values from this table or using the values directly taken from the ASME code [3.1.4] for a specific candidate material.

Table 3.1.6

LEVEL D: ALLOWABLE STRESS INTENSITY

Code:	ASME NF
Material:	A516 (A515) Grade 70
Service Conditions:	Accident
Item:	Stress Intensity

Temp. (Deg. F)	**Classification and Value (ksi)**		
	S_m	**P_m** AMAX ($1.2S_y$, $1.5S_m$), but < 0.7 S_u	**$P_m + P_b$** 150% of P_m
-20 to 100	23.3	45.6	68.4
200	23.2	41.8	62.7
300	22.4	40.3	60.4
400	21.6	39.0	58.5
500	20.6	37.2	55.8
600	19.4	34.9	52.4
650	18.8	33.8	50.7
700	18.1	32.9	49.4

Notes:

1. Level D allowable stress intensities per Appendix F, Paragraph F-1332.
2. S_m = Stress intensity values per Table 2A of ASME, Section II, Part D.
3. P_m and P_b denote Primary Membrane and Primary Bending Stress, respectively.

Table 3.1.7

DESIGN, LEVELS A AND B: ALLOWABLE STRESS INTENSITY

Code:	ASME NB
Material:	Alloy X
Service Conditions:	Design, Levels A and B (Normal and Off-Normal)
Item:	Stress Intensity

Temp. (Deg. F)	**Classification and Numerical Value**					
	S_m	P_m[†]	P_L[†]	$P_L + P_b$[†]	P_L+P_b+Q[††]	P_e[††]
-20 to 100	20.0	20.0	30.0	30.0	60.0	60.0
200	20.0	20.0	30.0	30.0	60.0	60.0
300	20.0	20.0	30.0	30.0	60.0	60.0
400	18.6	18.6	27.9	27.9	55.8	55.8
500	17.5	17.5	26.3	26.3	52.5	52.5
600	16.5	16.5	24.75	24.75	49.5	49.5
650	16.0	16.0	24.0	24.0	48.0	48.0
700	15.6	15.6	23.4	23.4	46.8	46.8
750	15.2	15.2	22.8	22.8	45.6	45.6
800	14.8	14.8	22.2	22.2	44.4	44.4

Notes:

1. S_m = Stress intensity values per Table 2A of ASME II, Part D.
2. Alloy X S_m values are the lowest values for each of the candidate materials at corresponding temperature.
3. Stress classification per NB-3220.
4. P_m, P_L, P_b, Q, and P_e are defined in Table 3.1.10.

[†] Evaluation required for Design condition only.

[††] Evaluation required for Levels A, B conditions only. P_e not applicable to vessels.

Table 3.1.8

LEVEL D: ALLOWABLE STRESS INTENSITY

Code:	ASME NB
Material:	Alloy X
Service Conditions:	Level D (Accident)
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	46.3	69.45	69.45
400	44.6	66.9	66.9
500	42.0	63.0	63.0
600	39.6	59.4	59.4
650	38.4	57.6	57.6
700	37.4	56.1	56.1
750	36.5	54.8	54.8
800	35.5	53.25	53.25

Notes:

1. Level D stress intensities per ASME NB-3225 and Appendix F, Paragraph F-1331.
2. The average primary shear strength across a section loaded in pure shear may not exceed 0.42 S_u.
3. Stress classification per NB-3220.
4. P_m, P_L, and P_b are defined in Table 3.1.10.

Table 3.1.9

FRACTURE TOUGHNESS TEST REQUIREMENTS

Material	Test Requirement	Test Temperature	Acceptance Criterion
Ferritic steel with nominal section thickness of 5/8" or less	Not required per NF-2311(b)(1)	-	-
A516 Gr. 70 (greater than 5/8") used for CEC base plate, CEC containment shell, CEC baffle plate, inlet plenum cover plate, inlet plenum corner gusset, inlet plenum side gusset, inlet plenum air-intake flange, MPC pedestal bearing pad, divider shell flange, divider shell flange gusset, lower and upper MPC guides, closure lid shear ring, closure lid strongback, closure lid bottom plate, closure lid outer shell, closure lid cover plate.	Not required per NF-2311 (b)(7)		
Weld material	Test per NF-2430 if: (1) either of the base materials of the production weld requires impact testing, or; (2) either of the base materials is A516 Gr. 70 with nominal section thickness greater than 5/8".	See Note 1	Per NF-2330

Note:
1. Required NDT temperature = -40 deg. F for all materials in the HI-STORM UMAX VVM "NF" materials.

Table 3.1.10

ORIGIN, TYPE AND SIGNIFICANCE OF STRESSES IN THE HI-STORM UMAX SYSTEM

Symbol	Description	Notes
P_m	Primary membrane stress	Excludes effects of discontinuities and concentrations. Produced by pressure and mechanical loads. Primary membrane stress develops in the MPC Enclosure Vessel shell. Limits on P_m exist for normal (Level A), off-normal (Level B), and accident (Level D) service conditions.
P_L	Local membrane stress	Considers effects of discontinuities but not concentrations. Produced by pressure and mechanical loads, including earthquake inertial effects. P_L develops in the MPC Enclosure Vessel wall due to impact between the VVM guides and the MPC (near the top of the MPC) under an earthquake (Level D condition). However, because there is no Code limit on P_L under Level D event, a limit on the local strain consistent with the approach in the HI-STORM FW docket is used.
P_b	Primary bending stress	Component of primary stress proportional to the distance from the centroid of a solid section. Excludes the effects of discontinuities and concentrations. Produced by pressure and mechanical loads, including earthquake inertial effects. Primary bending stress develops in the top lid and baseplate of the MPC, which is a pressurized vessel. Lifting of the loaded MPC using the so-called "lift cleats" also produces primary bending stress in the MPC lid. Similarly, the top lid of the HI-STORM UMAX module, a plate-type structure, withstands the snow load or pressure loading from explosion by developing primary bending stress.
P_e	Secondary expansion stress	Stresses that result from the constraint of free-end displacement. Considers effects of discontinuities but not local stress concentration (not applicable to vessels). It is shown that there is no interference between component parts due to free thermal expansion. Therefore, P_e does not develop within any HI-STORM UMAX component.
Q	Secondary membrane plus bending stress	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at gross structural discontinuities. Can be caused by pressure, mechanical loads, or differential thermal expansion. The junction of MPC shell with the baseplate and top lid locations of gross structural discontinuity, where secondary stresses develop as a result of internal pressure. Secondary stresses would also develop at the two extremities of the MPC shell if a thermal gradient were to exist. However, because the top and bottom regions of the MPC cavity also serve as the top and bottom plenums, respectively, for the recirculating helium, the temperature field in the regions of gross discontinuity is essentially uniform, and as a result, the thermal stress adder is insignificant and neglected .
F	Peak stress	Increment added to primary or secondary stress by a concentration (notch), or, certain thermal stresses that may cause fatigue but not distortion. Because fatigue is not a credible source of failure in a passive system with gradual temperature changes, the cumulative damage factor from fatigue is not computed for HI-STORM UMAX components.

Table 3.1.11

MPC CONFINEMENT BOUNDARY STRESS INTENSITY LIMITS FOR DIFFERENT LOADING CONDITIONS (ELASTIC ANALYSIS PER NB-3220)[†]

Stress Category	Design	Level A	Level D[††]
Primary Membrane, P_m	S_m	S_m	AMIN (2.4S_m, .7S_u)
Local Membrane, P_L	1.5S_m	1.5S_m	150% of P_m Limit
Membrane plus Primary Bending	1.5S_m	1.5S_m	150% of P_m Limit
Primary Membrane plus Primary Bending	1.5S_m	N/A	150% of P_m Limit
Membrane plus Primary Bending plus Secondary	N/A	3S_m	N/A
Average Shear Stress[††††]	0.6S_m	0.6S_m	0.42S_u

[†] Stress combinations including F (peak stress) apply to fatigue evaluations only.
[††] Governed by Appendix F, Paragraph F-1331 of the ASME Code, Section III.
[††††] Governed by NB-3227.2 or F-1331.1(d).

Table 3.1.12

STRESS AND ACCEPTANCE LIMITS FOR DIFFERENT LOADING CONDITIONS FOR THE STEEL STRUCTURE OF THE HI-STORM UMAX

STRESS CATEGORY	DESIGN + NORMAL	OFF-NORMAL	ACCIDENT[†]
Primary Membrane, P_m	S	1.33·S	See footnote
Primary Membrane, P_m, plus Primary Bending, P_b	1.5·S	1.995·S	See footnote
Shear Stress (Average)	0.6·S	0.6·S	See footnote

Definitions:

S = Allowable Stress Value for Table 1A, ASME Section II, Part D.
S_m = Allowable Stress Intensity Value from Table 2A, ASME Section II, Part D
S_u = Ultimate Stress

[†] Under accident conditions, the cask must maintain its physical integrity, the loss of solid shielding (concrete, steel, as applicable) shall be minimal and the MPC must remain retrievable.

Table 3.1.13

KEY INPUT DATA FOR FINITE ELEMENT MODEL OF HI-STORM UMAX VVM

Item	Value
Overall height of HI-STORM UMAX VVM (including Closure lid) from bottom of SFP to top of ISFSI pad	**Withheld in Accordance with 10CFR2.390**
Height of CEC shell cavity including the top surface of the flange	**Withheld in Accordance with 10CFR2.390**
Height of top lid above top of grade	**Withheld in Accordance with 10CFR2.390**
Inside diameter of HI-STORM UMAX storage cavity (CEC shell)	**Withheld in Accordance with 10CFR2.390**
Outside diameter of Closure Lid	**Withheld in Accordance with 10CFR2.390**
CEC shell thickness	**Withheld in Accordance with 10CFR2.390**
Thickness of CEC flange	**Withheld in Accordance with 10CFR2.390**
Lifting rib (in the Closure Lid outlet pipe) thickness	**Withheld in Accordance with 10CFR2.390**
CEC Baseplate thickness	**Withheld in Accordance with 10CFR2.390**
Material of construction	**Withheld in Accordance with 10CFR2.390**
Ref. temperature for material properties	**Withheld in Accordance with 10CFR2.390**
Concrete density(reference)	**Withheld in Accordance with 10CFR2.390**

Table 3.1.14

VALUES OF "K" AND "n" USED TO MODEL ELASTIC-PLASTIC BEHAVIOR OF HI-STORM UMAX COMPONENTS IN LS-DYNA

Component	Material	Ref. Temperature	K[†] (psi)	n[†]
MPC Lid	Alloy X	500°F	1.055×10^5	0.235
MPC Shell	Alloy X	475°F	1.156×10^5	0.246
MPC Baseplate	Alloy X	350°F	1.161×10^5	0.236
CEC Shell	A516 Gr. 70	150°F	1.124×10^5	0.171
Fuel Basket	Metamic	644°F	1.764×10^4	0.060
		617°F	1.879×10^4	0.056
		572°F	2.116×10^4	0.051
		392°F	2.712×10^4	0.075

[†] K and n are defined in Subsection 3.1.3.1.

Table 3.1.15

KEY INPUT DATA FOR LS-DYNA MODEL OF GOVERNING MPC ENCLOSURE VESSEL

Item	Value
Overall Height of MPC	213 in (for maximum length fuel)
Outside diameter of MPC	75.5 in
MPC upper lid thickness	4.5 in
MPC lower lid thickness	4.5 in
MPC shell thickness	0.5 in
MPC baseplate thickness	3.0 in
Material	Austenitic stainless steel (Alloy X in Docket # 72-1014)
Ref. temperature for material properties	[3.1.7]

3.2 WEIGHTS AND CENTERS OF GRAVITY

Table 3.2.1 provides bounding weight data of the movable components (Closure lid, MPC, HI-TRAC and the transporter) required for the structural analysis of the HI-STORM UMAX. The weight data is selected to bound all types of MPCs, HI-TRACs and transporters that may be employed with the HI-STORM UMAX system.

Table 3.2.2 provides limiting (maximum and minimum) dimensional data that bound the MPC types certified in docket number 72-1032.

Because the HI-STORM UMAX is immovable and is situated underground, its CG data is not germane to safety evaluation. The Closure Lid is essentially a radially symmetric structure and, as such, its center-of-gravity is closely aligned with its axis of symmetry.

Table 3.2.1

BOUNDING HI-STORM MPC, LID, HI-TRAC AND TRANSPORTER WEIGHT DATA

Item	Bounding Weight or Value
Closure Lid	35,000 lb
Loaded Transfer cask	270,000 lb (Note 1)
MPC	110,000 lb (Note 1)
LOADED TRANSPORTER DATA (Note 2)	
• Weight of empty Transporter plus rigging (used to carry the loaded transfer cask)	180,000 lbs
• Reference length and width of each load patch (two load patches per transporter)	197.1875 inch long × 29.5 inch wide (Note 2)
• Computed average normal pressure (based on loaded transporter weight and calculated area of two load patches)	38.68 psi

Notes:

1. Maximum MPC weight and HI-TRAC weights are intended to bound all MPCs (listed in Table 1.2.1) and transfer casks that may be used to load fuel in the HI-STORM UMAX VVM.
2. Transporter reference data is based on typical transporters being used at Holtec ISFSI sites.

Table 3.2.2

LIMITING PARAMETERS

	Item	PWR	BWR
1.	Minimum fuel assembly length, inch	157	171
2.	Maximum fuel assembly length, inch	199.2	181.5[1]
3.	Minimum gap between the bottom of the Closure Lid and top surface of the MPC, inch	24	24
4.	Maximum MPC length, inch	213	195
5.	Minimum MPC length, inch	171	185

---

[1] Maximum fuel assembly length for the BWR fuel assembly refers to the maximum fuel assembly length plus an additional 5" to account for a Damage Fuel Container (DFC).

3.3 MECHANICAL PROPERTIES OF MATERIALS

This section provides the mechanical properties used in the structural evaluation of the HI-STORM UMAX VVM. The properties include yield stress, ultimate stress, modulus of elasticity, Poisson's ratio, weight density, and coefficient of thermal expansion. Values are presented for a range of temperatures which envelope the maximum and minimum temperatures under all service conditions applicable to the HI-STORM UMAX system components.

The materials selected for use in the HI-STORM UMAX VVM are presented on the drawings in Section 1.5. In this chapter, the materials are divided into two categories, structural and nonstructural. Structural materials are materials that act as load bearing members and are, therefore, significant in the stress evaluations. Materials that do not support mechanical loads are considered nonstructural. For nonstructural materials, the principal property that is used in the structural analysis is weight density. In local deformation analysis, however, such as the study of penetration from a tornado-borne missile, the properties of plain concrete in the HI-STORM Closure Lid are included.

Table 2.6.2 lists applicable codes, materials of construction, and ITS designations for the functional parts in the HI-STORM UMAX system.

3.3.1 Structural Materials

Tables 3.3.1 and 3.3.2 provide the numerical values of the material properties needed for structural analysis.

a. Reinforced concrete is used in the construction of the concrete ISFSI Structures, namely, the ISFSI pad, the SFP, and possibly the optional Enclosure Wall. All reinforced concrete load bearing structures in the HI-STORM UMAX ISFSI will conform to stress criteria of ACI-318(2005). Table 3.3.4 provides the required properties for reinforced concrete.

b. Weld materials: All weld materials utilized in the welding of the Code components comply with the provisions of the appropriate ASME subsection (e.g., Subsection NB for the MPC enclosure vessel) and Section IX. All non-code welds will be made using weld procedures that meet Section IX of the ASME Code. The minimum tensile strength of the weld wire and filler material (where applicable) will be equal to or greater than the tensile strength of the base metal listed in the ASME Code.

3.3.2 Nonstructural Materials

Plain concrete used in the Closure lid and the non-organic insulation used on the outside surface of the Divider shell are the two non-structural materials used in the HI-STORM UMAX VVM assembly.

The primary function of the unreinforced concrete in the 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. Chapters 2 and Chapter 8 provide requirements on plain (unreinforced) concrete. The compressive strength, bearing stress limit and the reference dry density applicable to the Closure Lid plain concrete is specified in Table 3.3.3 herein. The allowable bearing strength of plain concrete for normal loading conditions is calculated in accordance with ACI-318 (2005) [3.4.6]. The procedure specified in ASTM C-39 [3.3.1] is utilized to verify that the assumed compressive strength will be realized in the actual in-situ pours.

3.3.3 ISFSI Materials

The mechanical properties of reinforced concrete, subgrade and undergrade required for stress and strength analysis are provided in Tables 3.3.4 and 3.3.5.

Table 3.3.1

RELEVANT MATERIAL PROPERTIES FOR HI-STORM UMAX YIELD, ULTIMATE, LINEAR THERMAL EXPANSION, YOUNG'S MODULUS

Temp. (Deg. F)	**A516 and A515, Grade 70**			
	S_y	S_u	α	E
-40	38.0	70.0	---	29.98
100	38.0	70.0	6.5	29.26
150	35.7	70.0	6.6	29.03
200	34.8	70.0	6.7	28.8
250	34.2	70.0	6.8	28.55
300	33.6	70.0	6.9	28.3
350	33.05	70.0	7.0	28.1
400	32.5	70.0	7.1	27.9
450	31.75	70.0	7.2	27.6
500	31.0	70.0	7.3	27.3
550	30.05	70.0	7.3	26.9
600	29.1	70.0	7.4	26.5
650	28.2	70.0	7.5	26.0
700	27.2	70.0	7.6	25.5
750	26.3	69.1	7.7	24.85
800	25.5	64.3	7.8	24.2

Table 3.3.2

A36 MATERIAL PROPERTIES

Temp. (Deg. F)	**A36**			
	S_y	S_u	α	**E**
-40	36.0	58.0	---	29.98
100	36.0	58.0	6.5	29.26
150	33.8	58.0	6.6	29.03
200	33.0	58.0	6.7	28.8
250	32.4	58.0	6.8	28.55
300	31.8	58.0	6.9	28.3
350	31.3	58.0	7.0	28.1
400	30.8	58.0	7.1	27.9
450	30.05	58.0	7.2	27.6
500	29.3	58.0	7.3	27.3
550	28.45	58.0	7.3	26.9
600	27.6	58.0	7.4	26.5
650	26.7	58.0	7.5	26.0
700	25.8	58.0	7.6	25.5

Definitions:

S_y = Yield Stress (ksi)
α = Mean Coefficient of thermal expansion (in./in./^{0}F x 10^{-6})
S_u = Ultimate Stress (ksi)
E = Young's Modulus (psi x 10^6)

Table 3.3.3

HI-STORM UMAX VVM LID PLAIN CONCRETE PROPERTIES

Input Parameter	**Value**
Density, lbf/ft^3	Table 2.3.2
Poisson's ratio	0.17
Compressive strength, psi	Table 2.3.2
Concrete Allowable Bearing Stress, psi	4,420 (Note 1)
Young's modulus, psi	57,000 × (Concrete compressive strength in psi)$^{1/2}$

Notes:

1. Per ACI-318 (2005), Sec. 10.17.1 and Sec. 9.3.2.4. Since the plain concrete in the HI-STORM UMAX VVM lid is always confined, the allowable value is doubled.

Table 3.3.4

REFERENCE AND DERIVED PROPERTIES OF ISFSI REINFORCED CONCRETE, SUBGRADE, AND UNDERGRADE

Property	**Value**
Concrete and SES Compressive Strengths (psi)	Table 2.3.2
Concrete Rupture Strength (psi)	335.4
SES Rupture Strength (psi)	158.1
Concrete Allowable Bearing Stress (psi)	2486.3
SES Allowable Bearing Stress (psi)	552.5
Concrete Mean Coefficient of Thermal Expansion (in/in-deg. F)	5.5E-06
Concrete Modulus of Elasticity (psi)	57,000 × (Concrete compressive strength in psi)$^{1/2}$
Concrete Reference Dry Density	Table 2.3.2
Subgrade and Undergrade Strain Compatible Modulus of Elasticity (ksi) (see Figure 2.4.4 for identification of subgrade spaces)	Subgrade Space A (i.e., SES): 102 Subgrade Space B: 14.0 Undergrade Spaces C and D: 17.7

Table 3.3.5

SOIL PROPERTIES, COMPUTED SETTLEMENT, AND CORRESPONDING ELASTIC MODULUS FOR THE UNDERGRADE

	Item	Value
1.	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 Undergrade (Notes 1 and 3): Computed Long-Term Settlement (in) (Note 2) Computed Elastic Modulus (psi)	 < 0.12 6,230
3.	Values used in the Structural Analyses Model for Undergrade: Limiting Long-Term Settlement (in) Corresponding Elastic Modulus (psi)	 From Table 2.3.2 3,200

Note 1: The substrate characteristics are obtained using the density data from Table 2-3 and Table 5-1 of reference [3.3.3]. The soil compaction index 'Cc' is a direct function of soil parameters w_n, a, and b per [3.3.3]. The long-term settlement and the elastic modulus are derived using the relationships in [3.3.4].

Note 2: See Table 2.3.2 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 SFP to allow for the variation in the soil parameters at a host site.

3.4 GENERAL STANDARDS FOR CASKS

3.4.1 Chemical and Galvanic Reactions

The potential of chemical and galvanic action in the HI-STORM UMAX VVM assembly is evaluated in Chapter 8 of this FSAR.

3.4.2 Positive Closure

The confinement boundary of the HI-STORM UMAX system is seal welded in its entirety. The only access to the MPC storage cavity is through the VVM Closure Lid, which weighs well over 16 tons and must be lifted vertically a substantial distance before it can be separated from the VVM body. Furthermore, the removal of the lid requires the use of a special lifting device. Thus inadvertent opening of the VVM cavity is not feasible or credible.

3.4.3 Lifting Devices

3.4.3.1 Identification of Lifting Devices and Required Safety Factors

The only component in the HI-STORM UMAX system requiring lifting and handling is the Closure Lid. The Closure Lid is equipped with a four point lift system that meets the stress requirement of ANSI N14.6 [3.4.3] and Regulatory Guide 3.61 [1.0.4].

As required by Reg. Guide 3.61, lifting operations applicable to the VVM Closure lid are analyzed. Because of the nature of the HI-STORM UMAX system, lid placement or removal may occur with loaded MPCs inside the VVM cavity. Therefore, a stress analysis to demonstrate compliance with ANSI N14.6 to provide the assurance that a structural failure will not occur during lifting is summarized in this chapter.

The governing requirement for the lifting component itself (the lift lug plates) is that they must meet the primary stress limits prescribed by ANSI N14.6-1993 [3.4.3]; 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. Only the lifting component itself is the "significant-to-handling" (STH) part.

The lifting analysis is performed by conservatively assuming that the dead load is amplified by 15%.

3.4.3.2 Analysis of Lifting Scenarios- HI-STORM UMAX VVM Closure Lid Lifting Analysis (Load Case 04 in Table 2.4.1)

The Closure Lid is an axi-symmetric plate-type structure filled with concrete to provide radiation shielding. As shown in the Licensing Drawings, three lift lug plates with four orthogonally situated lift holes are welded together to lift and handle the Closure Lid. The diameter of the Closure Lid is much larger than the CEC shell I.D. which eliminates the risk of the lid falling into the cavity and striking the MPC stored below. Nevertheless, the Closure Lid lifting points and the Lid itself are required herein to meet the most stringent stress criteria from the regulatory literature, as follows:

1. The primary stresses at the lifting points must meet the limits in ANSI N14.6 with the dead load amplified by 15% to incorporate dynamic effects. The allowable stress per ANSI N14.6 is lesser of 1/10th of the ultimate strength or 1/6th of the material Yield Strength.

2. The average stress in the welds joining the lift lug plates for Closure Lid handling under the amplified dead load must meet the limit set down in Regulatory Guide 3.61, which limits the stress to 1/3rd of the material's Yield Strength.

3. The primary stresses in the lid structure under the amplified dead load must meet Level A stress limits in the ASME Code, Subsection "NF" for class 3 linear structures.

Because of the simplicity of the Closure Lid configuration, the lifting analysis is performed using strength of material approach. The details of the calculations are presented in the calculation package [3.4.1] supporting this FSAR. Lifting slings that attach to the lugs shall be sized to meet the safety factors set forth in ANSI B30.3 [3.4.2].

Table 3.4.1 summarizes key results obtained from the lifting analyses for the reference HI-STORM UMAX VVM Closure Lid design for a bounding set of input design loads.

It is concluded that all structural integrity requirements are met during a lift of the HI-STORM UMAX VVM Closure Lid. All factors of safety are greater than 1.0.

3.4.3.3 Safety Evaluation of Lifting Scenarios

As can be seen from the above, the computed factors of safety have a large margin over the allowable (of 1.0) in every case. In the actual fabricated hardware, the factors of safety will likely be much greater because of the fact that the actual material strength properties are generally substantially greater than the Code minimums. Minor variations in manufacturing, on the other hand, may result in a small subtraction from the above computed factors of safety. A 10CFR72.48 safety evaluation will be required if the cumulative effect of manufacturing deviation and use of the CMTR (or CoC) material strength in a manufactured hardware renders a factor of safety to fall below the above computed value. Otherwise, a 10CFR72.48 evaluation is not necessary. The above criterion applies to all lift calculations covered in this FSAR.

3.4.4 Heat

The evaluation of the HI-STORM UMAX system under thermally significant conditions listed in Section 2.5 is reported in Chapter 4.

a. Summary of Pressures and Temperatures

Required input data for the structural analysis of the HI-STORM UMAX VVM assembly is contained in Tables 2.3.1, 2.3.2 and the Licensing Drawings.

b. Differential Thermal Expansion

i. Normal Hot Environment

All clearances between the MPC and the HI-STORM UMAX VVM are considerably larger than the thermal expansion that may occur during system operations. Therefore, no interferences between the MPC and the HI-STORM UMAX VVM will occur due to thermal expansion of the loaded MPC. The interfaces that may potentially be subject to interference and their reference dimensions from the Licensing Drawings are provided below:

Interfacing Parts	Engineered Gap in Inches (shown in Licensing Drawings)
MPC-to-Divider Shell (diametral clearance)	10
MPC-to-Closure Lid (vertical clearance)	24
MPC-to-MPC Top Guide Plates (diametral clearance)	0.5
MPC-to-MPC Bottom Guides (diametral clearance)	0.5
Closure Lid-to-CEC Flange (diametral clearance)	1.0

Simplified calculations summarized in Section 4.4 (Chapter 4) show that the engineered gap in the system for each of the above listed interfaces is an order of magnitude (or more) greater than its reduction from thermal expansion under the operating condition corresponding to the maximum temperature differential scenario between the mating parts that form the interface.

ii. Design Basis Fire Event (Load Case 05 in Table 2.4.1)

The thermal analysis of the Design Basis Fire event is documented in Chapter 4 and evaluated in Chapter 12 for its safety consequence. It is shown in Chapter 4 that the fire accident has a small effect on the MPC temperatures because of blocking action of the underground storage system and the short duration of the fire event. Therefore, a structural evaluation of the MPC under the postulated fire event is not required for HI-STORM UMAX.

Likewise, it is shown that the load bearing components in the HI-STORM UMAX assembly will remain well below the temperature that may induce a significant structural deformation or collapse.

3.4.4.1 Safety Analysis

3.4.4.1.1 Design Basis Flood (Load Case 07 in Table 2.4.1)

Unlike free standing casks, moving flood water is not an event of safety consequence to HI-STORM UMAX: The buried configuration of the HI-STORM UMAX system renders it immune from sliding (that is germane to above ground freestanding casks) under the action of a design basis flood.

3.4.4.1.2 Design Basis Earthquake (Load Case 03 in Table 2.4.1)

The HI-STORM UMAX system, plus its contents, may be subject to the Design Basis Earthquake (DBE) defined by the response spectra in Figures 2.4.1 and 2.4.2. As explained in Chapter 2, the DBE has been defined for the HI-STORM UMAX ISFSI to ensure that the operative spectra (Figures 2.4.1 and 2.4.2) essentially envelope the corresponding site DBE spectra at virtually all US sites. Because the VVM is buried in the substrate, tip-over of the MPC is not possible.

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:

1. Inertia force from CEC self-weight
2. Inertia forces from the Closure Lid self-weight
3. Interface forces from the rattling of the MPC within its confines of the CEC and the rattling of the contents inside the MPC
4. Interface forces from the subgrade and from the SFP

The CEC Container Shell may develop longitudinal stresses as it bends like a beam to resist the input seismic loads. In addition, the CEC Container Shell and the Divider Shell are subject to ovalizing action from the loads. Both effects are captured in the seismic analysis.

The seismic analysis consists of three discrete steps, namely:

A. Develop the Design Basis Seismic Model (DBSM) for the HI-STORM UMAX ISFSI and perform the Design Basis Earthquake Soil-Structure Interaction (SSI) analysis.

B. Seismic Qualification of the VVM Components based on the SSI analysis results.

C. Stress analysis of the ISFSI structures using the dynamic loads obtained from the LS-DYNA SSI analysis using DBSM.

A. Design Basis Seismic Model and SSI Analysis

As discussed in Section 2.4, based on the lower bound shear wave velocity profile of US nuclear power plants (Figure 2.4.3) and the input seismic acceleration time history derived from the Regulatory Guide 1.60 seismic response spectrum, a two-step soil seismic response analysis using the computer code SHAKE2000 [3.4.4] and LS-DYNA [3.4.5] is performed to establish a bounding seismic loading condition for the HI-STORM UMAX underground fuel storage system. The 1-D SHAKE analysis model consists of 21 native soil layers of the HI-STORM UMAX ISFSI site with a total thickness of 101 ft; the top of the 7th 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. Figure 3.4.1 shows the LS-DYNA soil model for the seismic response analysis. It is noted 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 [2.4.1], 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 soil seismic response analysis is used later in the DBSM developed to perform SSI analyses for the HI-STORM UMAX ISFSI.

The object of the DBSM is to obtain conservative values of the loads on the ISFSI structures under the Design Basis Earthquake, which is defined as the response spectra at both the ground surface and the ISFSI foundation elevations as shown in Figures 2.4.1 and 2.4.2 (obtained from the two-step SHAKE/LS-DYNA soil seismic response analysis). Following the approach used in the safety evaluation of HI-STORM 100U, the reference VVM assemblage used in the seismic qualification is a 5 by 5 array. The actual array size, as noted in the HI-STORM 100U (docket number 72-1014) may be much larger. The essential attributes of the DBSM are:

1. The DBSM is developed using the finite element code LS-DYNA; this HI-STORM UMAX ISFSI soil-structure model consists of loaded VVMs, concrete pads, and soil spaces with properties as defined in Table 2.3.2. The HI-STORM UMAX VVM Model is discussed in detail in Paragraph 3.1.3.1.

2. The model has the capability to remove the lateral subgrade all the way down to the bottom of the SFP (which conservatively represents an excavated configuration during additional site construction such as to extend the ISFSI).

3. The model has the ability to simulate a loaded cask transporter arrayed on top of the ISFSI pad to enable the stability of the transporter and the structural margin of safety in the ISFSI pad to be determined.

4. 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.

5. The ISFSI pad and SFP are simulated as a flexible plate-type structure represented by layered solid elements. Proper contact interfaces are defined among the ISFSI pad, the SFP, the ISFSI subgrade and undergrade. For conservatism, the optional enclosure wall is not considered in the DBSM.

6. The VCT, along with the carried transfer cask, is modeled as a freestanding rigid body.

7. The ISFSI pad is characterized by an LS-DYNA inelastic concrete model (MAT_PSEUDO_TENSOR) to account for energy dissipation in the concrete due to the impact loading from the loaded VCT. The SFP and soil are modeled using the LS-DYNA elastic material model. 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 [3.4.15].

8. Proper element size and time step controls in the dynamic model are implemented following the guidance in references [3.4.14] and [3.4.15].

The previously described DBSM is used to perform SSI analyses for the four applicable HI-STORM UMAX ISFSI loading scenarios identified and listed in Table 3.4.2. Figures 3.4.2 and 3.4.3 show the corresponding LS-DYNA models of the two ISFSI configurations considered in the four SSI analyses. In each case, the Design Basis Earthquake is applied to the bottom of the LS-DYNA model using the acceleration time histories obtained from the previously described 1-D SHAKE seismic response analysis.

Table 3.4.3 lists the peak ISFSI interface loads obtained from the LS-DYNA SSI simulations of the four loading scenarios listed in Table 3.4.2. These dynamic peak interface loads will be used in the structural qualification of the ISFSI. In addition to the ISFSI interface loads, the SSI analyses also demonstrate that the exposed SES due to excavation for ISFSI expansion can remain intact during the DBE event without the lateral support from the optional enclosure wall. Figure 3.4.4 shows the maximum tensile stress experienced by the SES. The SES has a much greater tensile capacity (see Table 3.3.4) and the safety factor of the SES against rupture is calculated as

$$Safety\ Factor = \frac{Rupture\ strength}{Maximum\ computed\ tensile\ stress\ from\ Figure\ 3.4.4}$$

$$= \frac{158.1 psi}{77.91 psi} = 2.03$$

Finally, the stability of the loaded VCT is confirmed by the LS-DYNA SSI analyses.

B. Seismic Qualification of VVM Components

In addition to the SSI analysis, a governing MPC to MPC guide impact analysis is performed. Figure 3.4.5 shows the MPC to guide impact model, where the MPC guide is fixed at its base and the loaded MPC rotates about the bottom pivot point with an angular velocity to result in an impact force that significantly bounds, or more precisely is over 2 times, the load capacity of the MPC guide (see Table 3.4.4 and Figure 3.4.6a). The MPC enclosure vessel and its contents are explicitly modeled with sufficiently fine mesh density, following the conclusion obtained from the mesh sensitivity study performed for the MPC shell in Docket number 72-1014, to capture the high stress gradient at the impact location. Results obtained from the MPC-to-guide impact analysis and those from the above mentioned SSI analyses are used to structurally qualify HI-STORM VVM components herein.

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

a. Divider and CEC 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 (subject to buckling)
d. Lateral loading on the fuel basket panels (must meet the g-load limit).
e. Localized strain in the MPC shell (due to impact of the MPC with the MPC guides if excessive, may cause breach of confinement)

The focus of safety analysis of each component under the DBE event is somewhat different as summarized below:

a. CEC and Divider Shell: These shells are subject to ovalizing forces which may, in theory, cause them to deform and impede future retrievability of the loaded MPC. Since the SES between the ISFSI pad and the SFP is much stiffer than the subgrade material in the HI-STORM 100U design (the SES modulus of elasticity is at least 6.76 times the value of 100U subgrade based on the required shear wave velocity values), ovalization is not a credible concern for HI-STORM UMAX VVM given the very high safety factor (>18) in the 100U design.

b. Primary stress in the MPC shell: The maximum stress intensity in the MPC shell is compared against the allowable stress intensity for the Level D condition. The safety factor is computed as the ratio of the allowable stress intensity under Level D service condition for "NB" components to the maximum computed longitudinal flexural stress intensity in the MPC shell. Figure 3.4.6b shows the distribution of maximum shear stress (i.e., ½ of the stress intensity) in the MPC shell under the bounding impact condition. As documented in the calculation package [3.4.1], the safety factor of the MPC shell against primary stress is well above 1.0.

c. Top and Bottom MPC Guides: The MPC guides are subject to in-plane rattling loads from the lateral movement of the MPC under the inertia loading from the earthquake. The maximum in-plane load bearing capacity of the longest MPC guide permitted by the system design (see Licensing Drawings) is computed and compared with the maximum dynamic loads obtained from the LS-DYNA analysis. The safety factor is calculated as the ratio of the in-plane load bearing capacity and the actual maximum load computed by the LS-DYNA analysis. The analyses summarized in the Calculation Package [3.4.1] shows that the minimum safety factor from the array of dynamic simulations is greater than 1.0.

d. Loading on the Fuel Basket panel: The minimum lateral g-load to which all of the MPCs listed in Table 1.2.1 have been qualified is 45 g's (corresponding to the non-mechanistic tip-over event). As shown in Figure 3.4.7, the maximum fuel g-load predicted by the LS-DYNA simulation, conservatively measured at the top lid of the MPC, is significantly smaller than the minimum permitted value for the array of MPC types that may be stored in the HI-STORM UMAX system.

e. Maximum Local Strain in the Confinement Boundary in the Impact Region: The MPCs are constrained from uncontrolled lateral motion by the radial guide plates located at their baseplate and top lid elevations. Even a small clearance between the MPCs 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. Based on the parametric study performed from HI-STORM 100 U, the extent of local strain from impact is minimized by locating the MPC top guide in the vertical direction such that the mid-height of the impact footprint is aligned with the lower surface of the MPC lid in the HI-STORM UMAX design. Thus the location of impact is removed from the lid-to-shell weld junction. Figure 3.4.8 shows the maximum MPC shell maximum plastic (true) strain obtained for the bounding MPC-to-guide impact simulation. The plastic strain developed in the MPC shell is only a small fraction of the acceptable value based on the very conservative recommendation in [3.1.3]. Therefore the integrity of the confinement boundary is assured.

Table 3.4.4 summarizes the seismic qualification analysis results for VVM components.

C. <u>Strength Qualification of the ISFSI Structure</u>

Under the Design Basis Earthquake (Figures 2.4.1 and 2.4.2), the loads exerted on the Support Foundation Pad and the ISFSI Pad are obtained from the LS-DYNA SSI simulations listed in Table 3.4.2. Table 3.4.3 lists the peak ISFSI interface loads obtained from various LS-DYNA runs listed in Table 3.4.2. 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. 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 ISFSI pad (see Table 2.3.2).

The SFP and ISFSI pad are required to meet the minimum structural requirements set down in Table 2.3.2 and the Licensing Drawings. The ISFSI pad is required to satisfy ACI-318 (2005) [3.4.6] strength limits under all applicable load combinations (Table 2.4.3).

Table 2.4.3 specifies the load combinations 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 previously, the long-term settlement of the undergrade from the loaded VVMs and the dead weight of the SFP are 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.

This methodology of settlement computation is based on classical soil mechanics and 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 [3.4.7].

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 subgrade below SFP is limited to the value specified in Table 2.3.2. Remedial measures such as pilings must be used if the Table 2.3.2 limit cannot be met.

(ii) 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.

(iii) 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 2.3.2.

(iv) Use the bounding peak loads obtained from the dynamic analysis to compute the stress fields in the pads (SFP and ISFSI pad).

(v) 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 the ISFSI pad.

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

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

The structural evaluation of the HI-STORM UMAX ISFSI is performed using the commercial computer code ANSYS [3.1.1]. The constituents of the ISFSI, namely the Support Foundation Pad (SFP), the subgrade under the support foundation pad (the undergrade), the ISFSI pad and the subgrade lateral to the CEC under the ISFSI pad are all modeled using linear elastic SOLID45 elements. The element mesh is intentionally kept fine in the areas of load application on the SFP and the ISFSI pad. The lateral subgrade adjacent to the HI-STORM UMAX ISFSI (Spaces B and D in Figure 2.4.4) is included in the FE model and extends laterally a distance that exceeds the overall depth of the FE model considered for structural analysis. 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 ISFSI pad, which is consistent with the Design Basis Seismic Model discussed previously. The "base" model (Simulation Model I) considers that all the storage locations in ISFSI are populated and experience identical peak vertical seismic loading from Table 3.4.3, which bounds the peak result obtained from the LS-DYNA SSI solution as discussed previously. Because of the symmetric geometry and loading, a quarter symmetric finite element model is sufficient to represent the fully loaded ISFSI. Figure 3.4.9 shows the finite element model of HI-STORM UMAX ISFSI. For a non-symmetric model as in case of Simulation Model II, a full FE model of the HI-STORM UMAX ISFSI as shown in Figure 3.4.10 is used. The "degraded" elastic modulus of the subgrade under the SFP is appropriately computed to account for the long-term settlement effects as described in the foregoing. Table 3.3.4 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 loaded configurations include a two row loaded ISFSI, 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 3.4.14, 3.4.16 and 3.4.18 illustrate the partial loading configurations for the ISFSI. These loading configurations are hereinafter referred to as Simulation Models II, III, and IV, respectively. The effects of exposed Self-hardening Engineered Subgrade between the ISFSI pad and SFP are evaluated in a fifth Simulation Model (Simulation Model V), which is shown in Figure 3.4.11. In this model, the lateral subgrade is completely removed from one side to bound any future excavation activities associated with the construction of a new underground ISFSI. For Simulation Model V, all VVM locations are assumed to be loaded and thus the transporter load is excluded.

To simulate the material continuity at the extreme boundary surface of the substrate under the SFP, translations are constrained at the lateral face of the subgrade. 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 footprint of the CEC base at all VVM locations.

2. The load from the transporter is applied as a normal pressure (see Figures 3.4.12 and 3.4.16) over the transporter load patch on the ISFSI pad. The transporter is assumed to be positioned over the central VVM cavity.

3. The dead weight from 11'×11' square ISFSI pad region that is centered above each VVM location (see Licensing Drawing in Section 1.5) is applied as a normal pressure on the SES elements directly beneath the ISFSI pad.

4. To simulate the self-weight of the modeled portion of the ISFSI pad, 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 is permissible 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 2.4.3 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 3.4.13a through 3.4.21c depict the maximum in-plane stresses in the ISFSI concrete structures 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 ISFSI pad 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 3.4.5 summarizes the results for the SFP and the ISFSI pad respectively for all ISFSI configurations analyzed. The safety factors listed in Table 3.4.5 show that the ISFSI pad contains a substantially greater strength reserve than that required by the ACI code. In establishing the safety factors, no credit has been taken the Dynamic Increase Factor of 25% for flexure and 10% for shear permitted by [3.4.8] in the strength qualification of reinforced concrete under the impactive loadings that are intrinsic to the seismic event.

Table 3.4.6 summarizes the punching shear safety factor for the SFP and the ISFSI pad. The minimum punching shear safety factor under the governing condition (when the loaded transporter is positioned on the ISFSI pad) is found to be well above 1.0.

The peak transporter load on the ISFSI pad from the LS-DYNA SSI analyses plus the load from the ISFSI pad are used to compute the maximum bearing stress in the substrate surface under the ISFSI pad. According to ACI-360 [3.4.9], the bearing stress can be calculated by uniformly distributing the load over the entire bearing area of the pad. The maximum computed bearing stress in the subgrade below the ISFSI pad (Table 3.4.7) meets the minimum safety factor of 2.0 (suggested by the ACI code [3.4.9]) with ample margin.

Detailed calculations for qualifying the HI-STORM UMAX ISFSI structures are documented in [3.4.17].

3.4.4.1.3 Design Basis Missile Loading (Load case 02 in Table 2.4.1)

3.4.4.1.3.1 Tornado Missile Strike on VVM Closure Lid (Load Case 02 in Table 2.4.1)

Design basis tornado missiles are specified in Table 2.3.3. The Closure Lid is the only component of the VVM that is accessible to a tornado missile; therefore, missile impact analyses focus on this component. The impact a large missile is evaluated to determine whether the Closure Lid can maintain its required shielding function. Because of its size and the steel cross structure in the central pipe of the Closure Lid, the large missile can only delivers its kinetic energy to the side and top surface of the lid and with no penetration. The medium missile, however, is able to pass through the top opening in the Closure Lid, impacting what is termed the "Lid Extension", a concrete filled steel weldment.

The formula from "Topical Report – Design of Structures for Missile Impact", BC-TOP-9A, Rev. 2, 9/74 [3.4.12]] 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

$$F(t) = 0.625\ \text{sec/ft} \times 184.8\ \text{ft/sec} \times 4000\ \text{lb} \times \sin(20t) = 462{,}000\ \text{lb} \times \sin(20t)\ \text{for}\ t < 0.0785\ \text{sec.}$$
$$= 0\ \text{for}\ t >= 0.0785\ \text{sec.}$$

This representation of the large missile impact load is appropriate as demonstrated by the result of a modern passenger vehicle full-scale impact testing. Figure 3.4.22 shows the force-time history from the full-scale test of a full-size Ford passenger vehicle [3.4.11]. 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 is found to be in good accord with the peak value predicted from [3.4.12], which provides a good confirmation of the methodology in [3.4.12]. Because of the simple geometric configuration of the Closure Lid, the large missile impact is evaluated using strength of materials approach. The calculation results indicate that the large missile event will neither cause the collapse of the Closure Lid nor dislodge the lid from the CEC cavity. Moreover, the lid concrete bearing capacity will not be exceeded by the large missile impact. The details of this calculation are found in [3.4.1].

The analyses performed for the intermediate missile (i.e., a rigid 275 lb 8" diameter cylindrical steel bar) and the small missile (i.e., a 1" diameter solid steel sphere) are based on the energy approach previously used in the missile impact analyses for HI-STORM 100 and HI-STORM FW storage systems. No credit for the central steel "cross" shaped structure is taken and the impact on the "Lid Extension" is also considered in the analysis. Analysis results demonstrate that the intermediate and small missiles will not penetrate the steel weldment and encased concrete of the Closed Lid or cause the drop of the Extended Lid to threat the stored MPC.

A summary of results are presented in Table 3.4.8. Thus, the assessment of all missile impact scenarios leads to the conclusion that the postulated missile strikes will not preclude MPC retrievability, will not cause loss of confinement, and will not affect criticality.

3.4.4.1.3.2 Tornado Missile Protection During Construction

The scenario of an excavation near the ISFSI has been considered. The optional Enclosure Wall on the exposed side of the ISFSI is not considered in the tornado missile analysis. The impact of the exposed lean concrete by the Design Basis Missiles (Table 2.3.3) using the methodology documented in [3.4.10] shows that the MPC storage cavities remain beyond the reach of the missiles.

3.4.4.1.4 Non-Mechanistic Tipover

Tipover is not an applicable load case for HI-STORM UMAX. The VVM is situated underground and cannot be moved; therefore, drop and tipover events are not credible accidents for this design configuration.

3.4.4.1.5 Maximum Temperature and Internal Pressure under Normal and Off-Normal Conditions

The HI-STORM UMAX VVM is open to the environment; therefore, it is not subject to any internal pressure.

The MPCs authorized for storage in HI-STORM UMAX (listed in Chapter 1) have been analyzed and qualified for normal and off-normal conditions of storage in their host docket (i.e., docket number 72-1032 for HI-STORM FW). Calculations in Chapter 4 show that the internal operating temperature in every MPC at its permissible maximum heat load when stored in HI-STORM UMAX is less than the value used in the stress analysis in docket number 72-1032. Because the internal pressure in the MPC bears a proportional relationship to the average internal temperature in the MPC cavity, it follows that the internal pressure in the MPC when stored in HI-STORM UMAX will be less than that assumed in the stress analysis of the MPC in docket number 72-1032. Therefore, the stress values computed for the MPC under normal and off normal operating conditions in docket number 72-1032 will envelope their corresponding values for storage in HI-STORM UMAX.

3.4.4.1.6 Maximum Temperature and Internal Pressure Under Accident Conditions

HI-STORM UMAX, being an open to environment cask, does not experience any internal pressure under accident conditions.

The MPCs authorized for storage in HI-STORM UMAX (listed in Chapter 1) have been analyzed and qualified for accident conditions of storage in their host docket(i.e., docket number 72-1032 for HI-STORM FW). Calculations in Chapter 4 show that the internal operating temperature in every MPC at its permissible maximum heat load when stored in HI-STORM UMAX is less than the value used in the stress analysis in docket number 72-1032. Because the internal pressure in the MPC bears a proportional relationship to the average internal temperature in the MPC cavity, it follows that the internal pressure in the MPC when stored in HI-STORM UMAX will be less than that assumed in the stress analysis of the MPC in docket number 72-1032. Therefore, the stress values computed for the MPC under accident conditions in docket number 72-1032 will envelope their corresponding values for storage in HI-STORM UMAX.

3.4.4.1.7 Handling of Components

The stress analyses of the HI-STORM UMAX VVM under normal handling conditions are presented in Subsection 3.4.3. The stress analyses of the MPC and the HI-TRAC transfer cask under normal handling conditions are presented in their host docket (i.e., docket number 72-1032 for HI-STORM FW).

3.4.4.1.8 Snow Load

Load Case 01 in Table 2.4.1, presented later in this section, is a bounding load combination that conservatively subsumes a number of normal and extreme environmental phenomena loads including snow load.

3.4.4.1.9 Transfer Cask and Mating Device Loading on VVM Container Shell (Load Case 06 in Table 2.4.1)

During HI-STORM UMAX system loading, a HI-TRAC transfer cask with a fully loaded MPC is placed over a HI-STORM UMAX VVM using a specially designed transporter and a lifting device meeting ANSI N14.6 stress margin requirements. The transfer cask is connected to the CEC using an ancillary mating device (see Chapter 9). Although the Self-hardening Engineered Subgrade will not settle relative to the SFP during the entire service time of the ISFSI, the CEC shell is evaluated herein by conservatively assuming that the entire weight of the transfer cask and the mating device is supported by the shell and that neither the ISFSI pad nor the SES provides any support to the CEC shell. Based on a conservatively assumed total weight (400 kips) of the transfer cask and mating device, the compressive stress of the CEC shell is compared with the Level A service stress limit for NF Class 3 plate and the critical buckling stress for thin-walled cylindrical shell. Results presented in Table 3.4.9 demonstrate that the CEC shell can support the total weight of transfer cask and mating device with large margins.

3.4.4.1.10 Dead Load plus Design Basis Explosion Pressure on VVM Components (Load Case 01 in Table 2.4.1)

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 a steady pressure that bounds the explosion pressure (see Table 2.3.1). Due to the simple configuration of the lid, the strength of materials method is used perform the evaluation. The stresses from the solution are compared, per the criteria in Table 2.4.1, 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 3.1.6 for Level D conditions.

As demonstrated in the structural calculation package [3.4.], the combined load from dead weight and the design basis explosion pressure is bounded by the maximum missile vertical impact force applied to the lid. Moreover, it's impossible for the CEC shell to deform under the design basis explosion pressure since it is directly against the SES with a bearing capacity of at least 10 times the design basis explosion pressure. It is therefore concluded that there is a large margin of safety in the HI-STORM UMAX Closure Lid and CEC Container Shell against the lateral pressure from Design Basis Explosion.

3.4.4.1.11 Design Basis Fire on VVM Closure Lid (Load Case 05 in Table 2.4.1)

With respect to the fire event (Load Case 05 in Table 2.4.1), where the Closure Lid steel temperature is conservatively assumed to rise to the limit set in Table 2.4.1, it is noted from Tables 3.1.4 and 3.3.1 that the Level A stress limit is reduced to 0.60 of the room temperature value, the yield strength is reduced to 0.67 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 structural collapse of the lid due to reduction of the ultimate strength because of the heat of the fire is not possible.

3.4.5 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 above ground HI-STORM certified in docket number 72-1032. Therefore, no new analyses are identified for the HI-STORM UMAX system.

3.4.6 Miscellaneous Evaluations

None.

3.4.7 Service Life of HI-STORM UMAX VVM

The term of the 10CFR72, Subpart L C of C, granted by the NRC is 40 years; therefore, the License Life (see Glossary) of all components is 40 years. The principal design considerations that bear on the adequacy of the storage module for the service life are addressed as follows:

Exposure to Environmental Effects

All exposed surfaces of the HI-STORM UMAX Cavity Enclosure Canister are made from ferritic steels that are painted and protected from corrosion on the outside by appropriate means as described in Chapter 8.The inside surface of the CECs and the Divider Shells is protected by paint. In addition, one side of the Divider Shell is further protected by insulation. Concrete, which serves strictly as a shielding material in the Closure lid, is completely encased in steel. Under normal storage conditions, the bulk temperature of the HI-STORM UMAX system will, because of its large thermal inertia, change very gradually with time. Therefore, material degradation from rapid thermal ramping conditions is not credible for the HI-STORM UMAX system. The configuration of the storage modules assures resistance to freeze-thaw degradation. In addition, the storage modules are specifically designed for a full range of enveloping design basis natural phenomena that could occur over the 60-year design life of the storage system. Chapter 8 provides further discussion on chemical and galvanic reactions, material compatibility and operating environments pertaining to HI-STORM UMAX.

Material Degradation

As discussed in Chapter 8, the relatively low neutron flux to which the storage modules are subjected is insufficient to produce measurable degradation of the cask's material properties and impair its intended safety function. Exposed carbon steel components are coated to prevent corrosion. The controlled environment of the ISFSI storage pad mitigates damage due to direct exposure to corrosive chemicals that may be present in other industrial applications.

Maintenance and Inspection Provisions

The requirements for periodic inspection and maintenance of the storage VVM throughout the 60-

year design life are defined in Chapter 10. These requirements include provisions for routine inspection of the inlet plenums and periodic visual or camera aided verification that the air flow paths are free and clear of debris. ISFSIs located in areas subject to atmospheric conditions that are particularly aggressive should be evaluated by the licensee on a site-specific basis to determine the frequency for such inspections to assure long-term performance. In addition, the HI-STORM UMAX system is designed for easy retrieval of the MPC from the storage VVM should it become necessary for any reason.

In summary, the VVM is engineered for a 60 years design life and a 100 year service life, while satisfying the conservative design requirements defined in Chapter 2. For information supporting the 60 year design life addressing chemical and galvanic reactions as well as other potentially degrading factors, reference is made to Chapter 8. Requirements for periodic inspection and maintenance of the HI-STORM UMAX VVM throughout the 60-year design life are defined in Chapter 10. The VVM is designed, fabricated, and inspected under the comprehensive Quality Assurance Program discussed in Chapter 14 and docket number 71-0784 (The service life of a system may exceed its design life if the system is maintained in accordance with the supplier's O&M manual).

The above findings supporting the HI-STORM UMAX service life are consistent with those of the NRC's Waste Confidence Decision Review [3.4.13], which concluded that dry storage systems designed, fabricated, inspected, and operated in accordance with such requirements are adequate for a 100-year service life while satisfying the requirements of 10CFR72.

Table 3.4.1

KEY STRESS RESULTS FOR HI-STORM UMAX CLOSURE LID NORMAL HANDLING

Item	Calculated Value (ksi)	Allowable Limit (ksi)	Safety Factor
Lifting Hole Tearout Stress	1.118	2.82	2.52
Lifting Hole Bearing Stress	6.708	8.46	1.26
Governing Weld Joint Stress	1.139	5.64	4.95

Table 3.4.2

SEISMIC LOADING SCENARIOS ANALYZED FOR HI-STORM UMAX

Scenario 1	All storage locations loaded with maximum weight MPCs, and a loaded VCT is placed at the center of the ISFSI.
Scenario 2	Same as Scenario 1 except that the Young's Modulus of the SFP concrete is reduced to one-half of its nominal value.
Scenario 3	Same as Scenario 1 except that the subgrade adjacent to one side of SES (Space A) is excavated down to the SFP and that the VCT is not considered.
Scenario 4	Same as Scenario 3 except that the Young's Modulus of the SFP concrete is reduced to one-half of its nominal value.

Table 3.4.3

ISFSI INTERFACE LOADS OBTAINED FROM LS-DYNA SSI SIMULATIONS

Interface Load	Scenario 1	Scenario 2	Scenario 3	Scenario 4
CEC to SFP Impact Load[1], lbf	7.7191×10^5	7.1945×10^5	7.1505×10^5	6.6774×10^5
Transporter to ISFSI Pad Contact Load per Track[2], lbf	8.6014×10^5	8.0838×10^5	NA	NA

Notes:

1. A bounding value of 8.0×10^5 lbf is conservatively used in the strength qualification of ISFSI structure reported in subparagraph 3.4.4.1.2;
2. A bounding value of 1.0×10^6 lbf is conservatively used in the strength qualification of ISFSI structure reported in subparagraph 3.4.4.1.2.

Table 3.4.4

HI-STORM UMAX VVM COMPONENTS SEISMIC QUALIFICATION ANALYSIS RESULTS

Item	Calculated Value	Allowable Limit	Safety Factor
Ovalization of VVM Shells	Not a credible concern; see discussion in subparagraph 3.4.4.1.2		
MPC Shell Primary Stress, ksi	25.88	42.0	1.62
MPC Guide Impact Load, lbf	2.1161×10^5†	2.368×10^5	1.12
MPC Peak Impact Deceleration, g's	27.854	45	1.62
Local Plastic Strain of MPC Shell, in/in	0.028	0.1	3.57

† This is the maximum impact load obtained from the four SSI runs listed in Table 3.4.2 and is bounded by the corresponding impact force (see Figure 3.4.6a) in the governing MPC to MPC guide impact analysis.

Table 3.4.5

MOMENT RESULTS AND CORRESPONDING MINIMUM SAFETY FACTORS FOR THE ISFSI STRUCTURES

ISFSI Load Configuration	Moment Induced (lbf-in/in)	Axial Force (lbf/in)	Corresponding Moment Capacity (lbf-in/in)	Minimum Safety Factor
Support Foundation Pad (SFP) ‡				
Simulation Model I	84,841	3095.8	207,792	2.449
Simulation Model II	94,625	-584.9	254,460	2.689
Simulation Model III	110,480	993.9	235,770	2.134
Simulation Model IV	96,271	770.3	238,750	2.479
Simulation Model V	78,835	4,502	189,080	2.398
ISFSI Pad ‡				
Simulation Model I	94,265	-39855	274,688	2.914
Simulation Model II	89,244	-14741	339,910	3.808
Simulation Model III	88,090	-31496	323,170	3.668
Simulation Model IV	87,086	-27938	343,800	3.947
Simulation Model V	62,025	4150	171,970	2.773

‡ The moment capacities for the SFP and ISFSI pad are calculated using axial-force-moment interaction diagram corresponding to the axial force and moment induced in the limiting element. Figure 3.4.13a through 3.4.21c also capture the stress plots for the governing load combination (LC-3 in Table 2.4.3) for all the ISFSI loading configurations analyzed.

Note that the flexural safety factors calculated above are based on the maximum moment induced in a single element, which is very conservative. Averaging over a width of the loaded section would result in much higher safety factors.

Table 3.4.6

MINIMUM SAFETY FACTORS AGAINST PUNCHING SHEAR FAILURE FOR THE ISFSI STRUCTURES

ISFSI Structure	Punching Shear Safety Factor
SFP	2.8
ISFSI Pad	1.5

Table 3.4.7

BEARING STRESS OF SUBGRADE UNDER THE ISFSI PAD

Computed Bearing Stress (psi)	Allowable Bearing Stress (psi)	Safety Factor	Minimum Safety Factor Required per [3.4.9]
38.7	100†	2.58	2.0

† Table 3.3.4 lists the actual bearing stress capacity, which is much greater than this conservatively specified allowable bearing stress.

Table 3.4.8

MISSILE IMPACT ANALYSIS RESULTS

Missile Type – Impact Location	Item	Calculated Value	Allowable Limit	Safety Factor
Large Missile – Impact on HI-STORM UMAX Closure Lid	Horizontal impact load that may dislodge the Closure lid, lbf	4.856×10^5	1.943×10^6	4.00
	Vertical impact load that may lead to the collapse of the Closure lid, lbf	3.237×10^5	2.66×10^6	8.21
Intermediate Missile – Impact on HI-STORM UMAX Closure Lid	Penetration, in	2.56	21	8.20
	Vertical impact load that may lead to the drop of the "extended lid", lbf	3.237×10^5	1.485×10^6	4.58
Small Missile – Impact on HI-STORM UMAX Closure Lid	Penetration, in	0.189	21	111.1
Large Missile – Impact on Exposed SES surface	Penetration, ft	0.177	10	56.5
Intermediate Missile – Impact on Exposed SES surface	Penetration, ft	0.544	10	18.4
Small Missile – Impact on Exposed SES surface	Penetration, ft	0.112	10	89.3

Table 3.4.9

BOUNDING STRESS AND BUCKLING ANALYSIS RESULTS OF THE SHELL DURING MPC TRANSFER OPERATION

Item	Calculated Value ksi	Allowable Limit ksi	Safety Factor
Compressive Stress of CEC Shell	1.698	Compression: 20	11.78
		Buckling: 263.5	155.2

Withheld in Accordance with 10CFR2.390

Figure 3.4.1; 3-D LSDYNA Soil Model for the Design Basis Seismic Response Analysis

Withheld in Accordance with 10CFR2.390

Figure 3.4.2; 3-D LSDYNA Model for the Non-Linear SSI Analysis of the HI-STORM UMAX ISFSI under the Loading Scenarios 1 and 2 in Table 3.4.2

Withheld in Accordance with 10CFR2.390

Figure 3.4.3; 3-D LSDYNA Model for the Non-Linear SSI Analysis of the HI-STORM UMAX ISFSI under the Loading Scenarios 3 and 4 in Table 3.4.2

Withheld in Accordance with 10CFR2.390

Figure 3.4.4; Maximum Tensile Stress Experienced by the Exposed SES due to Excavation during the DBE Event

Withheld in Accordance with 10CFR2.390

Figure 3.4.5; LSDYNA Model for the Governing MPC to Guide Impact

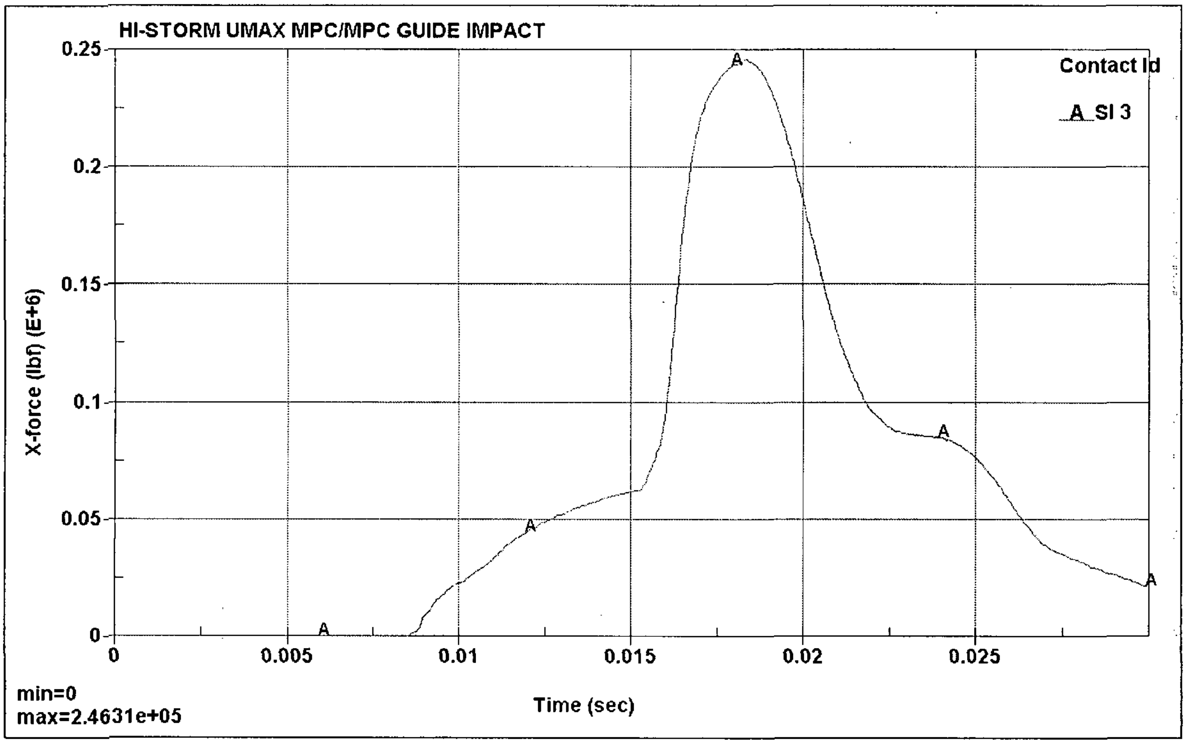


Figure 3.4.6a; Time History of the Impact Force at the MPC/MPC Top Guide Interface (Maximum force = $2\times2.4631\times10^5$ lbf = 4.9262×10^5 lbf due to the half model)

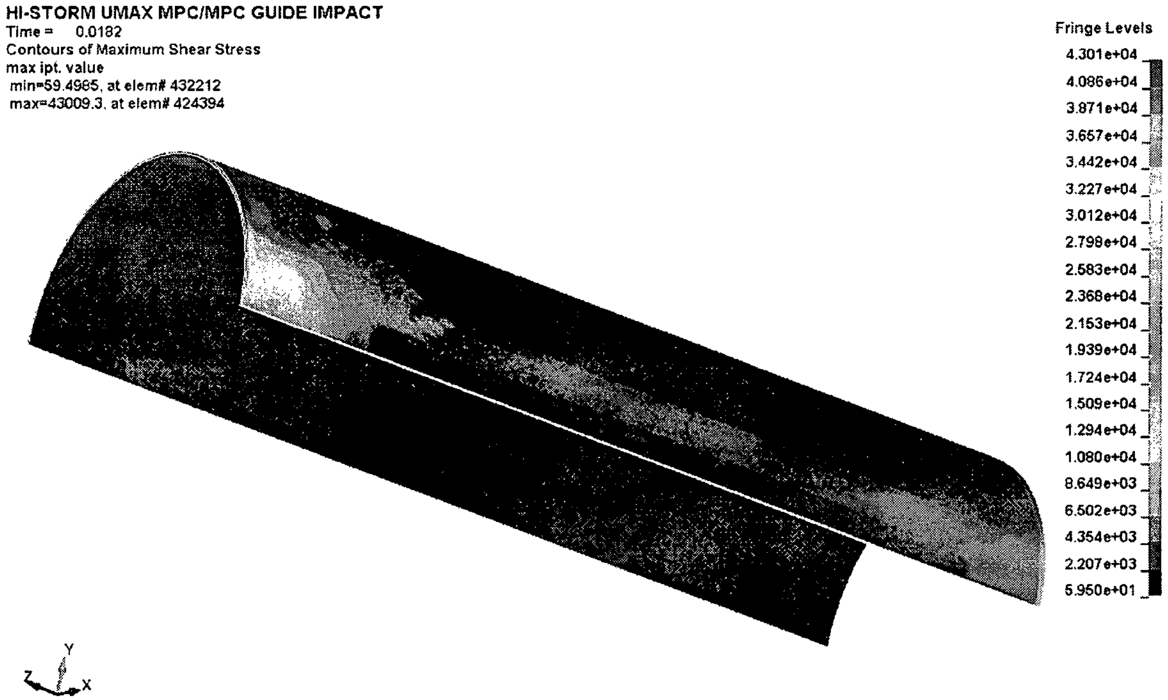


Figure 3.4.6b; Maximum Shear Stress of the MPC Shell
(Maximum Primary Stress Intensity = 2×12,940 psi = 25,880 psi)

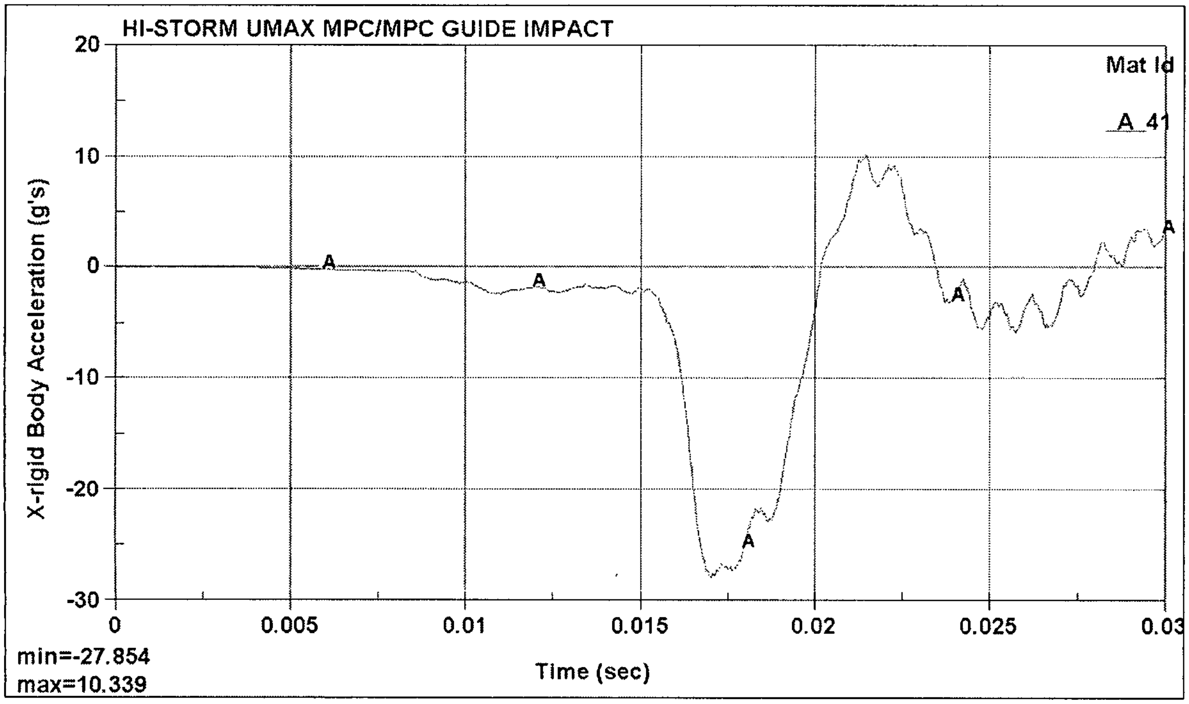


Figure 3.4.7; MPC Top Lid Impact Deceleration Time History under the DBE Condition

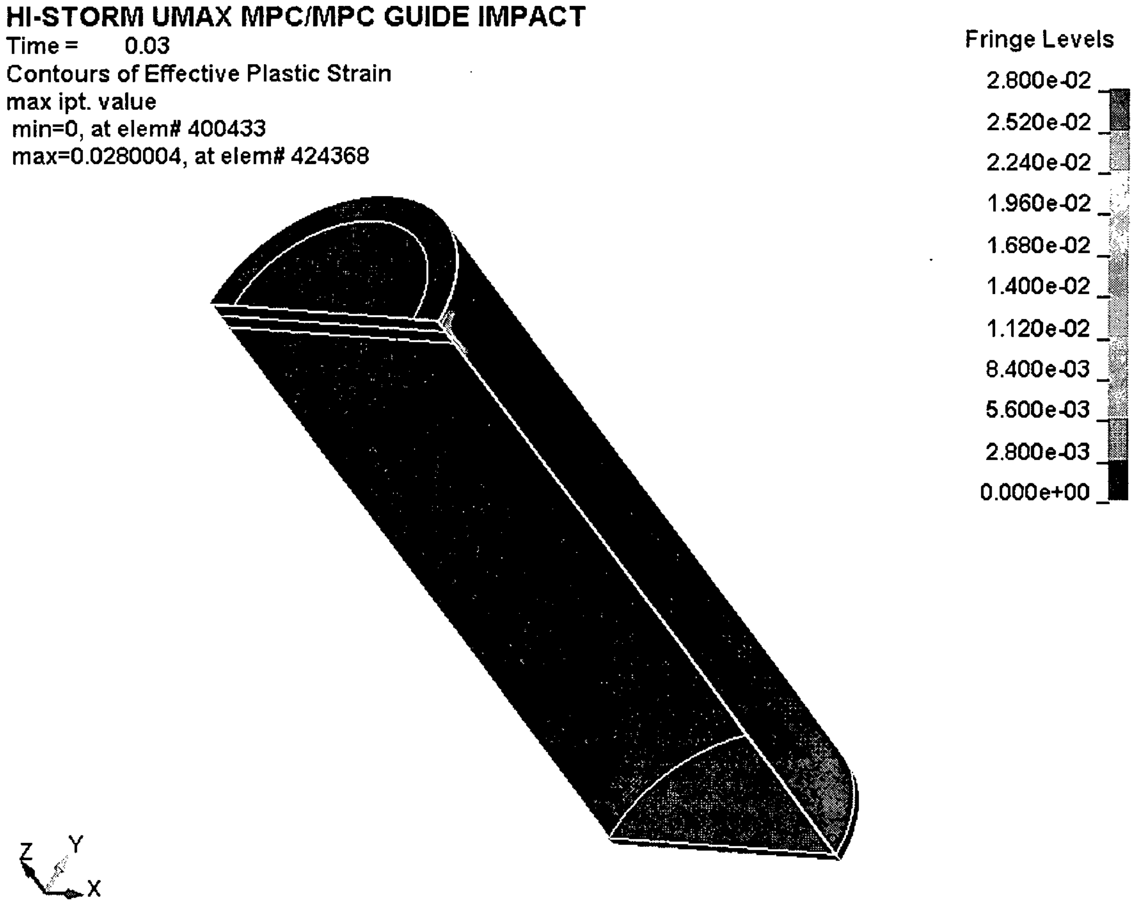


Figure 3.4.8; Maximum Plastic Strain of the MPC Enclosure Vessel Due to the Bounding Impact with the MPC Top Guide under the DBE Condition

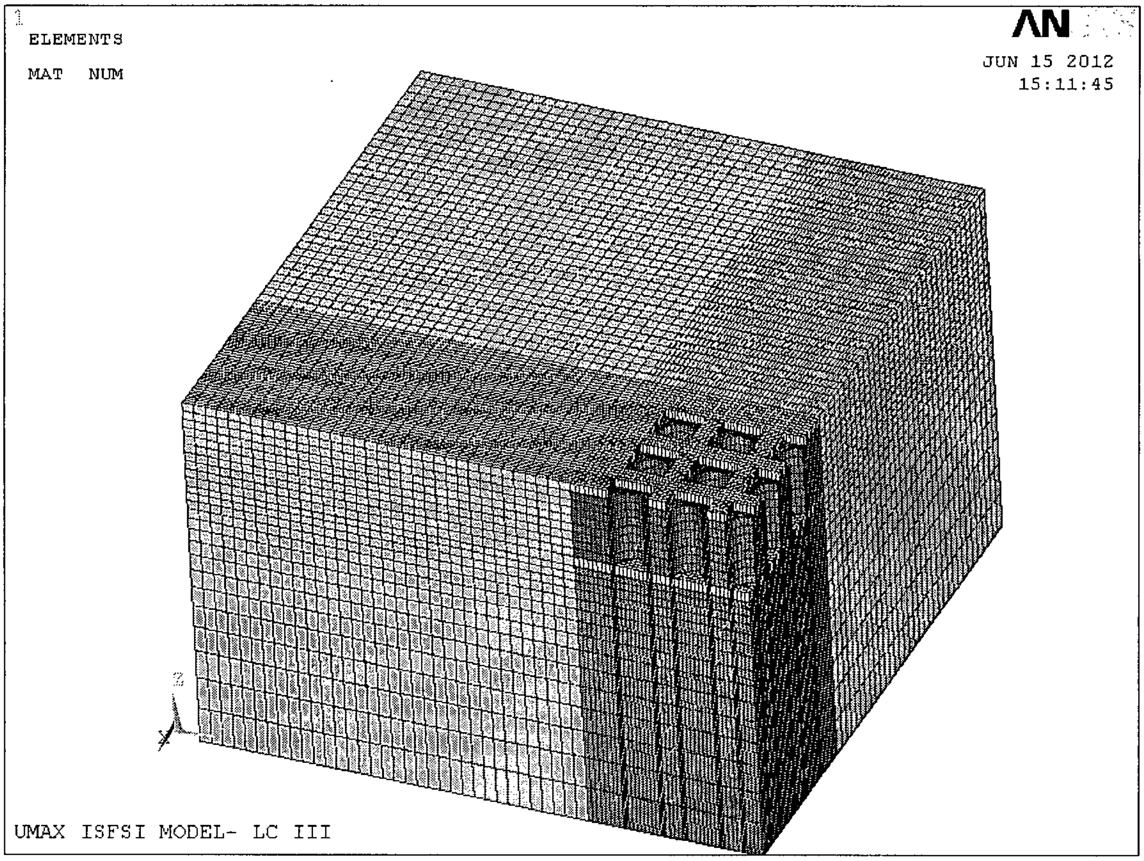


Figure 3.4.9; Finite Element Model of the ISFSI Reinforced Concrete Structures for Simulation Models I, III and IV

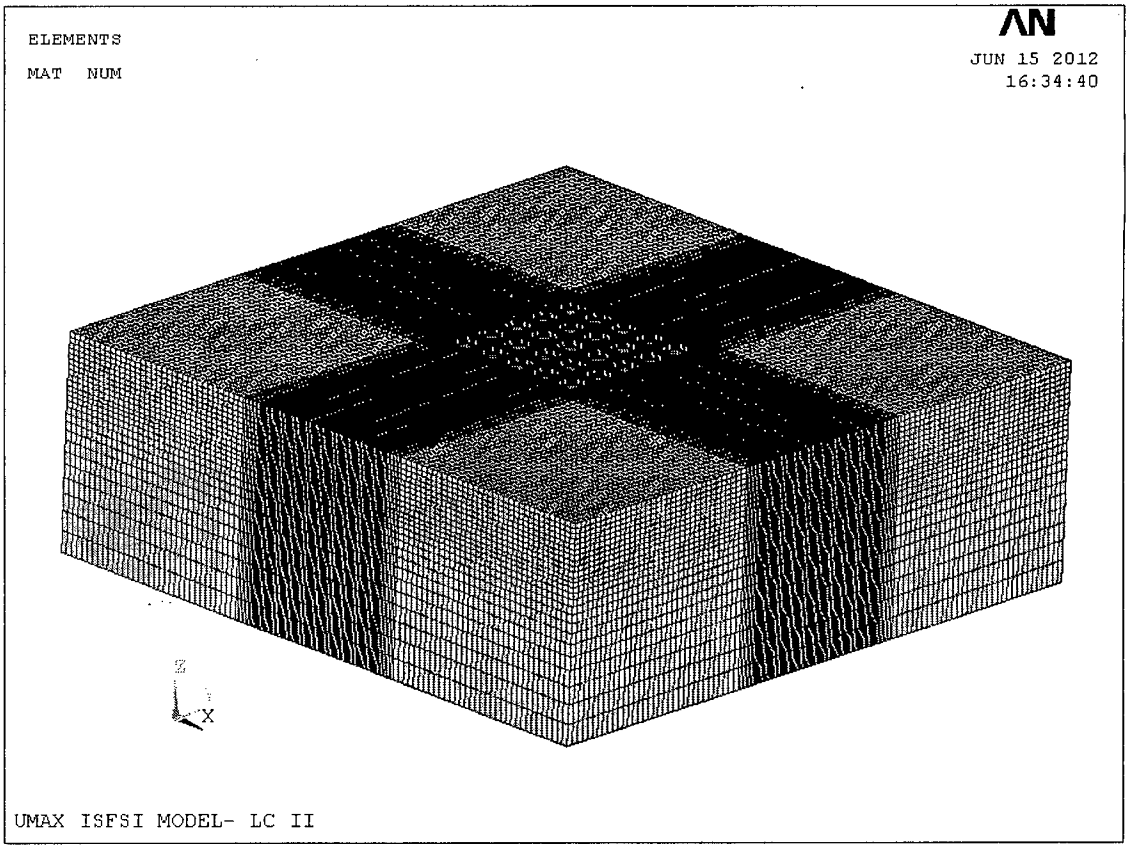


Figure 3.4.10; Finite Element Model of the ISFSI Reinforced Concrete Structures for Simulation Model II

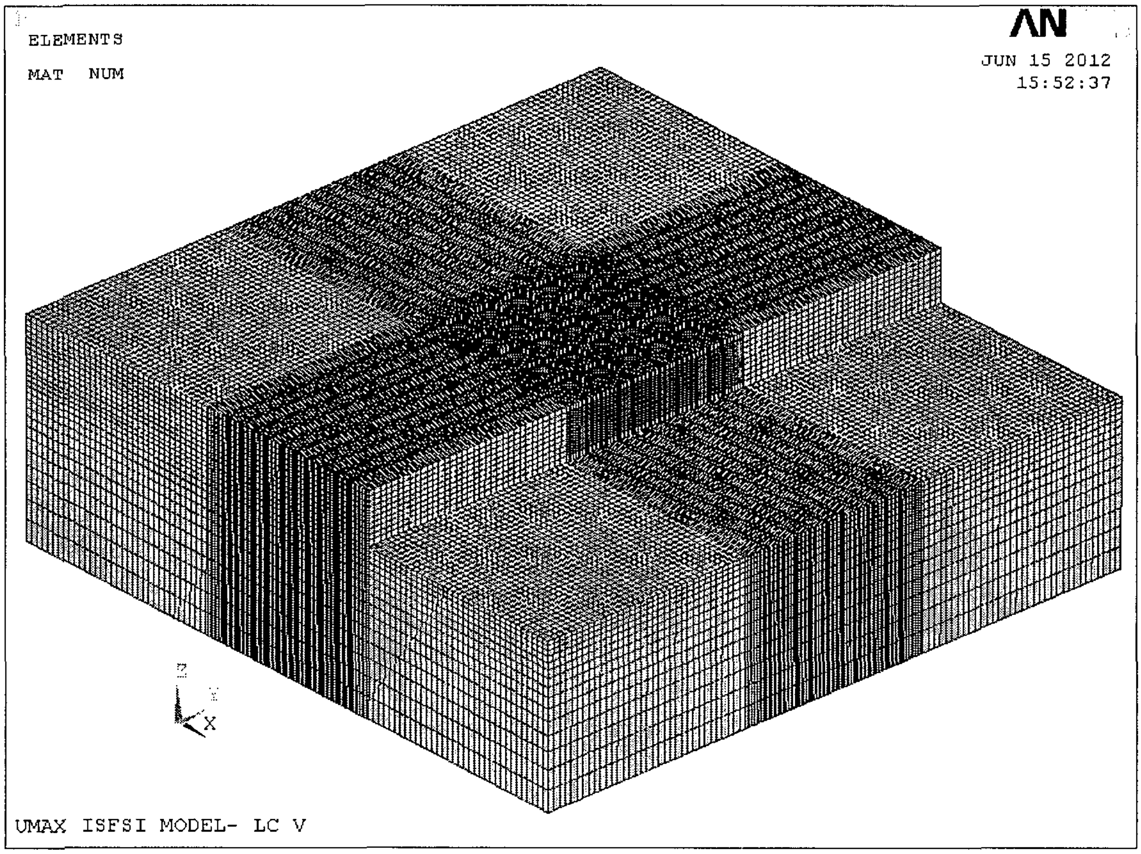
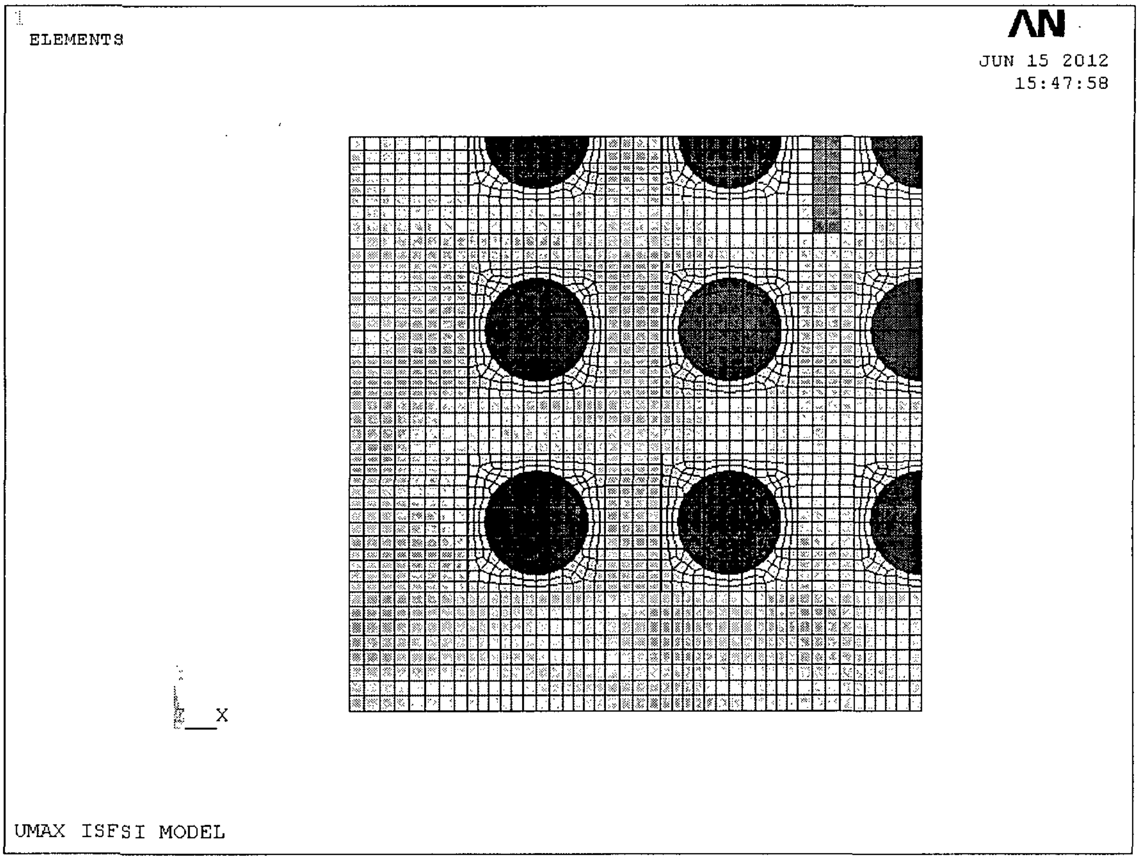


Figure 3.4.11; Finite Element Model of the ISFSI Reinforced Concrete Structures for Simulation Model V



Note: The blue footprints show the SFP area loaded with the SSC's and the red footprint represents the loaded TSP area with the transporter (VCT). The soil extending beyond the SFP boundary is not shown in the above plot for clarity.

Figure 3.4.12; ANSYS Finite Element Model of ISFSI Showing the Fully Loaded Configuration (Simulation Model I)

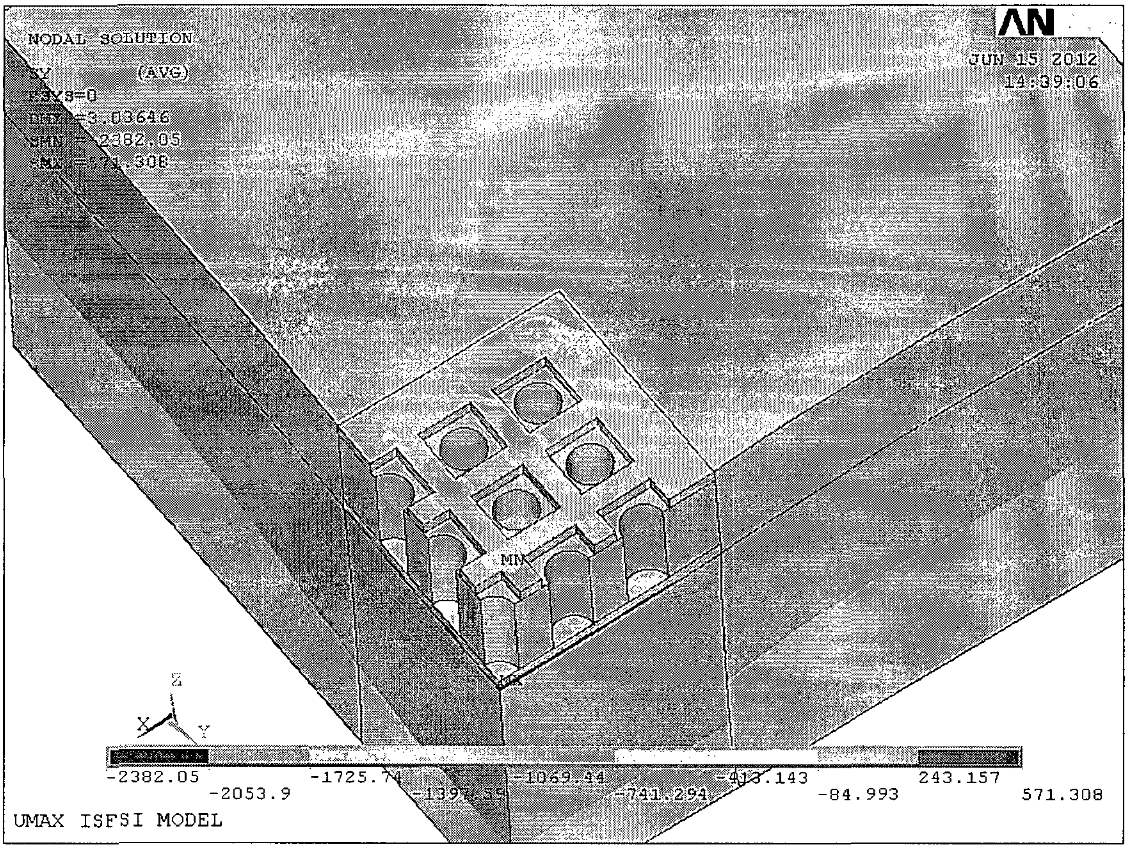


Figure 3.4.13a; Normal Stress (Sy) in the ISFSI in the Direction of the Transporter Path for Simulation Model I – Load Combination LC-3 from Table 2.4.3

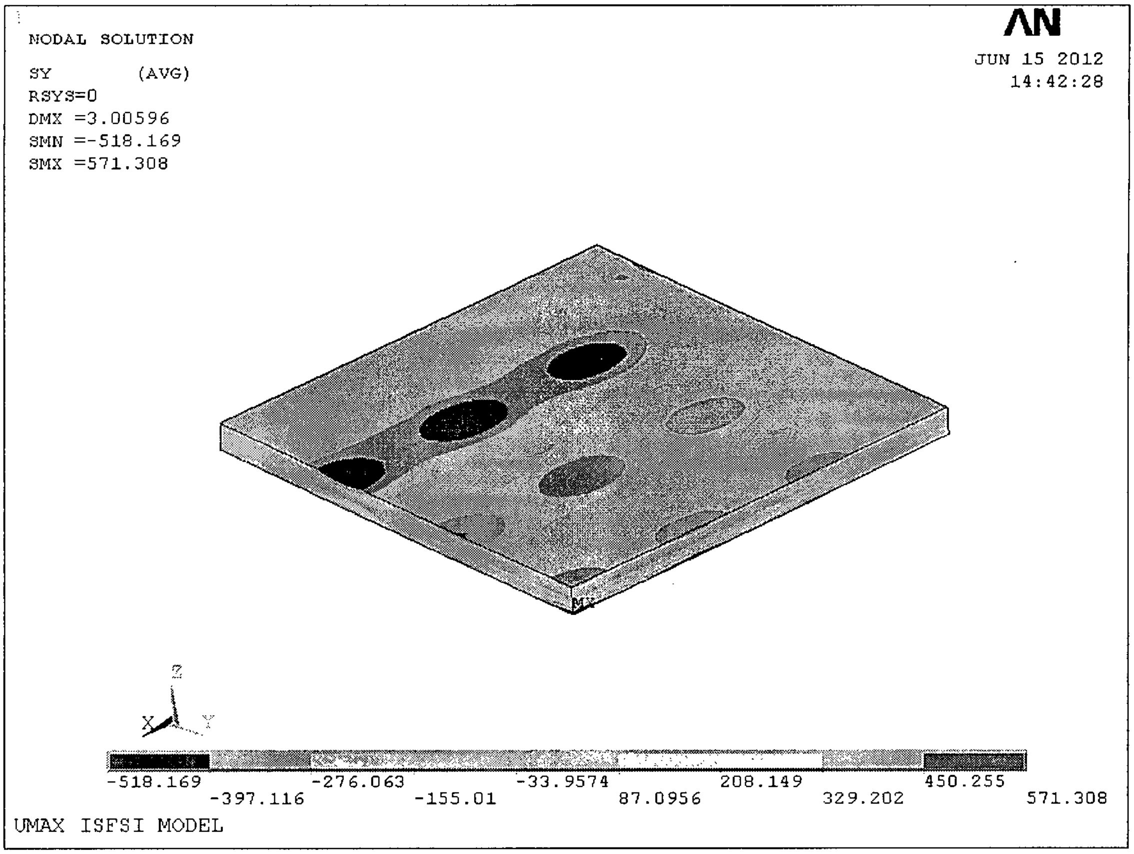


Figure 3.4.13b; Normal Stress (Sy) in SFP, Simulation Model I – Load Combination LC-3 from Table 2.4.3

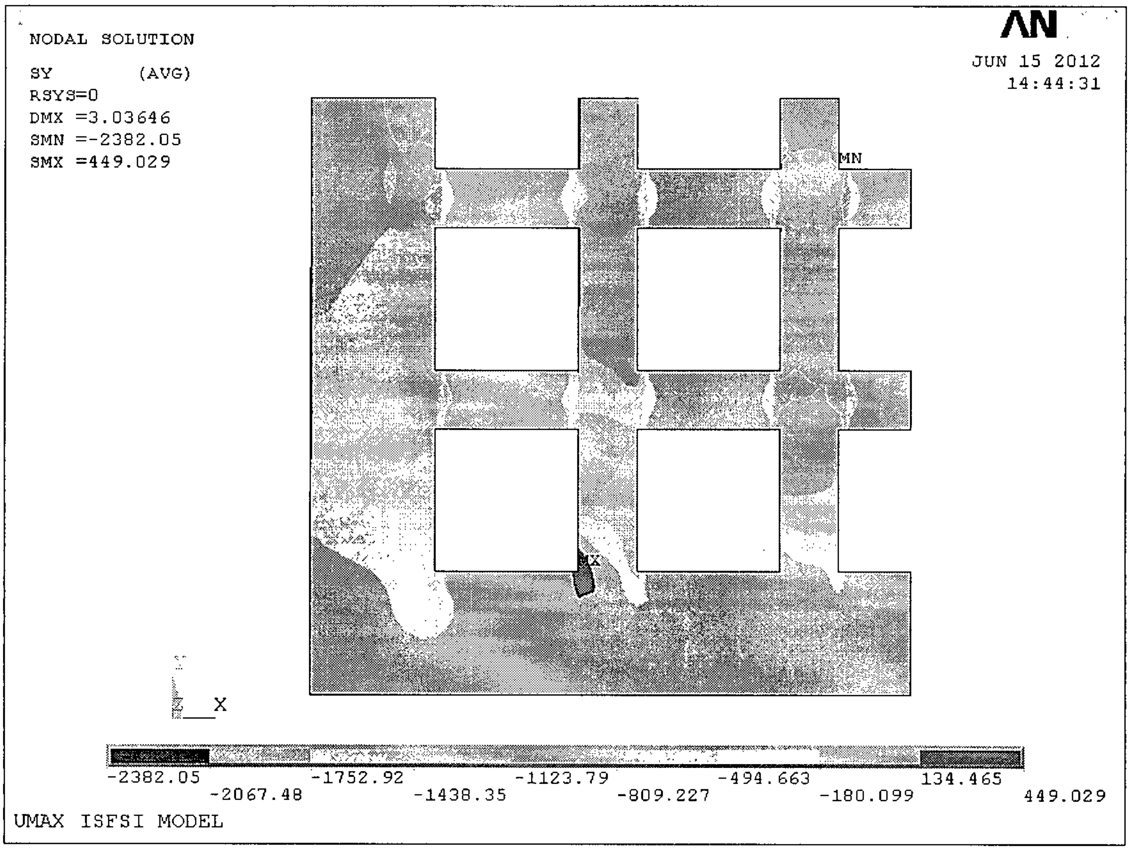


Figure 3.4.13c; Normal Stress (Sy) in ISFSI Pad Simulation Model I – Load Combination LC-3 from Table 2.4.3

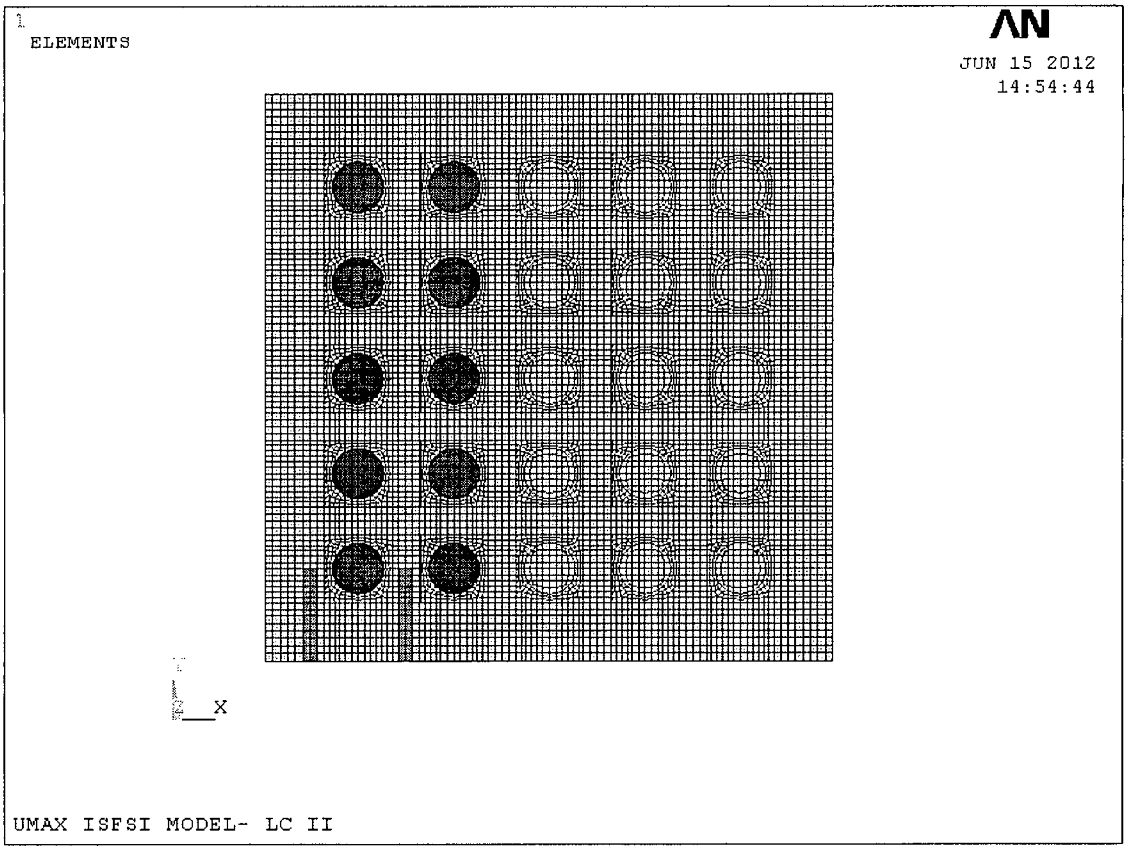


Figure 3.4.14; ANSYS Finite Element Model of ISFSI Showing the Partially Loaded Configuration (Simulation Model II)

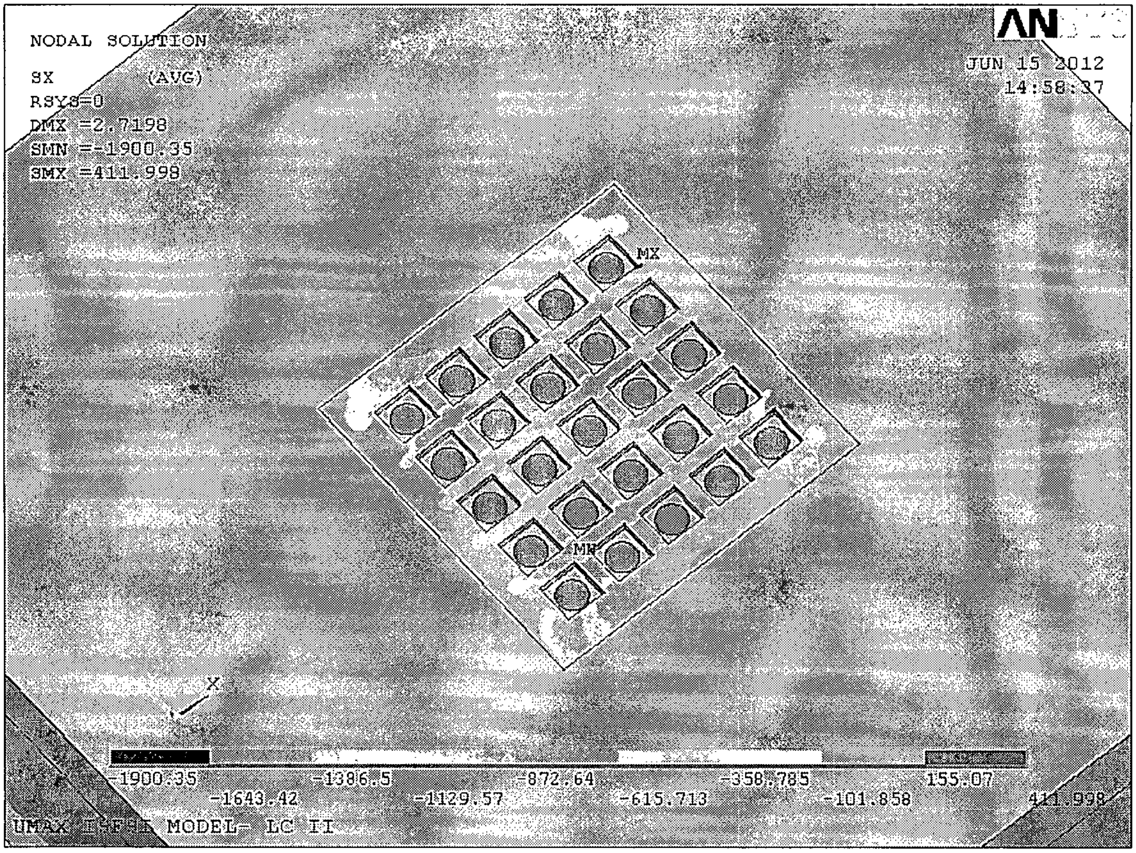


Figure 3.4.15a; Normal Stress in the ISFSI in the Direction of the Transporter Path for Simulation Model II – Load Combination LC-3 from Table 2.4.3

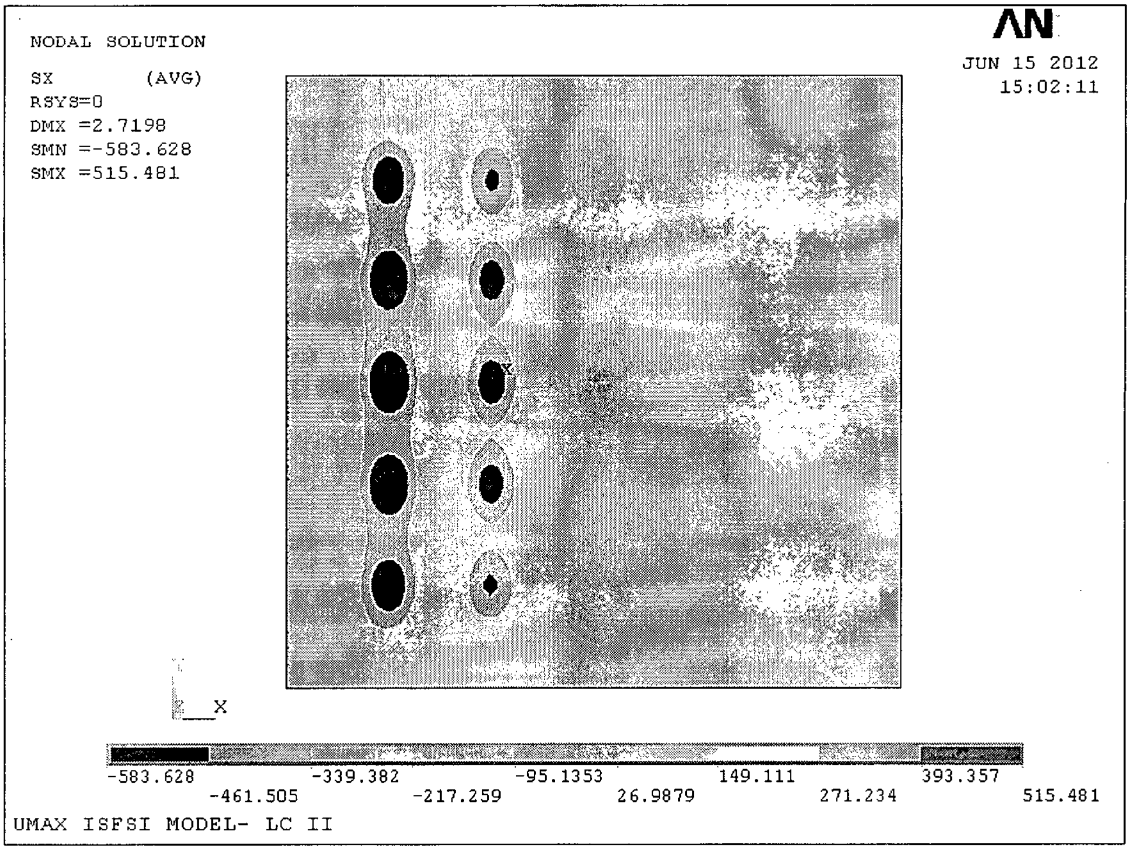


Figure 3.4.15b; Normal Stress (Sx) in SFP, Simulation Model II – Load Combination LC-3 from Table 2.4.3

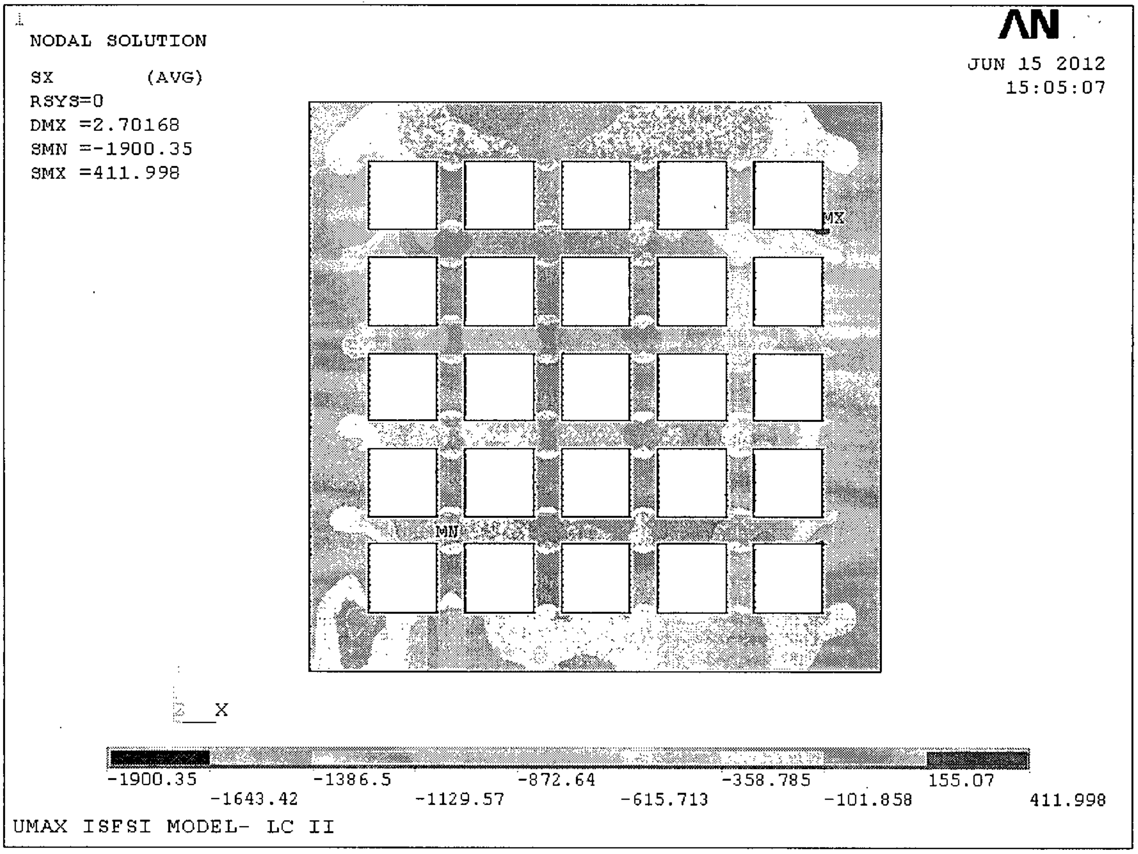


Figure 3.4.15c; Normal Stress (Sx) in ISFSI Pad, Simulation Model II – Load Combination LC-3 from Table 2.4.3

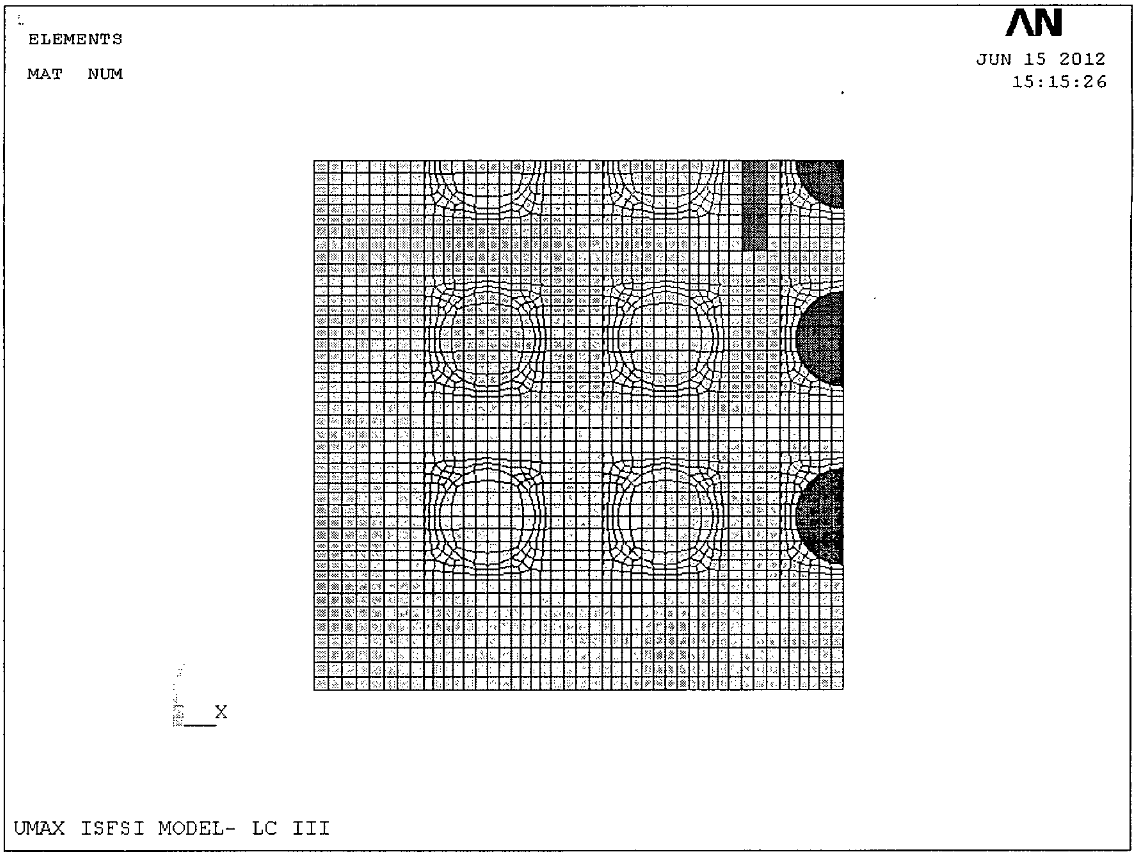


Figure 3.4.16; ANSYS Finite Element of ISFSI Showing the Center Row Loading (Simulation Model III)

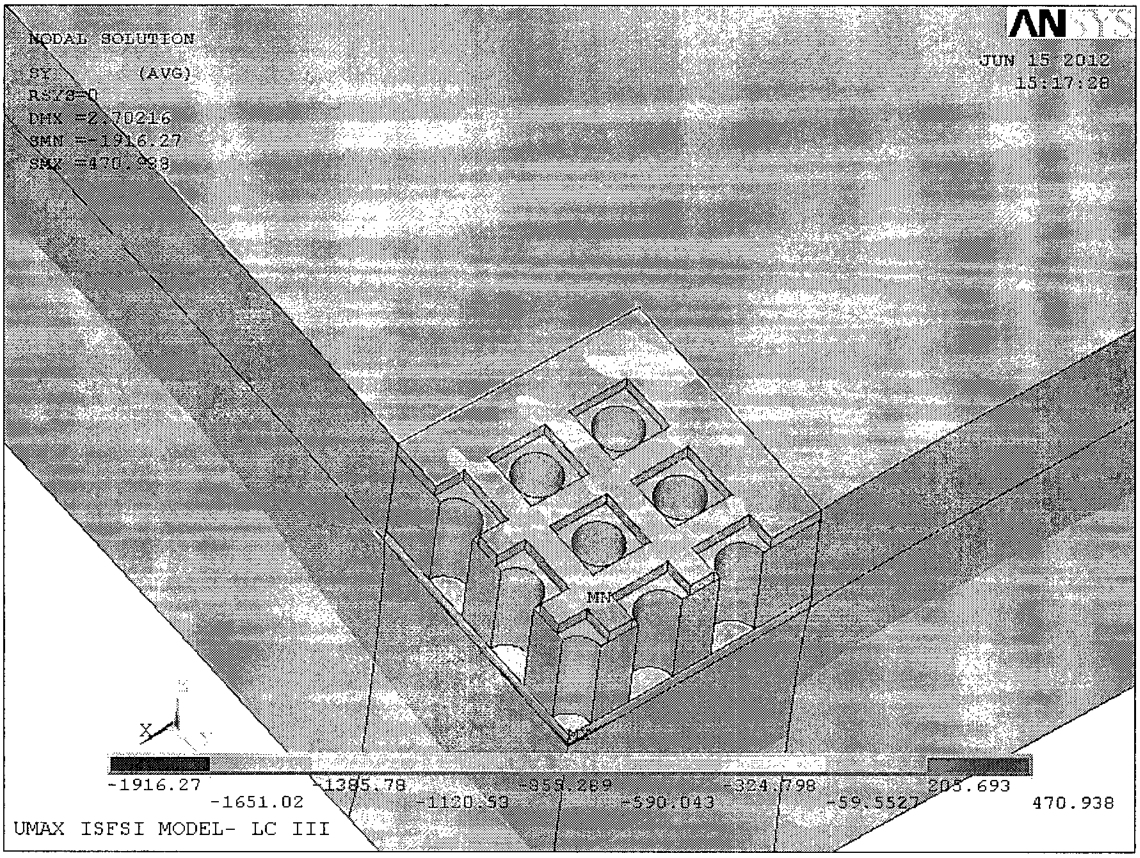


Figure 3.4.17a; Normal Stress in the ISFSI in the Direction of the Transporter Path for Simulation Model III – Load Combination LC-3 from Table 2.4.3

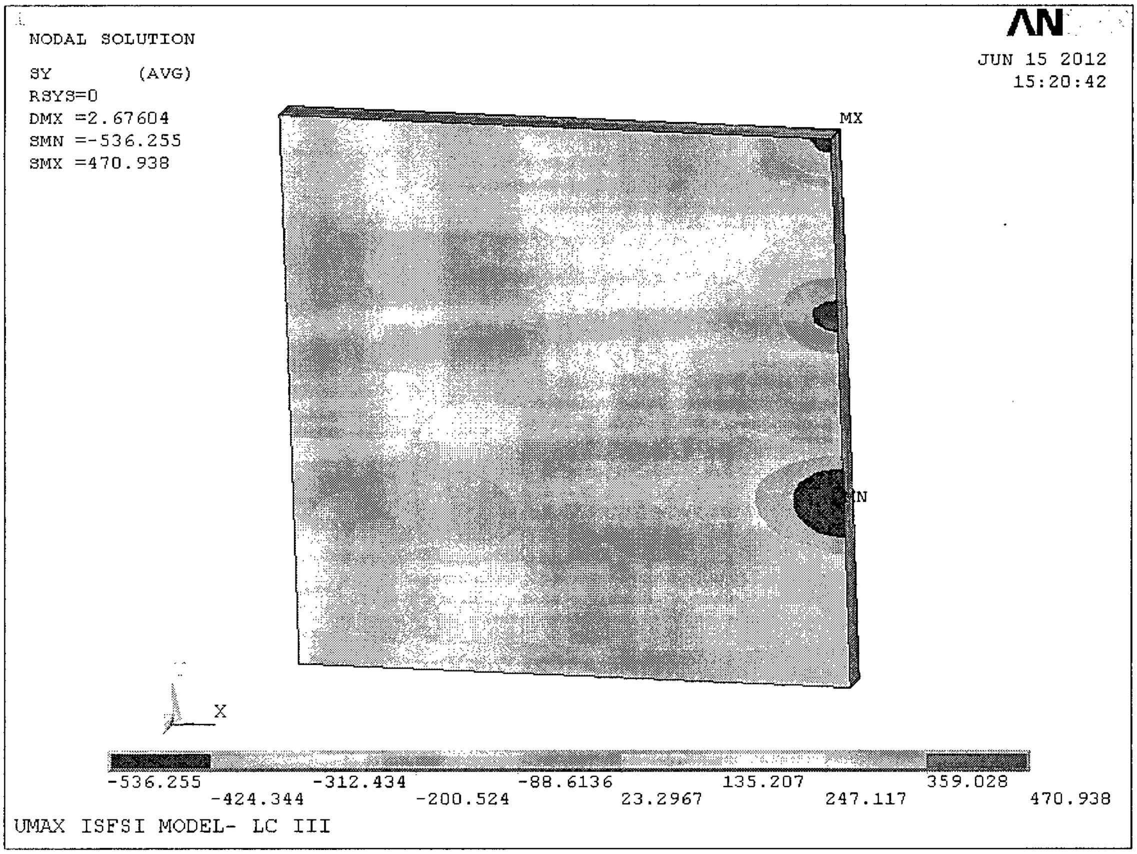


Figure 3.4.17b; Normal Stress (Sy) in SFP, Simulation Model III – Load Combination LC-3 from Table 2.4.3

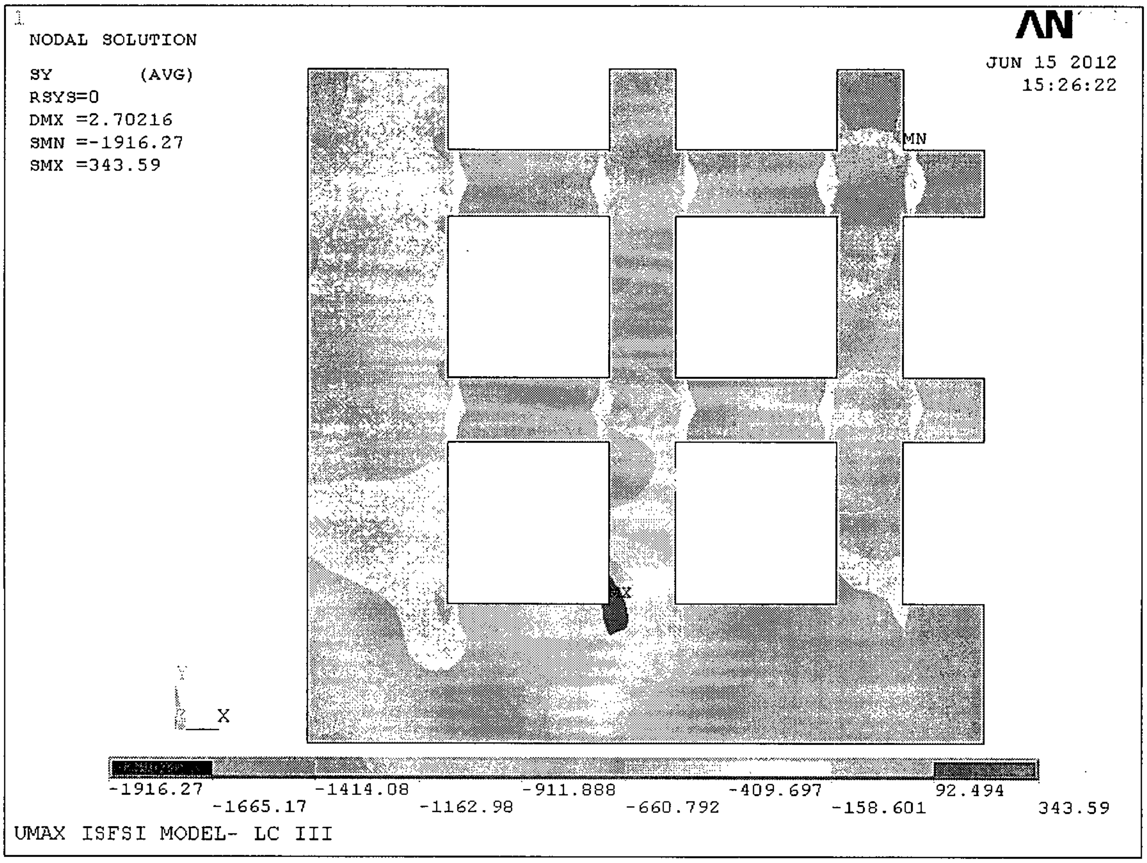


Figure 3.4.17c; Normal Stress (Sy) in ISFSI Pad, Simulation Model III – Load Combination LC-3 from Table 2.4.3

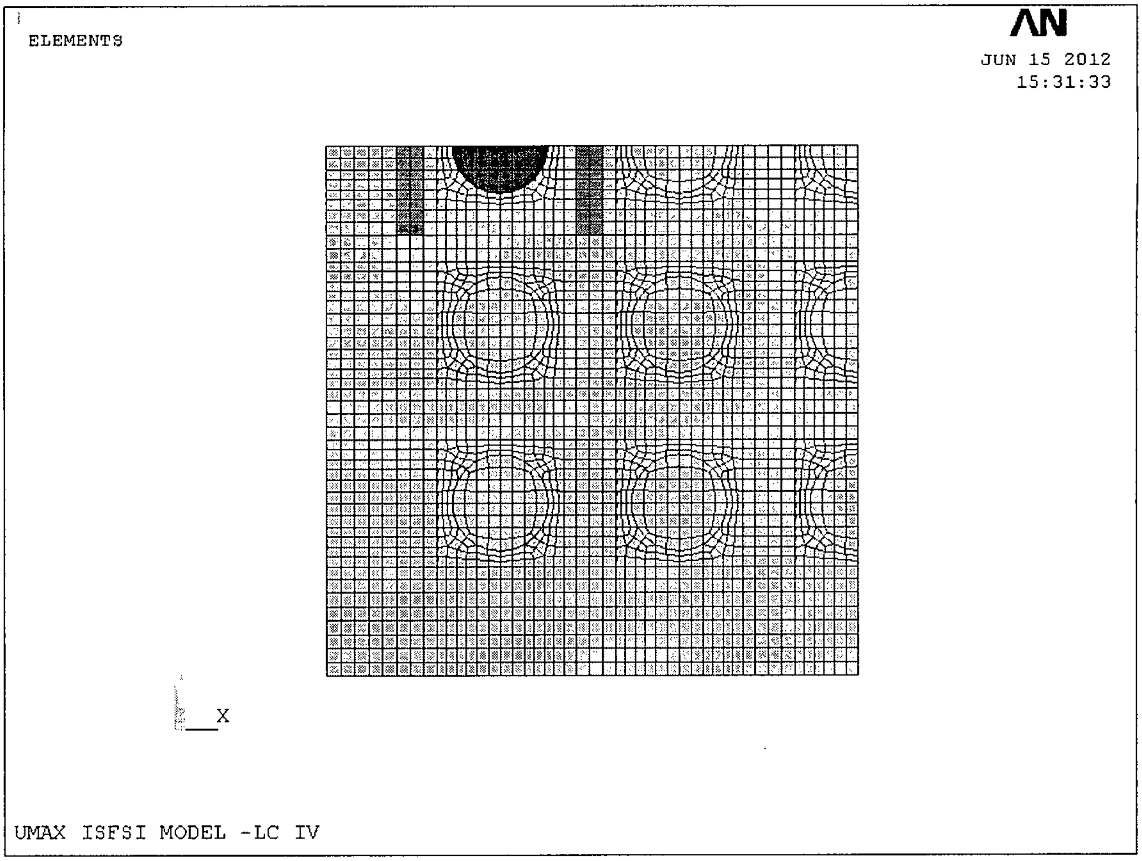


Figure 3.4.18; ANSYS Finite Element of ISFSI Showing the Single VVM Loaded (Simulation Model IV)

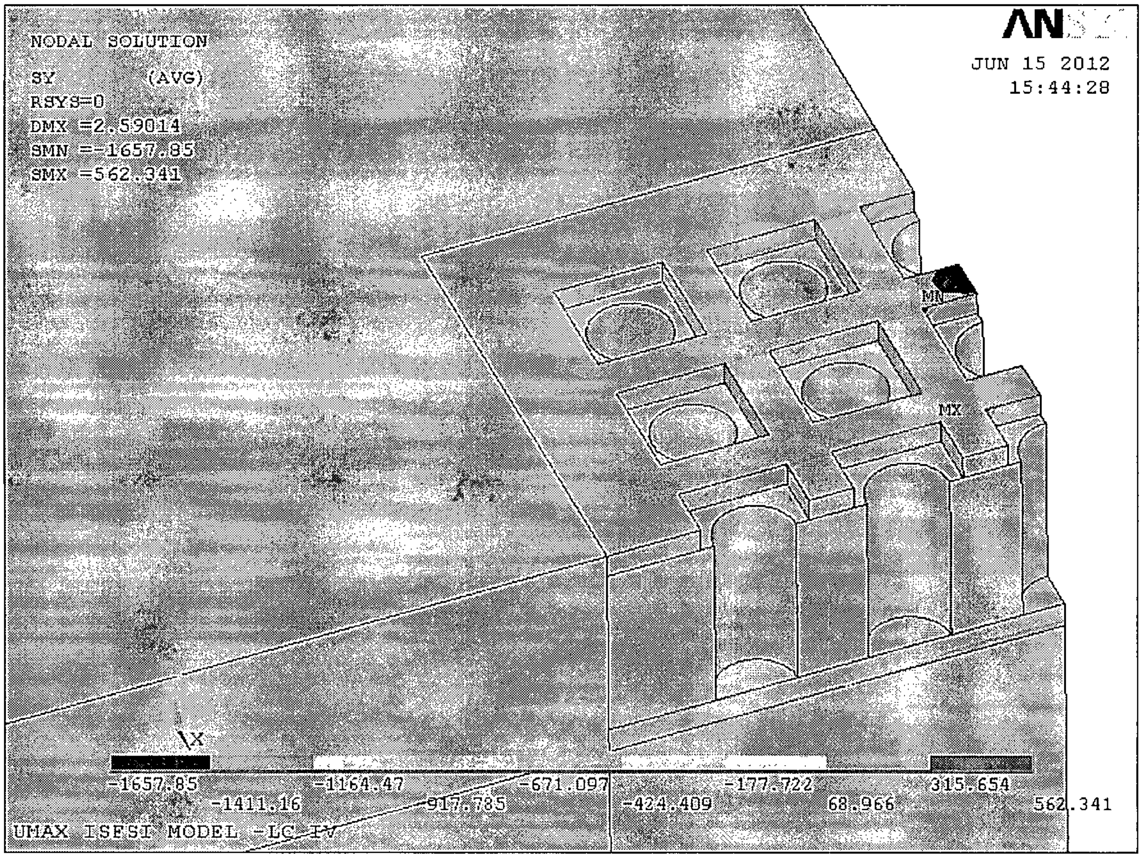


Figure 3.4.19a; Normal Stress in the ISFSI in the Direction of the Transporter Path for Simulation Model IV – Load Combination LC-3 from Table 2.4.3

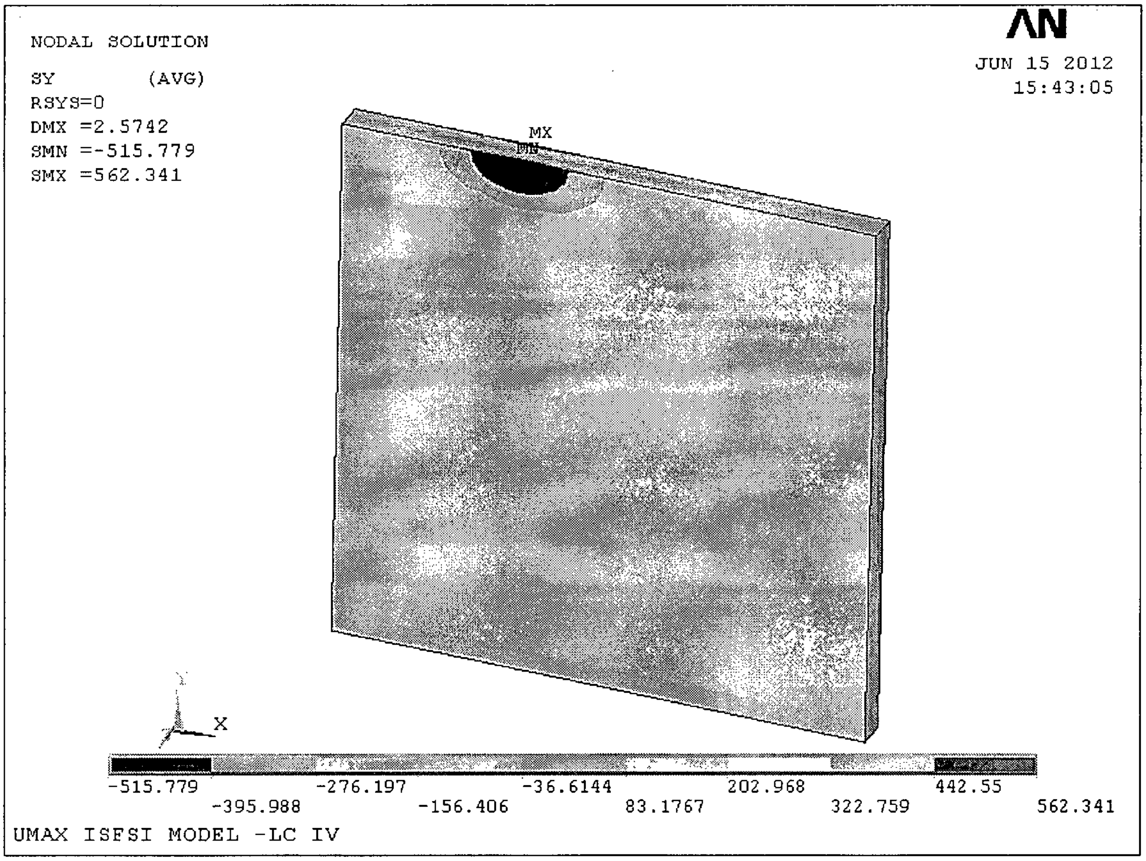


Figure 3.4.19b; Normal Stress (Sy) in SFP, Simulation Model IV – Load Combination LC-3 from Table 2.4.3

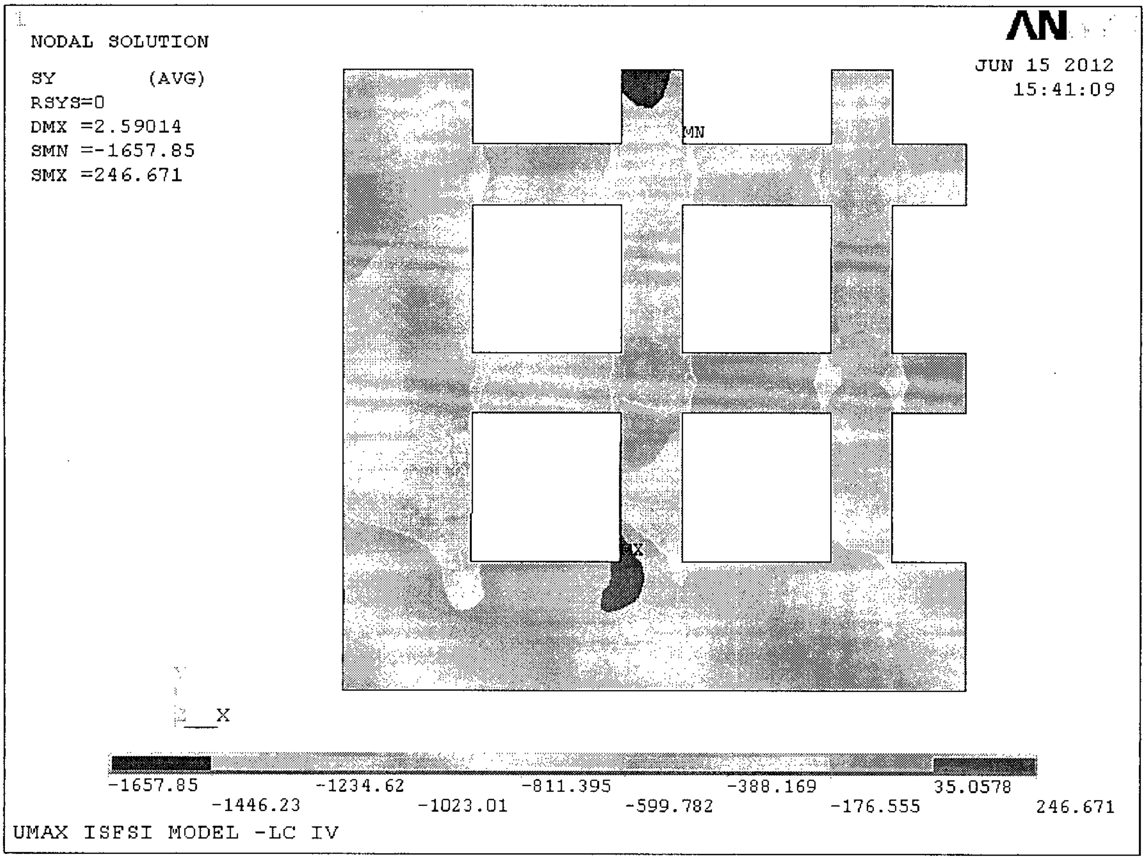


Figure 3.4.19c; Normal Stress (Sy) in ISFSI Pad, Simulation Model IV – Load Combination LC-3 from Table 2.4.3

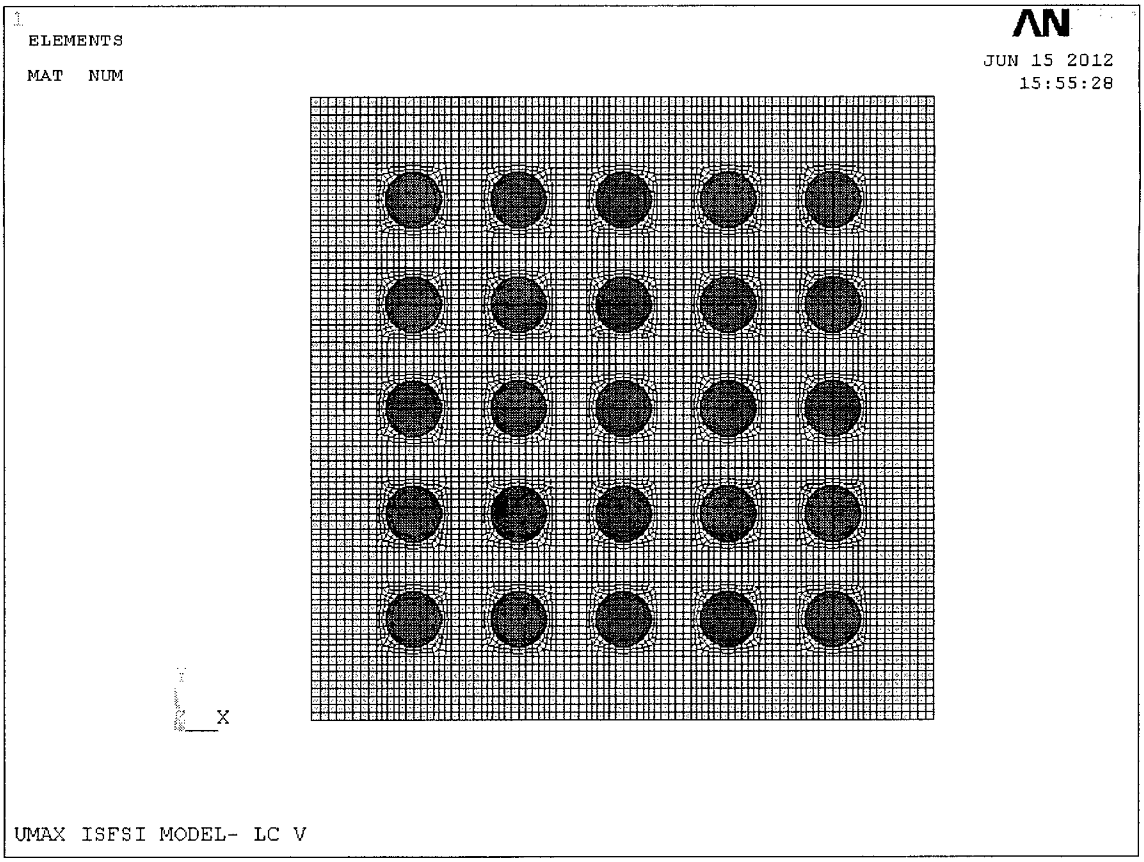


Figure 3.4.20; ANSYS Finite Element of ISFSI with fully loaded configuration (Simulation Model V)

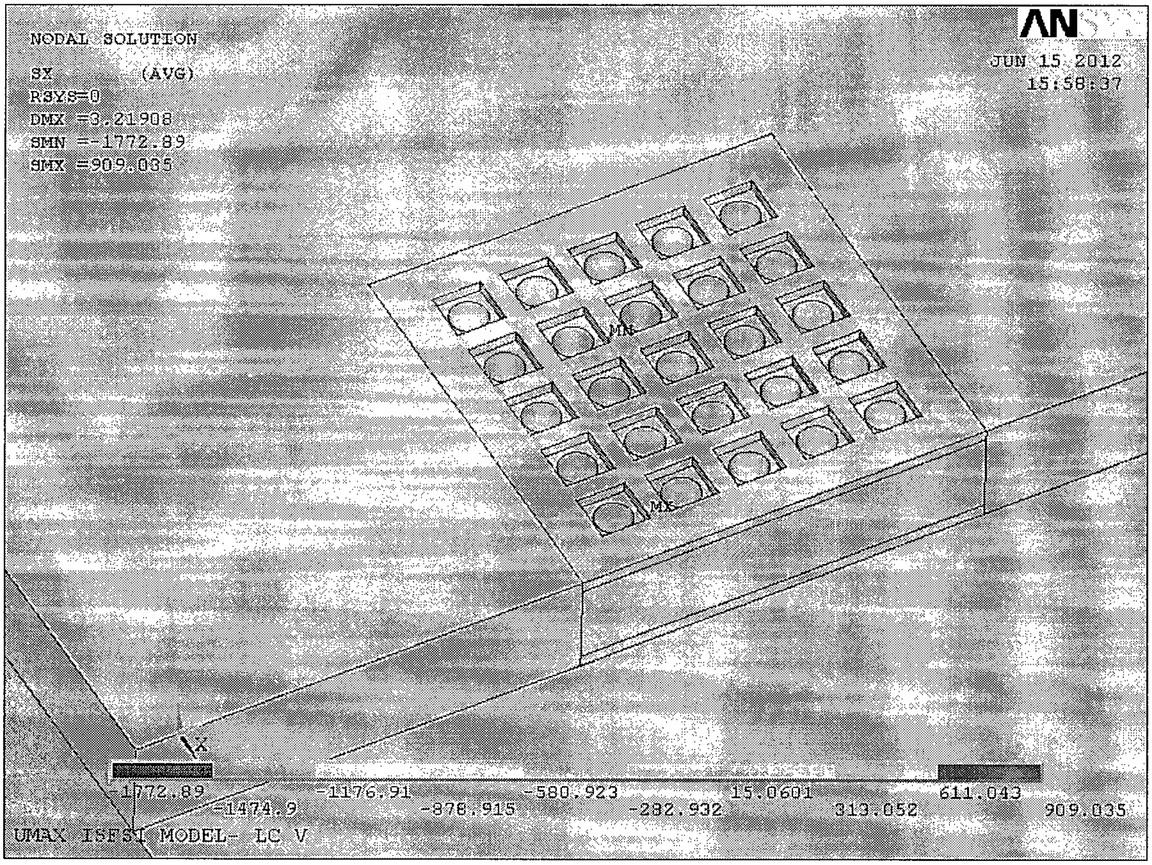


Figure 3.4.21a; Normal Stress in the ISFSI for Simulation Model V – Load Combination LC-3 from Table 2.4.3

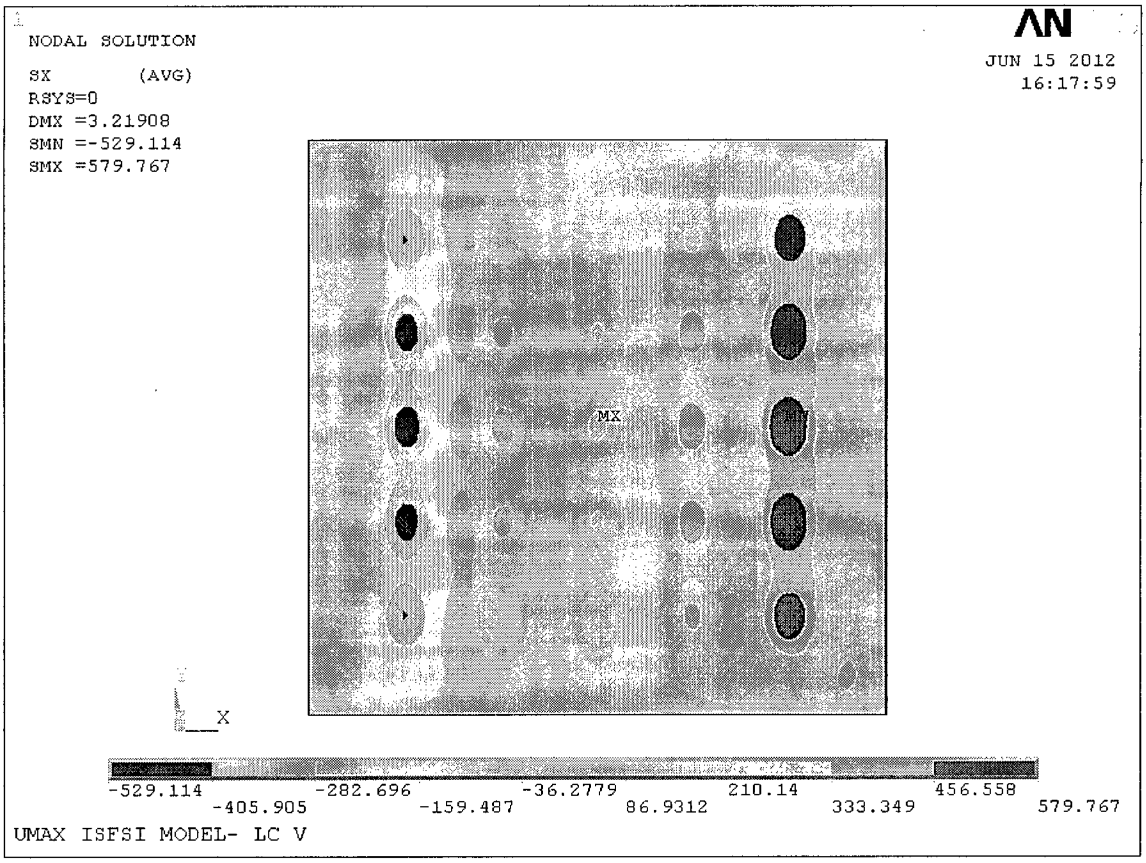


Figure 3.4.21b; Normal Stress (Sx) in SFP, Simulation Model V – Load Combination LC-3 from Table 2.4.3

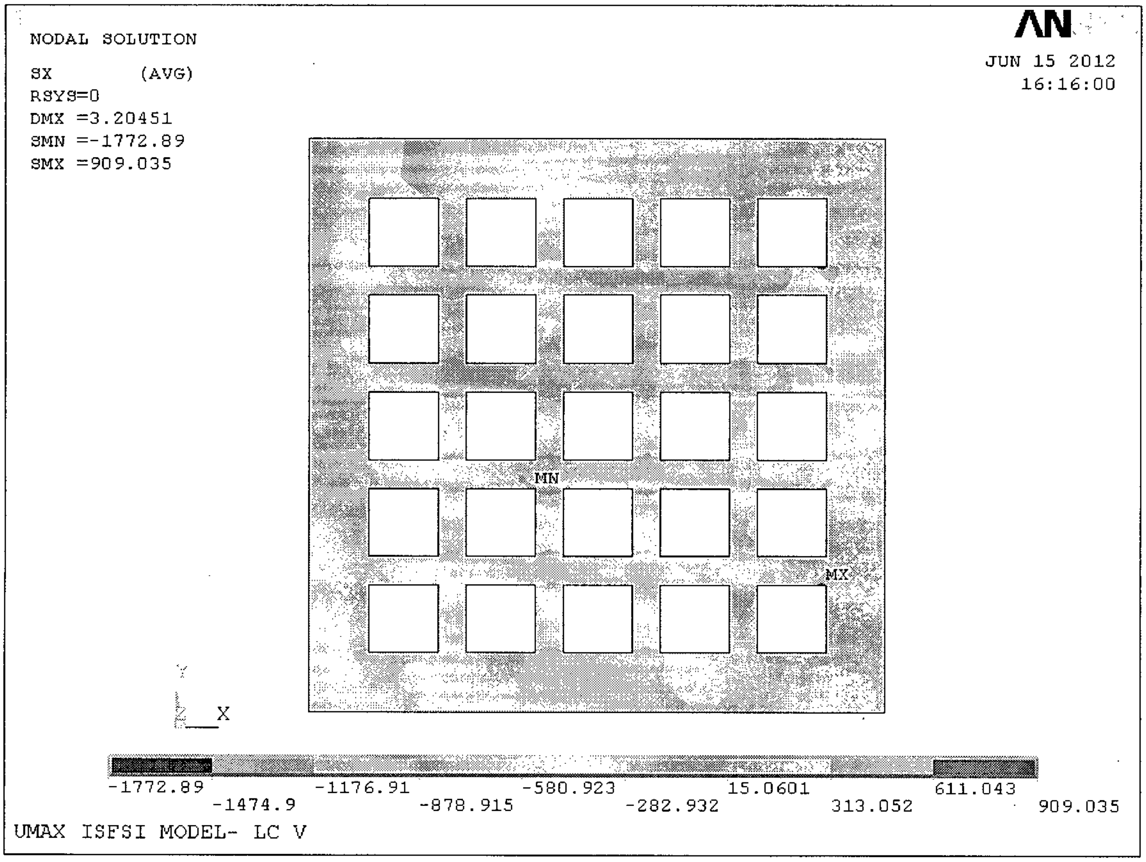


Figure 3.4.21c; Normal Stress (Sx) in ISFSI Pad, Simulation Model V – Load Combination LC-3 from Table 2.4.3

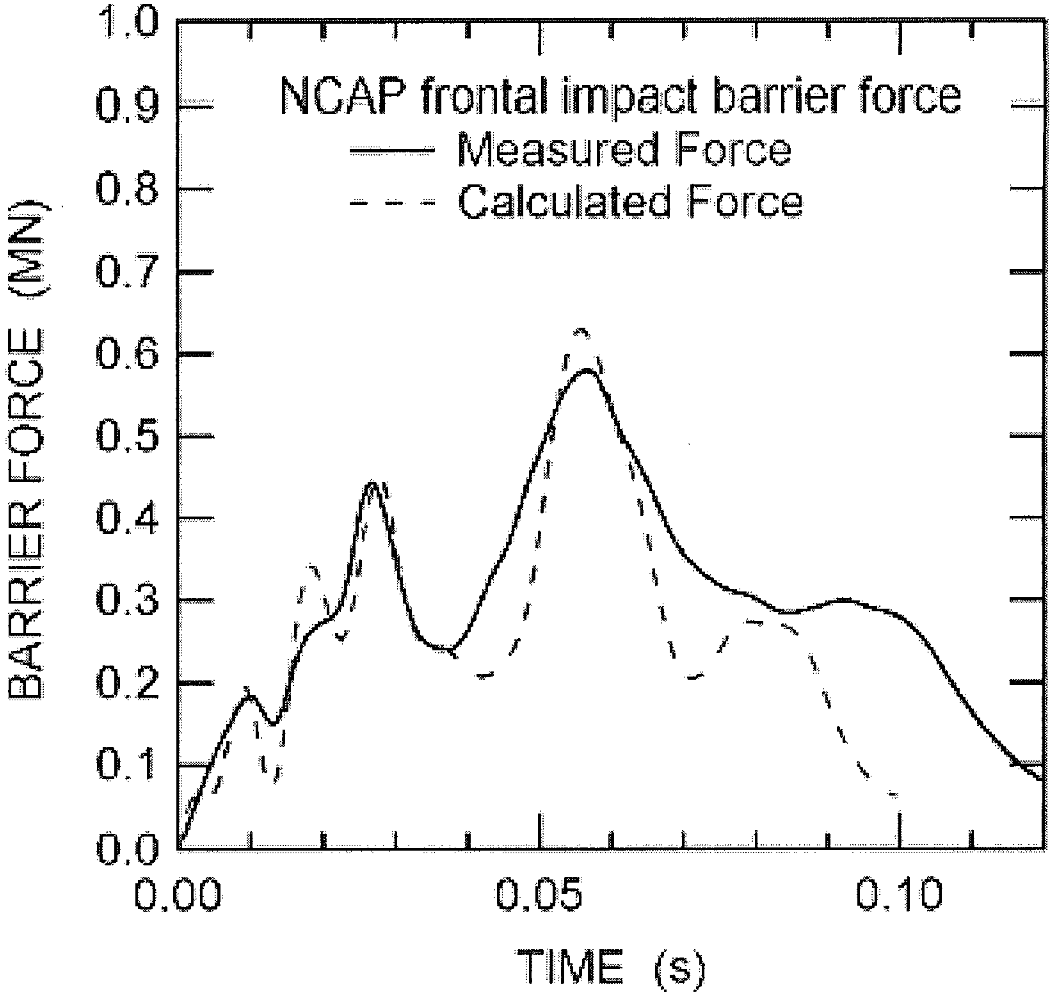


FIGURE 3.4.22; TEST RESULTS FROM 35 MPH IMPACT OF A FORD (1705 KG) AGAINST A RIGID WALL

3.5 FUEL RODS

The regulations governing spent fuel storage cask approval and fabrication (10 CFR 72.236) require that a storage cask system "will reasonably maintain confinement of radioactive material under normal, off-normal, and credible accident conditions" (§72.236(l)). Since fuel rod cladding is not considered in the design criteria for the confinement of radioactive material under normal, off-normal, or accident conditions of storage, no specific analysis or test results for the fuel rod cladding are required to demonstrate cladding integrity.

3.6 SUPPLEMENTAL DATA

3.6.1 Calculation Packages

In addition to the calculations presented in Chapter 3, supporting calculation packages have been prepared to document other information pertinent to the analyses. Supporting calculation packages back up the summary results reported in the FSAR. The Calculation Packages are referenced in the body of the FSAR and are maintained as proprietary documents in Holtec's Configuration Control system.

3.6.2 Computer Programs

Computer programs used in this FASR are summarized in this chapter.

i. ANSYS

ANSYS is a public domain code, well benchmarked code, which utilizes the finite element method for structural analyses. It is a self contained analysis tool incorporating pre-processing (geometry creation, meshing), solver, and post processing modules in a unified graphical user interface. 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 by Holtec International and used for structural analysis of casks, fuel racks, pressure vessels, and a wide variety of SSCs, for over twenty years.

ii. LS-DYNA

LS-DYNA is a general purpose finite element code for analyzing the large deformation static and dynamic response of structures including structures coupled to fluids. The main solution methodology is based on explicit time integration and is therefore well suited for the examination of the response to shock loading. A contact-impact algorithm allows difficult contact problems to be easily treated. Spatial discretization is achieved by the use of four node tetrahedron and eight node solid elements, two node beam elements, three and four node shell elements, eight node solid shell elements, truss elements, membrane elements, discrete elements, and rigid bodies. A variety of element formulations are available for each element type. Adaptive re-meshing is available for shell elements. LS-DYNA currently contains approximately one hundred constitutive models and ten equations-of-state to cover a wide range of material behavior.

In this safety analysis report, LS-DYNA is used to analyze all loading conditions that involve short-time dynamic effects.

LS-DYNA is maintained in a QA-validated status in Holtec's Configuration Control system.

iii. Shake 2000 [3.4.4]

SHAKE 2000, QA validated in [3.6.1] under Holtec International's quality program, has been used to characterize the transformation of the components of an earthquake as they traverse through layers of soil. SHAKE 200 is a linear ,elastic wave propagation code based on a 1972 report by P.B. Schnabel, Lysmer, J. and H.B. Seed at the Earthquake Engineering Research Center entitled "SHAKE: A Computer Program for Earthquake analysis of Horizontally Layered Sites", EERC report number 71-12. SHAKE 2000 has been used in this FSAR to define the earthquake response spectra at the TOG and at the SFP levels consistent with the assumed properties of the subgrade and the undergrade.

The above mentioned computer codes have been benchmarked and QA-validated to establish their veracity. The compliance matrix in Table 3.6.1 below provides the necessary information to document their validation status, and the measures employed pursuant to ISG-21 and Holtec's QA program, to ensure error-free solutions.

Table 3.6.1

ISG-21 AND QA COMPLIANCE MATRIX FOR COMPUTER CODES

	Item	ANSYS	LS-DYNA	Shake 2000
1.	Benchmark and QA-validation are documented in Holtec Report No.(s) (Proprietary Reports)	HI-2012627	HI-961519	HI-2022827 HI-2104792
2.	Computer Program Type (Public or Private Domain)	Public Domain	Public Domain	Public Domain
3.	Does Holtec maintain a system evaluating error notices if any are issued by the Code provider to evaluate their effect on the safety analyses carried out using the Code, including Part 21 notification? (Yes/No)	Yes	Yes	Yes
4.	Is the use of the Code restricted to personnel qualified under the Company's personnel qualification program? (Yes/No)	Yes	Yes	No
5.	Has benchmarking been performed against sample problems with known independently obtained numerical solutions (Yes/No)	Yes	Yes	Yes
6.	Have element types used in the safety analyses herein also employed in the benchmarking effort? (Yes/No)	Yes	Yes	N/A
7.	Are the element types used in this FSAR also used in other Holtec dockets that support other CoCs? (Yes/No)	Yes	Yes	N/A
8.	Is each update of the Code vetted for backwards consistency with prior updates? (Yes/No)	Yes	Yes	Yes
9.	Is the use of the Code limited to the range of parameters specified in the User Manual provided by the Code Developer? (Yes/No)	Yes	Yes	Yes
10.	Are the element aspect ratios, where applicable, used in the simulation model within the limit recommended by the Code Developer or Holtec's successful experience in other safety analyses? (Yes/No)	Yes	Yes	N/A
11.	Are element sizes used in the simulation models consistent with past successful analyses in safety significant applications? (Yes/No)	Yes	Yes	N/A
12.	Was every computer run in this chapter free of an error warning (i.e., in hidden warnings in the Code that indicate a possible error in the solution? (Yes/No)	Yes	Yes	Yes
13.	If the answer to the above is No, then is the annotated warning discussed in the discussion of the result in this report?	N/A	N/A	N/A

3.7 COMPLIANCEWITH THE STRUCTURAL REQUIREMENTS IN PART 72

Supporting information to provide reasonable assurance with respect to the adequacy of the HI-STORM UMAX system to store spent nuclear fuel in accordance with the stipulations of 10CFR72 is presented throughout this FSAR. The following statements are applicable to an affirmative structural safety evaluation:

- The design and structural analysis of the HI-STORM UMAX System is in full compliance with the provisions of Chapter 3 of NUREG-1536 as appropriate for a vertical ventilated module assembly (see Table 3.7.1).

- The HI-STORM UMAX structures, systems, and components (SSC) that are important to safety (ITS) are identified in the Licensing Drawings in Section 1.5. The Licensing Drawings present the HI-STORM UMAX SSCs in adequate detail and the explanatory narratives in this chapter provide sufficient textual details to allow an independent evaluation of their structural effectiveness.

- The requirements of 10CFR72.24 with regard to information pertinent to structural evaluation are provided in Chapters 2, 3, and 12.

- Technical Specifications pertaining to the structures of the HI-STORM UMAX system have been provided in Chapter 13 herein pursuant to the requirements of 10CFR72.26.

- A series of analyses to demonstrate compliance with the requirements of 10CFR72.122(b) and (c), and 10CFR72.24(c)(3) have been performed which show that SSCs in the HI-STORM UMAX VVM designated as ITS possess an adequate margin of safety with respect to all load combinations applicable to normal, off-normal, accident, and natural phenomenon events. In particular, the following information is provided:

    i. Load combinations for the HI-STORM UMAX VVM and the ISFSI structures for normal, off-normal, accident, and natural phenomenon events have been provided.

    ii. Stress limits applicable to the Code materials can be found in Section 3.3.

    iii. The stress and displacement response of the MPC Enclosure vessel, and the HI-STORM UMAX VVM for all applicable loads, have been computed by analysis and reported in Subsections 3.4.3 and 3.4.4. Descriptions of stress analysis models are presented in Subsection 3.1.3.

- The criticality safety of the stored MPCs is ensured by demonstrating that the maximum g-load sustained by the MPC stored inside the HI-STORM UMAX VVMs is less than their licensing basis value. This conclusion satisfies the requirement of 10CFR72.124(a), with respect to structural margins of safety for SSCs important to nuclear criticality safety.

- Structural margins of safety during handling, packaging, and transfer operations, under the provisions of 10CFR Part 72.236(b), imply that the lifting and handling devices be engineered to comply with the stipulations of ANSI N14.6, NUREG-0612. The requirements of the governing standards for handling operations are summarized in Subsection 3.4.3 herein. Factors of safety for all ITS components under lifting and handling operations are summarized in tables in Section 3.4, which show that adequate structural margins exist in all cases.

- Consistent with the requirements of 10CFR72.236(i), the confinement boundary for the HI-STORM UMAX System has been engineered to maintain confinement of radioactive materials under normal, off-normal, and postulated accident conditions. This assertion of confinement integrity is made on the strength of the MPC's licensing basis in docket number 72-1032 and the following information provided in this FSAR.

- The information on structural design included in this FSAR complies with the requirements of 10CFR72.120 and 10CFR72.122.

- The structural design features in the HI-STORM UMAX VVM (along with the previously certified MPCs) are in compliance with the specific requirements of 10CFR72.236(e), (f), (g), (h), (i), (j), (k), and (m).

Table 3.7.1

NUREG-1536 COMPLIANCE MATRIX FOR 10CFR72.120 AND 10CFR72.122 REQUIREMENTS

Item		Compliance	Notes
i.	Design and fabrication to acceptable quality standards	All ITS components designed and fabricated to recognized Codes and Standards: • Enclosure Vessel: Subsection NB, loc. cit. • HI-STORM UMAX Structure: Subsection NF, loc. cit.	Subparagraph 3.1.2.3
ii.	Erection to acceptable quality standards	• Concrete in HI-STORM UMAX closure lid meets requirements of: ACI –318 (2005)	Subsection 3.3.2
iii.	Testing to acceptable quality standards	• All non-destructive examination of structural components utilizes Section V of the ASME Code. • Testing for radiation containment per provisions of NUREG-1536 • Concrete testing	Chapter 8
iv.	Adequate structural protection against environmental conditions and natural phenomena.	Analyses presented in Chapter 3 demonstrate that the confinement boundary will preserve its integrity under all postulated off-normal and natural phenomena events listed in Chapter 2.	Subparagraph 3.4.4.1 Chapter 11
v.	Adequate protection against fires and explosions	• The extent of combustible (exothermic) material in the vicinity of the cask system is procedurally controlled (the sole source of hydrocarbon energy is diesel in the tow vehicle). • Analyses show that the heat energy released from the postulated fire	Subsections 12.3.20 and 12.3.21 Subsection 11.2.4

Table 3.7.1

NUREG-1536 COMPLIANCE MATRIX FOR 10CFR72.120 AND 10CFR72.122 REQUIREMENTS

Item	Compliance	Notes
	accident condition surrounding the cask will not result in impairment of the confinement boundary and will not lead to structural failure of the VVM. The effect on shielding will be localized to the external surfaces directly exposed to the fire without a significant change in HI-STORM UMAX VVM. • Explosion effects are shown to be bounded by the Code external pressure design basis and there is no adverse effect on ready retrievability of the MPC.	Subparagraph 3.4.4.1
vi. Appropriate inspection, maintenance, and testing	Inspection, maintenance, and testing requirements set forth in this FSAR are in full compliance with the governing regulations and established industry practice.	See Chapters 1 and 2.
vii. Adequate accessibility in emergencies.	The HI-STORM UMAX closure lid can be removed to gain access to the multi-purpose canister. All HI-TRAC transfer cask models have removable bottom and top lids.	Chapter 9 Chapter 9
viii. A confinement barrier that acceptably protects the spent fuel cladding during storage.	The peak temperature of the fuel cladding at design basis heat duty of each MPC has been demonstrated to be maintained below the limits specified in ISG-11 Revision 3. The confinement barriers consist of highly ductile stainless steel alloys. The multi-purpose canister is housed in the VVM, built from a steel structure whose materials are selected and examined to maintain protection against brittle fracture under off-normal ambient (cold) temperatures (minimum of -40°F).	Section 4.4 Subsection 3.1
ix. The structures are compatible with the appropriate monitoring systems.	The HI-STORM UMAX VVM with openings that are designed to prevent radiation streaming while enabling complete access to temperature monitoring probes, if used.	Section 1.5

Table 3.7.1

NUREG-1536 COMPLIANCE MATRIX FOR 10CFR72.120 AND 10CFR72.122 REQUIREMENTS

Item		Compliance	Notes
x.	Structural designs are compatible with ready retrievability of fuel.	The VVMs are designed to withstand accident loads without suffering permanent deformations of their structures that would prevent retrievability of the MPC by normal means. It is demonstrated by analysis that there is no physical interference between the MPC and the enveloping HI-STORM VVM under all postulated Design Basis loads.	Section 3.4
xi.	Adequate heat removal without active cooling systems.	Thermal analyses presented in Chapter 4 show that the HI-STORM UMAX System will remove the decay heat generated from the stored spent fuel by strictly passive means and maintain the system temperature within prescribed limits.	Section 4.4
xii.	Storage of spent fuel for a minimum of 20 years.	The service life of the storage modules is engineered to be in excess of 60 years.	Subsection 3.4.7
xiii.	Conspicuous and durable marking.	The exterior envelope of the VVM is marked in a conspicuous manner as required by 10CFR 72.236(k).	N/A
ix.	Compatibility with removal of the stored fuel from the site, transportation, and ultimate disposal by the U.S. Department of Energy.	The MPCs used in the HI-STORM UMAX System are intended to serve as a transportable waste package.	N/A

3.8 REFERENCES

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[3.1.2] H. Boyer, Atlas of Stress Strain Curves, ASM International, 1987.

[3.1.3] 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.

[3.1.4] ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, 2010.

[3.1.5] ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NF - Supports, 2010.

[3.1.6] "Construction of True-Stress-True-Strain Curves for LS-DYNA Simulations," Holtec Proprietary Position Paper DS-307, Revision 2.*

[3.1.7] HI-2114807, Thermal-Hydraulic Evaluation of HI-STORM UMAX, Revision 0, 2011 (Holtec Proprietary).

[3.3.1] ASTM C39, Standard Test Method for Compressive Strength of Cylindrical Concrete.

[3.3.2] ASME Boiler & Pressure Vessel Code, Section II, Part D, 2010.

[3.3.3] B.H.Hough, Basic Soils Engineerings, Second Edition.

[3.3.4] 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)

[3.4.1] HI-2125228, Structural Calculation Package for the HI-STORM UMAX System, Revision 0, 2012 (Holtec Proprietary).

[3.4.2] American National Standards Institute, ANSI B30.3

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* Supporting document submitted with the HI-STORM FW License Application (Docket 72-1032).

[3.4.3] ANSI N14.6-1993, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More for Nuclear Materials", June 1993.

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

[3.4.5] LS-DYNA, Version 971, Livermore Software.

[3.4.6] ACI-318(2005), Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05), American Concrete Institute, 2005.

[3.4.7] 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).

[3.4.8] 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.

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

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

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

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

[3.4.13] 10CFR71, Waste Confidence Decision Review, USNRC, September 11, 1990.

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

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

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

[3.4.17] HI-2125239, Structural Analysis of HI-STORM UMAX ISFSI Structures, Revision 0, 2012 (Holtec Proprietary).

[3.6.1] Validation Manual for SHAKE 2000; Holtec Report Number # HI-2104792 (2010)

CHAPTER 4: THERMAL EVALUATION

4.0 OVERVIEW

HI-STORM UMAX is an underground vertical ventilated module (VVM) with openings for air ingress and egress and internal air flow passages for ventilation cooling of loaded MPC. The licensing drawing package for the HI-STORM UMAX is provided in Section 1.5. Thermal design requirements are presented in Section 2.5. The analyses summarized in this chapter focus on the governing canisters out of the population of MPCs listed in Table 1.2.1. This chapter, however, supports the certification of only MPC-37 and MPC-89 at this time. The analyses reported for smaller canisters are for reference purposes only.

Section 1.2 provides a summary description of the HI-STORM UMAX system. The MPC types considered for evaluating storage in HI-STORM UMAX VVMs are listed in Table 1.2.1. In this chapter, compliance of HI-STORM UMAX system's thermal performance to 10CFR72 requirements for storage at an ISFSI using 3-D thermal simulation models is established. The analyses consider passive rejection of decay heat from the stored SNF assemblies to the environment under normal, off-normal, and accident conditions of storage. In particular, the thermal margins of safety for long-term storage of both moderate burnup (up to 45,000 MWD/MTU) and high burnup spent nuclear fuel (greater than 45,000 MWD/MTU) in the HI-STORM UMAX system are quantified. The HI-STORM UMAX deploys MPCs and HI-TRAC transfer casks that have been previously certified in HI-STORM FW FSAR and CoC (USNRC Docket 72-1032). The safety evaluations of all short term operations, such as welding and drying of the canister and its translocation to the ISFSI in the transfer cask are considered in the HI-STORM FW FSAR [4.1.2] and therefore don't warrant re-iteration in this FSAR. Likewise, the thermal performance of the MPC transfer operation at the ISFSI utilizing the HI-TRAC transfer cask does not pose any new & unanalyzed thermal scenario. The cases of normal, off-normal and accident conditions of storage, enumerated in Chapter 2, however, must be evaluated for the MPC designs in Table 1.2.1 to establish an acceptable safety case for their long term storage in the HI-STORM UMAX VVMs.

The thermal evaluation of HI-STORM UMAX follows the guidelines of NUREG-1536 [4.0.1] and ISG-11 [4.0.2]. These guidelines provide specific limits on the permissible maximum cladding temperature in the stored commercial spent fuel (CSF)* and other Confinement Boundary components, and on the maximum permissible pressure in the confinement space under certain operating scenarios. Specifically, the requirements are:

1. The fuel cladding temperature must meet the temperature limit appropriate to its burnup level and condition of storage / handling set forth in NUREG-1536 [4.0.1] and ISG-11 [4.0.2].

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* Defined as nuclear fuel that is used to produce energy in a commercial nuclear reactor (See Glossary).

2. The maximum internal pressure of the MPC should remain within its design pressures for normal, off-normal, and accident conditions set forth in Table 2.3.5.

3. The temperatures of the cask materials shall remain below their allowable limits set forth in Table 2.3.7 under all scenarios.

Section 2.5 of this FSAR contains a listing of all thermal analysis cases that warrant analysis. Section 2.1 in Chapter 2 provides the Design Basis heat loads. As demonstrated in this chapter, the HI-STORM UMAX system is designed to comply with all of the thermal criteria defined in Chapter 2.

Sections 4.1 through 4.3 describe thermal analyses and input data that are common to all conditions of storage, handling and on-site transfer operations. All required thermal analyses to evaluate normal conditions of storage in a HI-STORM UMAX storage module are described in Section 4.4. Thermal analyses to evaluate on-site transfer in a HI-TRAC transfer cask are considered in Section 4.5 and the evaluations to establish compliance under off-normal and accident conditions are summarized in Section 4.6.

To facilitate convenient access to the referenced material, the latest edition of the HI-STORM FW FSAR has been placed in this docket and a list of "FW" FSAR sections germane to this chapter is provided in a tabular form. The HI-STORM FW FSAR will be maintained in a configuration controlled status in this docket as a mandatory supplement to this FSAR. Table 4.0.1 provides a listing of the material adopted in this chapter by reference to the HI-STORM FW FSAR.

Table 4.0.1

HI-STORM FW FSAR MATERIAL GERMANE TO THE EVALUATIONS IN THIS FSAR *

Location of UMAX FSAR	**Subject of the reference**	**Location in HI-STORM FW FSAR, Revision 1**
Note 2 in Table 4.1.1 and Sub-Section 4.4.4 (i)	Limiting heat load configuration	Paragraph 4.4.1.5 and Table 4.4.3
Sub-Section 4.4.1	Description of MPC thermal models	Sub-Section 4.4.1
Sub-Section 4.4.1	Fuel region effective thermal properties	Paragraph 4.4.1.1
Sub-Section 4.4.5	Helium backfill pressure limits	Paragraph 4.4.5.1
Section 4.5	Short term operations	Section 4.5
Paragraph 4.6.1.5	FHD Malfunction	Paragraph 4.6.1.4
Sub-Section 4.6.2	Fire accident events	Paragraph 4.6.2.1
Paragraph 4.6.2.6	HI-TRAC VW jacket water loss accident	Paragraph 4.6.2.2
Section 4.7	Thermal compliance of short term operations	Sub-Section 4.7.2

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* For convenience of reference, the specific revision of the HI-STORM FW FSAR that is referenced in the safety analysis herein is placed in this docket. Updated versions of the HI-STORM FW FSAR shall be placed in this docket as necessary so as to ensure that the safety analyses on the "UMAX" docket (72-1040) remain aligned with the material referenced in the HI-STORM FW FSAR.

4.1 DESIGN BASIS HEAT LOAD AND GOVERNING MPC FOR THERMAL ANALYSIS

As stated in Section 2.0, the HI-STORM UMAX system has been designed to store all previously certified MPCs under NRC dockets No. 72-1014 and 72-1032. Therefore it is necessary to identify the governing MPC from the list in Table 1.2.1 along with its governing heat load. The governing MPC and its heat load combination are defined as the one that yields the maximum PCT. For this purpose, it is helpful to consider two fundamental facts relevant to the thermal performance of VVMs; namely,

a. Smaller the size of the flow annulus, smaller the air flow rate and a correspondingly lesser extent of heat extraction from the MPC surface and hence greater the PCT in the stored fuel.
b. Larger the heat load, greater the PCT. It must be noted that both the total heat load and per assembly heat load distribution must be considered.

Because the inside diameter of HI-STORM UMAX VVM is fixed, it is readily deduced that the larger diameter MPCs previously licensed in the HI-STORM FW docket [4.1.2] will have a smaller axial flow annulus compared to those in the HI-STORM 100 docket [4.1.1]. The DBHL is also substantially greater in the HI-STORM FW system compared to the HI-STORM 100 system. The input data for all MPCs previously licensed in HI-STORM FW docket, i.e. MPC-37 with short, standard and long fuels under bounding Heat Load Pattern A (see Table 2.1.8) and MPC-89 (see Table 2.1.9) are summarized in Table 4.1.1. The maximum peak cladding temperature results are calculated and reported in Table 4.1.2. The results verify that MPC-37 with the short fuel under Heat Load Pattern A produces the highest PCT, therefore it is designated as the governing thermal scenario.

It is noted that the MPCs in Docket # 72-1014 are smaller in diameter and are certified to lower DBHLs. Nevertheless, the hottest MPC from the HI-STORM 100 docket also warrants analysis because the stainless steel fuel baskets in it are less conductive than their counterparts in the HI-STORM FW docket (that contain METAMIC-HT fuel baskets). As noted in the HI-STORM 100 FSAR, MPC-32 under X=3* regionalized loading scenario (see Section 2.1.10) results in the highest PCT. Therefore it is the governing case among all MPCs in the HI-STORM 100 docket [4.1.1] and therefore is also selected as a candidate MPC type (with regionalized loading scenario X=3) for thermal analysis in HI-STORM UMAX. The case of X=0.5 (see Sub-Section 2.1.10), which is the other limit of regionalization ratio, is also included for completeness.

Thus for both MPC-37 and MPC-32, the limiting thermal scenarios are defined based on the information in their existing host dockets and summarized in Table 4.1.1. The thermal problem is then analyzed using the solution methodology approved in [4.1.1] and [4.1.2]. The temperatures

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* X is defined in the HI-STORM 100 FSAR [4.1.1] as the ratio of maximum permissible storage per cell heat load in the inner and outer regions.

presented in Tables 4.1.2 show that the ISG-11 Rev 3 limits are satisfied with comfortable margins.

The maximum peak cladding temperature results for limiting MPC-37 and MPC-32, reported in Table 4.1.2, show that MPC-37 with short fuel under Heat Load Pattern A produces the highest PCT. Therefore, MPC-37 with short fuel under Heat Load Pattern A fulfills the criterion for designation as the governing thermal configuration. This governing thermal configuration is used to perform the thermal safety analyses that are reported in the subsequent sections in this chapter.

Table 4.1.1

CANDIDATE GOVERNING CANISTERS & HEAT LOAD CASES STORAGE IN THE HI-STORM UMAX SYSTEM

Item	**MPC-37 (Docket 72-1032)**	**MPC-89 (Docket 72-1032)**	**MPC-32**[Note 1] **(Docket 72-1014)**
MPC Decay Heat [Note 4]	Pattern A[Note 2]: 44.7 kW (short fuel) 44.7 kW (standard fuel) 47.05 kW (long fuel)	46.36 kW	30.17 kW @X=3 36.9 kW @X=0.5
MPC Minimum Backfill Pressure [Note 3]	42.0 psig	42.5 psig	43.7 psig
MPC Maximum Backfill Pressure [Note 3]	45.5 psig	47.5 psig	48.5 psig
Normal Ambient Temperature	Table 2.3.6	Table 2.3.6	Table 2.3.6
Temperature of the Subgrade Supporting the Support Foundation Pad	Table 2.3.6	Table 2.3.6	Table 2.3.6
MPC External Diameter	75-1/2"	75-1/2"	68-3/8"
Divider Shell Inner Diameter	86"	86"	86"
Insulation Thickness	2-3/4"	2-3/4"	2-3/4"
Inner Diameter of Container Shell	100"	100"	100"

Note 1: MPC-32 bounds MPC-68, 68M and MPC-24 as noted in HI-STORM 100 Docket 72-1014.

Note 2: Pattern A is evaluated since it the most limiting heat load configuration as noted in HI-STORM FW Docket 72-1032.

Note 3: Specification at a reference temperature of 21.1°C (70°F)

Note 4: All heat loads reported in this table are obtained by applying the heat load reduction factor defined in Table 2.1.7 to the heat load specified in applicable host CoC amendment.

Table 4.1.2

PEAK CLADDING TEMPERATURE RESULTS FOR LONG-TERM NORMAL STORAGE FOR MPC-32, MPC-37 AND MPC-89 IN HI-STORM UMAX SYSTEM

MPC Types		**Fuel Cladding Temperature ^{o}C (^{o}F)**
MPC-37 (Pattern A)	Short Fuel	**367 (693)***
	Standard Fuel	358 (676)
	Long Fuel	348 (658)
MPC-89		358 (676)
MPC-32 (X=3)		366 (691)

* MPC-37 with short fuel under Heat Load Pattern A is selected as the governing thermal configuration and is used to perform all the licensing basis calculations for HI-STORM UMAX System.

4.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

The thermo-physical properties listed in the tables in this section are identical to those used in the HI-STORM FW FSAR [4.1.2] and in the HI-STORM 100 FSAR [4.1.1]. Materials present in the MPCs listed in Table 1.2.1 include Alloy X[*], Metamic-HT, aluminum, and helium. Materials present in the HI-STORM UMAX storage overpack include carbon steels, insulation and concrete (in the Closure Lid). In Table 4.2.1, a summary of references used to obtain cask material properties for performing all thermal analyses is presented.

Tables 4.2.2 and 4.2.3 provide numerical thermal conductivity data of materials at several representative temperatures. Table 4.2.4 provides the data on emissivity.

In Table 4.2.5, the heat capacity and density of the MPC, overpack and CSF materials are presented. These properties are used in performing transient (i.e., 32 hours inlet duct block and hypothetical fire accident condition) analyses. The temperature-dependent values of the viscosities of helium and air are provided in Table 4.2.6.

To minimize heating of the air in the intake down flow passage, the overpack divider shell is thermally insulated. The density and specific heat of the insulation material are conservatively assumed to be the same as air. The upper bound insulation conductivity is specified in Table 4.2.7.

The properties listed in the tables in this section are consistent across all previously established HI-STORM dockets.

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[*] Alloy X is defined in [4.1.1] to designate a group of stainless steel alloys permitted for use in the HI-STORM MPCs. In this chapter the terms Alloy X and stainless steel are used interchangeably.

Table 4.2.1

SUMMARY OF HI-STORM UMAX SYSTEM MATERIALS THERMAL PROPERTY REFERENCES

Material	Emissivity	Conductivity	Density	Heat Capacity
Helium	N/A	Handbook [4.2.2]	Ideal Gas Law	Handbook [4.2.2]
Air	N/A	Handbook [4.2.2]	Ideal Gas Law	Handbook [4.2.2]
Zircaloy	[4.2.3], [4.2.13], [4.2.14], [4.2.7]	NUREG [4.2.13]	Rust [4.2.4]	Rust [4.2.4]
UO_2	Note 1	NUREG [4.2.13]	Rust [4.2.4]	Rust [4.2.4]
Stainless Steel (machined forgings)$^{\text{Note 2}}$	Kern [4.2.5]	ASME [4.2.8]	Marks' [4.2.1]	Marks' [4.2.1]
Stainless Steel Plates$^{\text{Note 3}}$	ORNL [4.2.11], [4.2.12]	ASME [4.2.8]	Marks' [4.2.1]	Marks' [4.2.1]
Carbon Steel	Kern [4.2.5]	ASME [4.2.8]	Marks' [4.2.1]	Marks' [4.2.1]
Concrete	Incropera [4.2.9]	Marks' [4.2.1]	Chapter 2	Handbook [4.2.2]
Water	Note 1	ASME [4.2.10]	ASME [4.2.10]	ASME [4.2.10]
Metamic-HT	Appendix 1.B of HI-STORM FW FSAR [4.1.2]	Test Data [4.2.6]	Test Data [4.2.6]	Test Data [4.2.6]
Insulation	Table 4.2.7	Table 4.2.7	Table 4.2.7	Table 4.2.7
Aluminum	Appendix 1.B of HI-STORM FW FSAR [4.1.2]	ASM [4.2.15]	ASM [4.2.15]	ASM [4.2.15]

Note 1: Emissivity not reported as radiation heat dissipation from these surfaces is conservatively neglected.

Note 2: Used in the MPC lid.

Note 3: Used in the MPC shell and baseplate.

Table 4.2.2

SUMMARY OF HI-STORM UMAX SYSTEM MATERIALS THERMAL CONDUCTIVITY DATA

Material	**At 200°F (Btu/ft-hr-°F)**	**At 450°F (Btu/ft-hr-°F)**	**At 700°F (Btu/ft-hr-°F)**	**At 1000°F (Btu/ft-hr-°F)**
Helium	0.0976	0.1289	0.1575	0.1890
Air*	0.0173	0.0225	0.0272	0.0336
Alloy X	8.4	9.8	11.0	12.4
Carbon Steel	24.4	23.9	22.4	20.0
Concrete**	1.05	1.05	1.05	1.05
Water	0.392	0.368	N/A	N/A
Metamic-HT	**Withheld in Accordance with 10CFR2.390**	**Withheld in Accordance with 10CFR2.390**	**Withheld in Accordance with 10CFR2.390**	**Withheld in Accordance with 10CFR2.390**
Aluminum**	69.3	69.3	69.3	69.3

* At lower temperatures, Air conductivity is between 0.0139 Btu/ft-hr-°F at 32°F and 0.0176 Btu/ft-hr-°F at 212°F.

** Conservatively assumed to be constant for the entire range of temperatures.

Table 4.2.3*

SUMMARY OF FUEL ELEMENT COMPONENTS THERMAL CONDUCTIVITY DATA

Zircaloy Cladding		**Fuel (UO_2)**	
Temperature (°F)	Conductivity (Btu/ft-hr-°F)	Temperature (°F)	Conductivity (Btu/ft-hr-°F)
392	8.28	100	3.48
572	8.76	448	3.48
752	9.60	570	3.24
932	10.44	793	2.28

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* See Table 4.2.1 for cited references.

Table 4.2.4

SUMMARY OF MATERIALS SURFACE EMISSIVITY DATA*

Material	Emissivity
Zircaloy	0.80
Painted surfaces	0.85
Stainless steel (machined forgings)	0.36
Stainless Steel Plates	0.587**
Carbon Steel	0.66
Concrete	0.88**
Metamic-HT***	**Withheld in Accordance with 10CFR2.390**
Aluminum***	**Withheld in Accordance with 10CFR2.390**

* See Table 4.2.1 for cited references.

** Lower bound value from the cited references in Table 4.2.1.

*** **Withheld in Accordance with 10CFR2.390**

Table 4.2.5

DENSITY AND HEAT CAPACITY PROPERTIES SUMMARY*

Material	**Density (lbm/ft^3)**	**Heat Capacity (Btu/lbm-^{o}F)**
Helium	(Ideal Gas Law)	1.24
Air	(Ideal Gas Law)	0.24
Zircaloy	409	0.0728
Fuel (UO_2)	684	0.056
Carbon steel	489	0.1
Stainless steel	501	0.12
Concrete	140**	0.156
Water	62.4	0.999
Metamic-HT	**Withheld in Accordance with 10CFR2.390**	**Withheld in Accordance with 10CFR2.390**
Aluminum	177.3	0.207

* See Table 4.2.1 for cited references.

** Conservatively understated value.

Table 4.2.6

GASES VISCOSITY* VARIATION WITH TEMPERATURE

Temperature (^{o}F)	**Helium Viscosity (Micropoise)**	**Temperature (^{o}F)**	**Air Viscosity (Micropoise)**
167.4	220.5	32.0	172.0
200.3	228.2	70.5	182.4
297.4	250.6	260.3	229.4
346.9	261.8	338.4	246.3
463.0	288.7	567.1	293.0
537.8	299.8	701.6	316.7
737.6	338.8	1078.2	377.6
921.2	373.0	-	-
1126.4	409.3	-	-

* See Table 4.2.1 for applicable reference.

Table 4.2.7 THERMAL PROPERTIES OF INSULATION	
Density, kg/m^3	1.2 Note 2
Heat Capacity, J/kg-K	1004 Note 2
Thermal Conductivity, W/m-K	0.072 Note 1
Surface Emissivity	0.3 Note 2
Note 1: Important to Safety property (see Section 4.2). Note 2: NITS properties.	

4.3 SPECIFICATIONS FOR COMPONENTS

Permissible temperatures for the HI-STORM UMAX system materials and components designated as "Important to Safety" (i.e., required to be maintained within their safe operating temperature ranges to ensure their intended function) are summarized in Table 2.3.7. Long-term integrity of SNF is ensured by the HI-STORM UMAX system thermal evaluation which demonstrates that fuel cladding temperatures are maintained below design basis limits.

Compliance to 10CFR72 requires, in part, identification and evaluation of short-term, off-normal and hypothetical accident conditions. The inherent mechanical characteristics of cask materials and components ensure that no significant functional degradation is possible due to exposure to short-term temperature excursions outside the normal long-term temperature limits. Fuel temperature limits specified in ISG-11 [4.0.2] are compiled in Table 2.3.7 for evaluation of cladding integrity under normal, short term operations, off-normal, and accident conditions.

4.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF STORAGE

The HI-STORM UMAX System thermal evaluation is performed in accordance with the guidelines of NUREG-1536 [4.0.1] and ISG-11 [4.0.2]. Table 1.2.1 lists the canister types and their host dockets where their thermal qualifications are performed. By perusing through the results of long term storage solutions in the appropriate FSARs, the candidate canisters and the regionalized loading pattern that produce maximum PCT in each docket are identified and summarized in Table 4.1.1. These candidate thermal configurations, as mentioned in Section 4.1, are analyzed using the FLUENT model described below to identify the "governing thermal configuration", defined as the one that yields the highest PCT.

4.4.1 FLUENT Thermal Model

The thermal analysis model for the HI-STORM UMAX system utilizes the MPC models for MPC-37 and MPC-89 described in reference [4.1.2] and that for MPC-32 described in [4.1.1] without any modification. The effective properties of the fuel storage cells used in the thermal analysis of MPC-37 and MPC-89 in the HI-STORM UMAX System are exactly the same as those used in the HI-STORM FW FSAR [4.1.2]. A geometrically accurate 3D thermal model of the HI-STORM UMAX VVM is constructed in the manner of HI-STORM 100U in Docket number 72-1014 for analysis. The VVM closure lid, inlet and outlet duct, the inner and outer annulus, the U-turn and the air plenum above the MPC are explicitly modeled.

The airflow through the cooling passages of the VVM is modeled as **Withheld in Accordance with 10CFR2.390** recommended in the Holtec-proprietary benchmarking report [4.4.1]. This is the *same* modeling approach as used in docket numbers 72-1014 and 72-1032. The underside of the VVM Support Foundation Pad is assumed to be supported on a subgrade at **Withheld in Accordance with 10CFR2.390**. The VVM thermal models are constructed using the same modeling platform used for aboveground analysis (FLUENT version 6.3).

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4.4.2 Grid Sensitivity Studies

To insure fully converged CFD results, a grid sensitivity study was performed. **Withheld in Accordance with 10CFR2.390**

A number of grids were generated to study the effect of mesh refinement on the component temperatures. All sensitivity analyses were carried out for the case of MPC-37 with short fuel under Heat Load Pattern A, which is determined to be the governing thermal configuration in Section 4.1. Table 4.4.1 gives a brief summary of the different sets of grids evaluated and PCT results.

Table 4.4.1 shows that Mesh 3 and Mesh 5 report essentially the same results. Therefore it can be concluded that Mesh 3 is reasonably converged [4.4.7]. To provide further assurance of convergence, the uncertainty of CFD result was evaluated in accordance with the ASME V&V 20-2009 for control of numerical accuracy [4.4.2]. The Grid Convergence Index (GCI), which is a measure of the solution uncertainty, is computed to be 0.627% for Meshes 1, 3 and 5. This provides further assurance of grid convergence.

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It is noted that Mesh 3 (moderate mesh size) yields a slightly higher PCT than Mesh 5 (largest mesh size). Considering the computational cost and available PCT margin, the Mesh configuration 3 was conservatively used in all thermal analyses reported herein.

4.4.3 Test Model

The HI-STORM UMAX thermal analysis is performed on the FLUENT [4.4.3] Computational Fluid Dynamics (CFD) program. To ensure a high degree of confidence in the HI-STORM UMAX thermal evaluations, the FLUENT code has been benchmarked using data from tests conducted with casks loaded with irradiated SNF ([4.4.4], [4.4.6]). The benchmark work is archived in QA validated Holtec reports ([4.4.1], [4.4.5]). These evaluations show that the FLUENT solutions are conservative in all cases. In view of these considerations, additional experimental verification of the thermal design is not necessary. Furthermore, FLUENT has been relied to secured certification in all Holtec International Part 71 and Part 72 dockets.

4.4.4 Maximum and Minimum Temperatures

i. Maximum Temperatures

A comprehensive set of thermal analyses of all candidate "thermal configurations" (meaning the combination of canister type, regionalized loading pattern and fuel type that may produce highest fuel cladding temperature) were performed using the FLUENT model described in Section 4.4.1 to quantify their thermal margins under long term storage conditions. By inspection of results in the HI-STORM 100 and HI-STORM FW dockets, the following cases were deemed to warrant analysis:

A. Docket # 72-1032: MPC-37 with short fuel under Heat Load Pattern A and MPC-89 described in Table 4.1.1*.
B. Docket # 72-1014: MPC-32 under two extreme regionalized loading scenarios (X=0.5 and X=3) described in Table 4.1.1.

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* Design basis heat load scenario bounds sub-design basis and threshold heat load scenarios defined in Tables 4.4.3, 4.4.4 and 4.4.5 (See Section 4.4.5).

The maximum spatial values of the computed temperatures of the fuel cladding, the fuel basket material, the divider shell, the closure lid concrete, the MPC lid, the MPC shell and the average air outlet for all cases are summarized in Table 4.4.2. It can be seen that the governing case is that of MPC-37 with short fuel under the regionalized storage Pattern A.

The following conclusions are reached from the solution data:

a. The PCT is below the temperature limit set forth in NUREG-1536 [4.0.1] and ISG-11 [4.0.2].
b. The maximum temperatures of all MPC and VVM constituent parts are below their respective limits set down in Table 2.3.7.

It is therefore concluded that the HI-STORM UMAX system provides a thermally acceptable storage environment for the eligible MPCs listed in Table 1.2.1 and that the governing thermal configuration corresponds to the case of MPC-37 with short fuel (Heat Load Pattern A): All other thermal configurations will yield a lower PCT result.

ii. Minimum Temperatures

In Table 2.3.6 of this report, the minimum ambient temperature condition for the HI-STORM UMAX storage overpack and MPC is specified to be -40 deg. F. If, conservatively, a zero decay heat load with no solar input is applied to the stored fuel assemblies, then every component of the system at steady state would be at a temperature of -40 deg. F. Low service temperature (-40°F) evaluation of the HI-STORM UMAX is provided in Chapter 8. All HI-STORM UMAX storage overpack and MPC materials of construction will satisfactorily perform their intended function in the storage mode under this minimum temperature condition.

4.4.5 Maximum Internal Pressure in the MPC

The MPC is initially filled with dry helium after fuel loading and drying prior to installing the MPC closure ring. In the MPC host dockets (72-1014 and 72-1032), the different helium backfill pressure specifications are allowed according to the different CoC amendments. For each type of MPC, the specification of helium backfill pressure for HI-STORM UMAX System envelop all allowed specifications defined in the MPC host docket. The helium backfill pressure for the MPCs authorized to be stored in HI-STORM UMAX are reproduced in Table 4.4.6 from their governing FSARs.

To provide additional helium backfill range for less than design basis heat load, the following Sub-Design-Basis (SDB) heat load scenarios are allowed for MPC-37 and MPC-89:

(i) MPC-37 under 80% Pattern A Design Heat Load (Table 4.4.3)
(ii) MPC-37 under 90% Pattern A Design Heat Load (Table 4.4.3)
(iii) MPC-89 under 80% Design Heat Load (Table 4.4.4)
(iv) MPC-37 under threshold heat load (Table 4.4.5)

(v) MPC-89 under threshold heat load (Table 4.4.5)

The scenarios defined herein are identical to the SDB scenarios defined in HI-STORM FW FSAR [4.1.2]. The storage cell and MPC heat load limits under the 80% and 90% of Design Heat Load scenarios are obtained by applying the heat load reduction factors defined in Table 2.1.7 to the Design Heat Load, and reported in Tables 4.4.3 and 4.4.4. The storage cell and MPC heat load limits under the threshold heat load scenario in the HI-STORM UMAX and HI-STORM FW FSAR [4.1.2] are identical and repeated in Table 4.4.5.

The helium backfill pressure limits supporting these scenarios are identical to HI-STORM FW FSAR [4.1.2], are repeated in Table 4.4.6. These backfill limits maybe optionally adopted by a cask user if the decay heats of the loaded fuel assemblies meet the SDB decay heat limits stipulated above.

As evaluated in HI-STORM FW FSAR [4.1.2], SDB scenarios (i) thru (iii) are bounded by the Pattern A Design Heat Load scenario. These scenarios do not require explicit analysis in the UMAX because these SDB scenarios incorporate heat load penalty factors defined in Table 2.1.7. However, MPC-37 and MPC-89 under threshold heat loads (Scenarios (iv) and (v)) require confirmatory analysis under UMAX storage. Considering that MPC-37 loaded with short fuel yields the highest temperatures an explicit calculation is performed for this case. The principal results are reported in Table 4.4.10. The results comply with the temperature and pressure limit Tables 2.3.7 and 2.3.5. The results support the conclusion that threshold heat load scenario is bounded by Pattern A Design Heat Load scenario.

During normal storage, the gas temperature within the MPC rises to its maximum operating basis temperature. The gas pressure inside the MPC will also increase with rising temperature. The pressure rise is determined using the ideal gas law. The MPC gas pressure is also subject to substantial pressure rise under hypothetical rupture of fuel rods and large gas inventory non-fuel hardware (PWR BPRAs).

The MPC maximum gas pressure is computed for a postulated release of fission product gases from fuel rods into this free space. For these scenarios, the amounts of each of the release gas constituents in the MPC cavity are summed and the resulting total pressures determined from the ideal gas law. A concomitant effect of rod ruptures is the increased pressure and molecular weight of the cavity gases with enhanced rate of heat dissipation by internal helium convection and lower cavity temperatures. As these effects are substantial under large rod ruptures the 100% rod rupture accident is evaluated with due credit for increased heat dissipation under increased pressure and molecular weight of the cavity gases. Based on fission gases release fractions (NUREG 1536 criteria [4.0.1]), rods' net free volume and initial fill gas pressure, the maximum gas pressures with 1% (normal), 10% (off-normal) and 100% (accident condition) rod rupture are given in Table 4.4.7 for all thermal scenarios analyzed in Section 4.4.4. The maximum calculated gas pressures reported in Table 4.4.7 are all below the MPC internal design pressures for normal, off-normal and accident conditions specified in Table 2.3.5.

4.4.6 Engineered Clearances to Eliminate Thermal Interferences

Thermal stress in a structural component is the resultant sum of two factors, namely: (i) restraint of free end expansion and (ii) non-uniform temperature distribution. To minimize thermal stresses in load bearing members, the HI-STORM UMAX system is engineered with adequate gaps to permit free thermal expansion of the fuel basket and MPC in axial and radial directions. In this subsection, differential thermal expansion calculations are performed for the governing thermal configuration, i.e. MPC-37 with short fuel under Heat Loading Pattern A, to demonstrate that engineered gaps in the HI-STORM UMAX System are adequate to accommodate thermal expansion of the fuel basket and MPC.

The following gaps are evaluated:

a. Fuel Basket-to-MPC Radial Gap
b. Fuel Basket-to-MPC Axial Gap
c. MPC-to-Divider Shell Radial Growth
d. MPC-to-VVM Closure Lid Axial Growth

The FLUENT thermal model provides the 3-D temperature field in the HI-STORM UMAX system from which the changes in the above gaps are directly computed. Table 4.4.8 provides the initial minimum gaps and their corresponding value during long-term storage conditions. Significant margins against restraint to free-end expansion are indicated by the data in Table 4.4.8.

4.4.7 Effect of Elevation

The reduced ambient pressure at site elevations significantly above the sea level will act to reduce the ventilation air mass flow, resulting in a net elevation of the peak cladding temperature. However, the ambient temperature (i.e., temperature of the feed air entering the overpack) also drops with the increase in elevation. Because the peak cladding temperature also depends on the feed air temperature (the effect is one-for-one within a small range, i.e., 1°F drop in the feed air temperature results in ~1°F drop in the peak cladding temperature), the adverse ambient pressure effect of increased elevation is partially offset by the ambient air temperature decrease. The table below illustrates the variation of air pressure and corresponding ambient temperature as a function of elevation.

Elevation (ft)	Pressure (psia)	Ambient Temperature Reduction versus Sea Level
Sea Level (0)	14.70	0°F
2000	13.66	7.1°F

4000	12.69	14.3°F

A survey of the elevation of nuclear plants in the U.S. shows that nuclear plants are situated near about sea level or elevated slightly (~1000 ft). The effect of the elevation on peak fuel cladding temperatures is evaluated by performing calculations for a HI-STORM UMAX system situated at an elevation of 1500 feet. At this elevation the ambient temperature would decrease by approximately 5°F (See Table above). The peak cladding temperatures are calculated under the reduced ambient temperature and pressure at 1500 feet elevation for the MPC-37 with the short fuel under heat load pattern A. The results are presented in Table 4.4.9.

These results show that the PCT, including the effects of site elevation, continues to be well below the regulatory cladding temperature limit of 752°F. In light of the above evaluation, it is not necessary to place ISFSI elevation constraints for HI-STORM UMAX deployment at elevations up to 1500 feet. If, however, an ISFSI is sited at an elevation greater than 1500 feet, the effect of altitude on the PCT shall be quantified as part of the 10 CFR 72.212 evaluation for the site using the site ambient conditions.

4.4.8 Burnup Effects on Thermal Performance of HI-STORM UMAX System

Withheld in Accordance with 10CFR2.390 The effective properties of the fuel storage cells used in the thermal analysis of MPC-37 and MPC-89 in the HI-STORM UMAX System are exactly the same as those used in the HI-STORM FW FSAR [4.1.2]. Thermal conductivities of fresh UO_2 were used to determine the effective thermal properties of the fuel storage cells. However, it is known that the thermal conductivity of the fuel pellet (UO_2) will reduce with increasing burn-ups. The progressive buildup of fission products with increasing fuel burnup in the fuel pellets progressively reduces its thermal conductivity [4.4.9]. The effect of reduction in the fuel pellet thermal conductivity with fuel burnup and therefore, on the effective planar thermal conductivities of the rodded region is evaluated in [4.4.8].

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To quantitatively assess the magnitude of the impact of the burnup effects on thermal performance of the HI-STORM UMAX System, a sensitivity study is performed with the revised effective thermal conductivities of the fuel storage cells on the most limiting normal storage condition case (i.e., MPC-37 with short fuel, see Section 4.1). The temperatures of fuel and primary system components are reported in Table 4.4.11. The results confirm that the burnup effect is extremely small.

4.4.9 Evaluation of System Performance for Normal Conditions of Storage

The HI-STORM UMAX System thermal analysis is based on a detailed 3-D heat transfer model that conservatively accounts for all modes of heat transfer in the MPC and overpack. The thermal model incorporates conservative assumptions that render the computed temperature results for long-term storage to be conservative. The computed temperatures in "UMAX" under the governing thermal scenarios show that in each case:

a. The peak cladding temperature is below the ISG-11 Rev 3 limit.
b. The temperatures of structural members in the VVM, which are made of either carbon steel or stainless steel, is well below their allowable values set down in the Chapter 2 (presented in Table 2.3.7).
c. The temperature of shielding concrete mass and insulation (both non-structural members) are also well within their stipulated limits set forth in Table 2.3.7

The modest metal temperatures reached in "UMAX" insure that the components of the system will not suffer long term degradation from elevated temperature effects such as creep, alloy phase transformation, recrystallization of the materials' grain structure, and the like. Therefore, safety of long term storage from the thermal standpoint is assured.

Table 4.4.1

NORMAL LONG-TERM STORAGE TEMPERATURES FOR LIMITING MPC-37 WITH SHORT FUEL (HEAT LOAD PATTERN A) USING DIFFERENT MESHES

Mesh No	Total Cell Number	PCT °C (°F)	Permissible PCT Limit °C (°F)	PCT Margin °C (°F)
1	932,307	371 (700)	400 (752)	28 (51)
3*	2,075,968	367 (693)	400 (752)	33 (59)
5	4,724,915	365 (689)	400 (752)	35 (63)

* Mesh 3 is reasonably converged and is adopted for all licensing basis calculation.

Table 4.4.2

NORMAL LONG-TERM STORAGE TEMPERATURES FOR CANDIDATE CANISTERS UNDER DESIGN BASIS HEAT LOADS

Component	**MPC-37 with Short Fuel (Heat Load Pattern A)** **°C (°F)**	**MPC-89 Design Basis Heat Load** **°C (°F)**	**MPC-32 under Heat Load Pattern X=0.5** **°C (°F)**	**MPC-32 under Heat Load Pattern X=3** **°C (°F)**
Fuel Cladding	367 (693)	358 (676)	363 (685)	366 (691)
MPC Basket	354 (669)	349 (660)	361 (682)	364 (687)
Basket Periphery	292 (558)	288 (550)	302 (576)	274 (525)
Aluminum Basket Shims	273 (523)	266 (511)	-	-
MPC Shell	238 (460)	243 (469)	230 (446)	217 (423)
MPC Lid*	244 (471)	244 (471)	246 (475)	241 (466)
Divider Shell	175 (347)	177 (351)	150 (302)	134 (273)
Containment Shell	56 (133)	56 (133)	53 (127)	52 (126)
Closure Lid Concrete†	107 (225)	109 (228)	97 (207)	89 (192)
Insulation	175 (347)	177 (351)	150 (302)	134 (273)
Average Air Outlet‡	73 (163)	79 (174)	74 (165)	69 (156)

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* Maximum section average temperature reported.

† Maximum section average temperature reported.

‡ Section average temperature on the cross section area of outlet duct below the outlet vent screen reported. Reported herein for the option of temperature measurement surveillance of outlet duct air temperature as set forth in the Technical Specifications. The bounding air outlet temperature of 170°F corresponding to MPC-37 with long fuel is specified in the Technical Specifications.

Table 4.4.3

HI-STORM UMAX MPC-37 SUB-DESIGN BASIS HEAT LOAD DATA (See Figure 2.1.7)

Number of Regions: 3			
Number of Storage Cells: 37			
Short and Standard Fuel	**80% of PATTERN A in Table 2.1.8 - Total Heat Load: 35.738 kW**		
	Region No.	Decay Heat Limit per Cell, kW	Number of Cells per Region
	1	0.858	9
	2	1.352	12
	3	0.737	16
	90% of PATTERN A in Table 2.1.8 - Maximum Heat Load: 40.21 kW		
	1	0.966	9
	2	1.521	12
	3	0.829	16
Long Fuel	**80% of PATTERN A in Table 2.1.8 - Total Heat Load: 37.64 kW**		
	1	0.904	9
	2	1.424	12
	3	0.776	16
	90% of PATTERN A in Table 2.1.8 - Total Heat Load: 42.345 kW		
	1	1.017	9
	2	1.602	12
	3	0.873	16

Table 4.4.4

HI-STORM UMAX MPC-89 80% SUB-DESIGN BASIS HEAT LOAD DATA
(See Figure 2.1.8)

Number of Regions: 3

Number of Storage Cells: 89

Maximum Heat Load: 37.088 kW

Region No.	Decay Heat Limit per Cell, kW	Number of Cells per Region
1	0.352	9
2	0.496	40
3	0.352	40

Table 4.4.5

HI-STORM UMAX THRESHOLD HEAT LOAD DATA (See Figures 2.1.7 and 2.1.8)

MPC-37	Total Heat Load: 34.36 kW		
	1	0.8	9
	2	0.97	12
	3	0.97	16
MPC-89	Total Heat Load: 34.75 kW		
	1	0.35	9
	2	0.35	40
	3	0.44	40

Table 4.4.6
MPC HELIUM BACKFILL SPECIFICATIONS*

	Item	Specification[†] psig
MPC-37, Pattern A (Table 2.1.8)	Minimum Gauge Pressure	42.0
	Maximum Gauge Pressure	45.5
MPC-37, 80% of Pattern A (Table 4.4.3)	Minimum Gauge Pressure	42.0
	Maximum Gauge Pressure	50.0
MPC-37, 90% of Pattern A (Table 4.4.3)	Minimum Gauge Pressure	42.0
	Maximum Gauge Pressure	47.8
MPC-37, Threshold Heat Load (Table 4.4.5)	Minimum Gauge Pressure	42.0
	Maximum Gauge Pressure	50.0
MPC-37, Pattern B (Table 2.1.8)	Minimum Gauge Pressure	41.0
	Maximum Gauge Pressure	46.0
MPC-89 Design Heat Load (Table 2.1.9)	Minimum Gauge Pressure	42.5
	Maximum Gauge Pressure	47.5
MPC-89, 80% of Design Heat Load (Table 4.4.4)	Minimum Gauge Pressure	42.0
	Maximum Gauge Pressure	50.0
MPC-89, Threshold Heat Load (Table 4.4.5)	Minimum Gauge Pressure	42.0
	Maximum Gauge Pressure	50.0
MPC-32	Minimum Gauge Pressure	43.7
	Maximum Gauge Pressure	48.5
MPC-24/24E/24EF	Minimum Gauge Pressure	42.5
	Maximum Gauge Pressure	48.5
MPC-68/68F/68FF/ 68M	Minimum Gauge Pressure	43.5
	Maximum Gauge Pressure	48.5

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* The helium backfill specification for each MPC envelops the helium backfill specification defined in its host docket.

[†] Specification at a reference temperature of 21.1°C (70°F).

Table 4.4.7

SUMMARY OF MPC INTERNAL PRESSURES UNDER THE LIMITING THERMAL SCENARIOS FOR LONG-TERM STORAGE*

Condition	**MPC-37 with Short Fuel (Heat Load Pattern A)** **(psig)**	**MPC-89 Design Basis Heat Load** **(psig)**	**MPC-32 under Heat Load Pattern X=0.5** **(psig)**	**MPC-32 under Heat Load Pattern X=3** **(psig)**
Normal:				
intact rods	97.4	99.2	96.6	89.9
1% rods rupture	98.5	99.8	97.6	90.8
Off-Normal (10% rods rupture)	108.4	104.9	106.3	99.0
Accident (100% rods rupture)	195.5	156.2	193.7	181.1

* Per NUREG-1536, pressure analyses with ruptured fuel rods (including BPRA rods for PWR fuel) is performed with release of 100% of the ruptured fuel rod fill gas and 30% of the significant radioactive gaseous fission products.

Table 4.4.8

SUMMARY OF HI-STORM UMAX DIFFERENTIAL THERMAL EXPANSIONS FOR LIMITING MPC-37 WITH SHORT FUEL (HEAT LOAD PATTERN A)

Gap Description	**Cold Gap U (in)**	**Differential Expansion δ_i (in)**	**Is Free Expansion Criterion Satisfied (i.e., $U > \delta_i$)**
Fuel Basket-to-MPC Radial Gap	0.125	0.117	Yes
Fuel Basket-to-MPC Axial Gap	1.5	0.434	Yes
MPC-to-Divide Shell Radial Gap	0.25	0.151	Yes
MPC-to-Closure Lid Axial Gap	24	0.525	Yes

Table 4.4.9

NORMAL LONG-TERM STORAGE TEMPERATURES FOR LIMITING MPC-37 WITH SHORT FUEL (UNDER HEAT LOAD PATTERN A) AT AN ELEVATED SITE

Component	**Temperature °C (°F)**
Fuel Cladding	369 (696)
MPC Basket	355 (671)
Basket Periphery	293 (559)
Aluminum Basket Shims	274 (525)
MPC Shell	241 (466)
MPC Lid*	243 (469)
Divider Shell	176 (349)
Containment Shell	54 (129)
Closure Lid Concrete†	107 (225)
Insulation	176 (349)
Average Air Outlet‡	77 (171)

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* Maximum section average temperature reported.

† Maximum section average temperature reported.

‡ Section average temperature on the cross section area of outlet duct below the outlet vent screen reported. Reported herein for the option of temperature measurement surveillance of outlet duct air temperature as set forth in the Technical Specifications

Table 4.4.10

NORMAL LONG-TERM STORAGE TEMPERATURES AND PRESSURE FOR MPC-37 WITH SHORT FUEL UNDER THRESHOLD HEAT LOAD

Component	**Temperature** **°C (°F)**
Fuel Cladding	299 (570)
MPC Basket	286 (547)
Basket Periphery	241 (466)
Aluminum Basket Shims	225 (437)
MPC Shell	200 (392)
MPC Lid*	202 (396)
Divider Shell	144 (291)
Containment Shell	52 (126)
Closure Lid Concrete†	91 (196)
Insulation	144 (291)
MPC Cavity Pressure (psig)	
Normal Condition – No Rods Rupture	95.7

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* Maximum section average temperature reported.

† Maximum section average temperature reported.

Table 4.4.11

BURNUP EFFECTS ON NORMAL LONG-TERM STORAGE TEMPERATURES FOR MPC-37 WITH SHORT FUEL UNDER DESIGN BASIS HEAT LOAD

Component	**Design Basis Temperature**[Note 1] **°C (°F)**	**High Burnup Fuel Effects °C (°F)**
Fuel Cladding	367 (693)	368 (694)
MPC Basket	354 (669)	354 (669)
MPC Shell	238 (460)	240 (464)
Divider Shell	175 (347)	176 (349)

Note 1: The design basis results are extracted from Table 4.4.2.

4.5 SHORT-TERM OPERATIONS

Short-Term Operations are those activities that are required to load and package the fuel in a waste package (i.e., a multi- purpose canister) and to place it in long term storage at an ISFSI. In the regulatory literature, all activities that originate in the plant's spent fuel pool and culminate in the MPC emplaced on the ISFSI pad in a passive storage mode or vice-verse from ISFSI to pool under the unlikely scenario requiring fuel unloading are collectively referred to as Short Term Operations. These include operations that occur inside the part 50 facility such as dewatering, drying, and backfilling the canister, establishing the confinement boundary by welding the lid and the Closure Ring and those that occur outside of it, namely transporting the canister to the ISFSI and transferring the MPC to the storage module. All of the short term operations have one common feature: They all involve the transfer cask. In fact, the beginning and end of Short Term Operations can be identified by the moment the fuel enters the MPC inside HI-TRAC to the time when the MPC is delivered to the storage module. The qualification of Short Term Operations, therefore, is integral to the certification of the transfer cask. Because this FSAR envisages using MPCs and their associated transfer casks certified in the HI-STORM FW FSAR [4.1.2] under heat loads bounding the HI-STORM UMAX design heat loads, satisfaction of the safety considerations pertaining to the transfer operations is assured. Therefore, consideration of Short Term Operations except for the MPC-to-UMAX transfer operation during storage or the reverse operation to support fuel unloading is not germane to the safety analysis of HI-STORM UMAX to serve as the storage system for previously licensed MPCs. The MPC transfer operation is evaluated in the following.

The operational steps that occur during MPC transfer operations include the Mating Device installed and the drawer closed. As explained below this operational step must be performed in an expeditious manner to avoid excessive heating of the MPC and fuel (See Section 9.2). As the Mating Device in the closed drawer position blocks air flow it must be opened to establish air cooling. In the event of equipment malfunction that results in the blockage of air flow, corrective actions must occur within the time limits of the 100% blocked duct accident condition evaluated in Section 4.6. During MPC transfer operation from HI-TRAC to the UMAX (or reverse operation to support fuel unloading), air flow through the VVM cavity will be completely stopped under a complete closure of the Mating Device drawer. This scenario is same as the all inlet duct blockage condition analyzed in Section 4.6.2.3. Therefore, the temperature rise of fuel with time under this event, as shown in Figure 4.6.1 is applicable to evaluation of the closed drawer event. The maximum allowable time duration to ensure temperature limits of limiting fuel (high burnup fuel) remain within short term limits is computed as 4 hours. The time limit computed herein is for an example case of design basis heat load and MPCs containing one or more high burnup fuel assemblies. Additional site-specific analysis may be performed to compute applicable time limits under less than design-basis loadings.

4.5.1 Thermally Limiting Evolutions During Short-Term Operations

Except for MPC-to-UMAX transfer operations evaluated in Section 4.5 herein thermally limiting evolutions under short-term operations defined in the HI-STORM FW FSAR Section 4.5.1 [4.1.2] are incorporated by reference.

4.5.2 HI-TRAC VW Thermal Model

The HI-TRAC VW thermal model defined in the HI-STORM FW FSAR Section 4.5.2 [4.1.2] addressing on-site transfer and vacuum drying operations is incorporated by reference.

4.5.3 Maximum Time Limit During Wet Transfer Operations

Time limits evaluated under wet transfer operations in the HI-STORM FW FSAR Section 4.5.3 [4.1.2] are incorporated by reference.

4.5.4 Analysis of Limiting Thermal States During Short-Term Operations

Limiting thermal states evaluated in the HI-STORM FW FSAR Section 4.5.4 [4.1.2] are incorporated by reference.

4.5.5 Cask Cooldown and Reflood During Fuel Unloading Operation

Cask cooldown and reflood evaluation in the HI-STORM FW FSAR Section 4.5.5 [4.1.2] is incorporated by reference.

4.5.6 Maximum Internal Pressure

Maximum internal pressure evaluated in the HI-STORM FW FSAR Section 4.5.6 [4.1.2] is incorporated by reference.

4.6 OFF-NORMAL AND ACCIDENT EVENTS

The safety evaluation of off-normal and accident conditions described in Section 2.5 is presented in this section. Thermal analysis of the HI-STORM UMAX System is performed for the "governing thermal configuration", i.e. MPC-37 with short fuel under heat load Pattern A, identified by the analysis in Section 4.1.

4.6.1 Off-Normal Events

4.6.1.1 Off-Normal Environmental Temperature

To evaluate the effect of off-normal weather conditions, an off-normal ambient temperature (Table 2.3.6) is postulated to persist for a sufficient duration to allow the HI-STORM UMAX system to reach steady state conditions. Because of the large mass of the HI-STORM UMAX system, with its corresponding large thermal inertia and the limited duration for the off-normal temperatures that arise in real life, 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 UMAX system are conservatively assumed to be elevated by the difference between the off-normal and normal ambient temperatures. The HI-STORM UMAX extreme ambient temperatures computed in this manner are reported in Table 4.6.1. The co-incident MPC pressure is also computed (Table 4.6.5) and compared with the off-normal design pressure (Table 2.3.5), which shows a positive safety margin. The results are confirmed to be below the corresponding limits in Chapter 2.

4.6.1.2 Partial Blockage of Air Inlets

The HI-STORM UMAX 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. However, as required by the design criteria presented in Chapter 2, it is postulated that the HI-STORM UMAX 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 assuming that steady state conditions have been reached for the "governing thermal configuration" established by a series of thermal analyses in Section 4.4 in the foregoing. The computed temperatures and pressures are reported in Tables 4.6.1 and 4.6.5 respectively. The results are confirmed to be below the allowable limits for both internal pressure and temperature limits presented in Tables 2.3.5 and 2.3.7 respectively.

4.6.1.3 Sustained Wind

Text withheld in Accordance with 10 CFR 2.390

4.6.1.4 Off-Normal Pressure

This event is defined as a combination of (a) maximum helium backfill pressure permitted, (b) 10% fuel rods rupture, (c) governing thermal configuration, and (d) normal ambient temperature defined in Table 2.3.6. The principal objective of the analysis is to demonstrate that the MPC off-normal design pressure (Table 2.3.5) is not exceeded. Table 4.4.7 provides the computed pressures for the off-normal event as defined above which show that all applicable pressure limits are met with positive margins.

4.6.1.5 FHD Malfunction

FHD malfunction evaluated in the HI-STORM FW FSAR Section 4.6.1 [4.1.2] is incorporated by reference.

4.6.2 Accident Events

4.6.2.1 Fire Accident

(a) HI-STORM UMAX Fire
The Design Basis Fire event for HI-STORM UMAX, described in Section 2.5, is identical to that of HI-STORM FW[4.1.2] and HI-STORM 100 [4.1.1]. The fire evaluation for limiting MPC-37 with short fuel stored in HI-STORM UMAX is bounded by the analysis reported in the HI-STORM FW FSAR [4.1.2], due to the following facts:

- The initial PCT and component temperatures of MPC stored in HI-STORM UMAX system are lower than that of the same MPC in the HI-STORM FW system.
- HI-STORM UMAX system has much lesser surface directly exposed to fire than that of above-ground system.

Consequently, the conclusion that PCT and components' temperatures and MPC pressure are below temperature and pressure limits for the Design Basis Fire event drawn in HI-STORM FW FSAR [4.1.2] will remain valid for the HI-STORM UMAX system.

(b) HI-TRAC VW Fire
HI-TRAC VW fire evaluated in the HI-STORM FW FSAR Section 4.6.2 [4.1.2] is incorporated by reference.

4.6.2.2 Extreme Environmental Temperatures

To evaluate the effect of extreme weather conditions, an extreme ambient temperature (Table 2.3.6) is postulated to persist for a sufficient duration to allow the HI-STORM UMAX system to reach steady state conditions. Because of the large mass of the HI-STORM UMAX system, with its corresponding large thermal inertia and the limited duration for the extreme temperatures that arise in real life, 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 UMAX system are conservatively assumed to be elevated by the difference between the extreme and normal ambient temperatures. The HI-STORM UMAX extreme ambient temperatures computed in this manner are reported in Table 4.6.6. The co-incident MPC pressure is also computed (Table 4.6.10) and compared with the accident design pressure (Table 2.3.5), which shows a positive safety margin. The results are confirmed to be below the corresponding limits in Chapter 2.

4.6.2.3 100% Blockage of Air Inlets

This event is defined as a postulated complete blockage of all inlet ducts for a specified duration. The immediate consequence of a complete blockage of the air inlets is that the normal circulation of air for cooling the MPC is interrupted. A small amount of heat will continue to be removed by localized air circulation patterns in the VVM annulus and outlet ducts, and the MPC will continue to dissipate heat to the relatively cooler subgrade. As the temperatures of the MPC and its contents rise, the rate of heat rejection will increase correspondingly. Nevertheless, under this condition, the temperatures of the storage system including the MPC and the stored fuel assemblies will rise monotonically 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 HI-STORM UMAX thermal model for 100% air inlet blockage is the same 3-Dimensional model constructed for normal storage conditions (see Section 4.4) except for the inlet ducts, which are assumed to have become impervious to air flow. Using this model, a transient thermal solution of the HI-STORM UMAX system starting from normal storage conditions is obtained. The results of the 32 hours blocked ducts transient analysis are presented in Table 4.6.7 and compared against the accident temperature limits (Table 2.3.7). The history of PCT increasing during the early time stage is plotted in Figure 4.6.1 to provide guideline for fuel loading operation. The co-incident MPC pressure (Table 4.6.10) is also computed and compared with the accident design pressure (Table 2.3.5). All computed results are found to remain well below their respective limits under the postulated 32 hours blockage duration.

4.6.2.4 Burial Under Debris

Burial of the HI-STORM UMAX system under debris is not a credible accident. During storage at the ISFSI there are no structures that loom over the casks whose collapse could completely bury the casks in debris. Minimum regulatory distances from the ISFSI to the nearest ISFSI security fence precludes the close proximity of substantial amount of vegetation. Thus, even though there is no credible mechanism for the HI-STORM UMAX system to become completely buried under debris, the scenario of complete burial under debris is analyzed herein to quantify the system's resistance to such an event.

Thus, burial under debris is a postulated accident scenario that is analyzed in this FSAR to determine the length of time that is available to the plant's emergency response organization to remedy the condition. The generic burial-under-debris analysis is performed under the following assumptions:

a. The ISFSI is assumed to be populated with the limiting MPC type containing the most adverse thermal loading, i.e. MPC-37 with short fuel under heat load pattern A.

b. The burial medium serves as a perfect insulation blocking off any conductive or convective means for heat rejection to the environment.

c. The burial is assumed to affect all VVMs at the ISFSI. Thus no heat transmission path to the adjacent subgrade is available.

d. Heat rejection to the under-grade is also assumed to be (non-mechanistically) lost.

Under the above scenario, the contents of the HI-STORM UMAX 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 *lower bound* on $\Delta\tau$, the HI-STORM UMAX VVM's 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 4.6.8. Using these parameters $\Delta\tau$ is computed as follows:

$$\Delta\tau = \frac{m \times c_p \times \Delta T}{Q}$$

where:

$\Delta\tau$ = minimum available burial time (hr)
m = Mass of HI-STORM UMAX System (lb)
c_p = Specific heat capacity (Btu/lb-^{o}F)
ΔT = Permissible temperature rise (^{o}F)
Q = Decay heat load (Btu/hr)

Substituting the parameters in Table 4.6.8, the minimum available burial time is computed as 24 hours. The co-incident MPC pressure (see Table 4.6.10) is also computed and compared with the accident design pressure (Table 2.3.5). These results indicate that HI-STORM UMAX has a substantial thermal heat sink capacity to withstand a complete burial-under-debris event.

The above simplified computation may be used to compute the permissible burial-under-debris time for a VVM cavity corresponding to its actual content conditions. The available time to restore full ventilation in a loaded VVM is computed above for guiding the Emergency Response plan for an ISFSI for which a burial-under-debris event can be credibly postulated.

4.6.2.5 Flood

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4.6.2.6 Jacket Water Loss

HI-TRAC VW jacket water loss accident evaluated in the HI-STORM FW FSAR Section 4.6.2 [4.1.2] is incorporated by reference.

Table 4.6.1

OFF-NORMAL EVENTS - MAXIMUM TEMPERATURES

Component	**Off-Normal Ambient Temperature Condition °C (°F)**	**Partial Inlet Ducts Blockage Condition °C (°F)**
Fuel Cladding	378 (713)	369 (696)
MPC Basket	365 (689)	356 (673)
Basket Periphery	303 (578)	294 (561)
Basket Shims	284 (543)	274 (525)
MPC Shell	249 (480)	240 (464)
MPC Lid*	255 (491)	246 (475)
Divider Shell	186 (367)	177 (351)
Containment Shell	67 (153)	56 (133)
Closure Lid Concrete†	118 (245)	109 (228)
Insulation	186 (367)	177 (351)

---

* Maximum section average temperature reported.

† Maximum section average temperature reported.

Table 4.6.2

EFFECT OF WIND ON PEAK CLADDING TEMPERATURE - A SINGLE HI-STORM UMAX SYSTEM SIMULATED

Wind Speed	**Fuel Cladding Temperature °C (°F)**
0 MPH	367 (693)*
2 MPH	371 (700)
5 MPH	376 (709)
7 MPH	379 (714)
10 MPH	379 (714)

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* Reproduced from Table 4.4.2 for the quarter symmetric model.

Table 4.6.3

EFFECT OF WIND ON AIR INLET TEMPERATURES OF HI-STORM UMAX SYSTEMS STORED IN AN ISFSI ARRAY

	Air Inlet Temperature [Note 1], °F				
	0 MPH [Note 2]	2 MPH	5 MPH	7 MPH	10 MPH
Module 1[Note 3]	82	84	84	85	84
Module 2	82	83	85	86	86
Module 3	82	86	86	87	88
Module 4	82	90	86	89	91
Module 5	82	89	87	90	91
Module 6	82	88	90	89	90
Module 7	82	90	**93**	90	92
Module 8	82	88	91	88	88

Note 1: Air inlet temperature reported in this table is the mass-average temperature calculated in the cross-section surface of inlet pipe immediate below the inlet vent screen.

Note 2: Reference from the quarter symmetric model described in Section 4.4.

Note 3: The series of module is numbered in the sequence as the wind direction, i.e. Module 1 is the front module facing the wind inlet.

Table 4.6.4

MAXIMUM HI-STORM UMAX STEADY STATE STORAGE TEMPERATURES UNDER WIND CONDITION

Component	**Temperature** ^{0}**C (**^{0}**F)**
Fuel Cladding	385 (725)
MPC Basket	372 (702)
Basket Periphery	309 (588)
Aluminum Basket Shims	289 (552)
MPC Shell	254 (489)
MPC Lid*	258 (497)
Divider Shell	194 (381)
Containment Shell	60 (140)
Closure Lid Concrete†	125 (257)
Insulation	194 (381)

---

* Maximum section average temperature reported.

† Maximum section average temperature reported

Table 4.6.5

OFF-NORMAL CONDITION MAXIMUM MPC PRESSURES FOR LIMITING MPC-37 WITH SHORT FUEL UNDER HEAT LOAD PATTERN A

Condition	**Gauge Pressure (psig)**
Off-Normal Ambient Temperature	99.7
Partial Blockage of Inlet Ducts	97.8
Maximum Wind Effect	101.1

Table 4.6.6

EXTREME ENVIRONMENTAL CONDITION
MAXIMUM HI-STORM UMAX TEMPERATURES

Component	**Temperature** °C (°F)
Fuel Cladding	392 (738)
MPC Basket	379 (714)
Basket Periphery	317 (603)
Aluminum Basket Shims	298 (568)
MPC Shell	263 (505)
MPC Lid*	269 (516)
Divider Shell	200 (392)
Containment Shell	81 (178)
Closure Lid Concrete†	132 (270)
Insulation	200 (392)

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* Maximum section average temperature reported.

† Maximum section average temperature reported.

Table 4.6.7

MAXIMUM TEPERATURES REACHED AFTER 32 HOURS OF COMPLETE DUCT BLOCKAGE(GOVERNING THERMAL CONFIGURATION CASE)

Component	**Initial Condition °C (°F)**	**Final Condition °C (°F)**
Fuel Cladding	367 (693)	518 (964)
MPC Basket	354 (669)	502 (936)
Basket Periphery	292 (558)	438 (820)
Aluminum Basket Shims	273 (523)	417 (783)
MPC Shell	238 (460)	389 (732)
MPC Lid*	244 (471)	333 (631)
Divider Shell	175 (347)	368 (694)
Containment Shell	56 (133)	246 (475)
Closure Lid Concrete† Concrete†	107 (225)	217 (423)
Insulation	175 (347)	367 (693)

---

* Maximum section average temperature reported.

† Maximum section average temperature reported.

Table 4.6.8

SUMMARY OF INPUTS FOR BURIAL- UNDER- DEBRIS ANALYSIS

Thermal Inertia Inputs: M (Lowerbound HI-STORM UMAX Weight) Cp (Carbon steel heat capacity)	 46000 kg 419 J/kg-°C
Clad initial temperature	367°C
Q (Decay heat)	44.7 kW
ΔT (clad temperature margin)	200°C

Table 4.6.9

MAXIMUM COMPONENT TEMPERATURES DURING FLOOD ACCIDENT

Component	**CASE 1** Note 1 **°C (°F)**	**CASE 2** Note 1 **°C (°F)**
Fuel Cladding	368 (694)	389 (732)
MPC Basket	354 (669)	376 (709)
Basket Periphery	293 (559)	314 (597)
Aluminum Basket Shims	273 (523)	293 (559)
MPC Shell	239 (462)	260 (500)
MPC Lid*	244 (471)	264 (507)
Divider Shell	176 (349)	208 (406)
Containment Shell	56 (133)	72 (162)
Closure Lid Concrete†	108 (226)	140 (284)
Insulation	176 (349)	208 (406)

Note 1: Case 1 and Case 2 are defined in Section 4.6.2.5 as flood events of different heights to block air flow up to pedestal height and MPC baseplate respectively.

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* Maximum section average temperature reported.

† Maximum section average temperature reported.

Table 4.6.10

ACCIDENT CONDITION MAXIMUM MPC PRESSURES

Condition	**Gauge Pressure (psig)**
Extreme Ambient Temperature	102.5
32 hours 100% blockage of air inlet	127.9
Burial under Debris @ Maximum Allowable Burial Time	138.9
Flood Case 1 *	97.4
Flood Case 2 *	101.5

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* Flood scenario defined in Section 4.6.2.5.

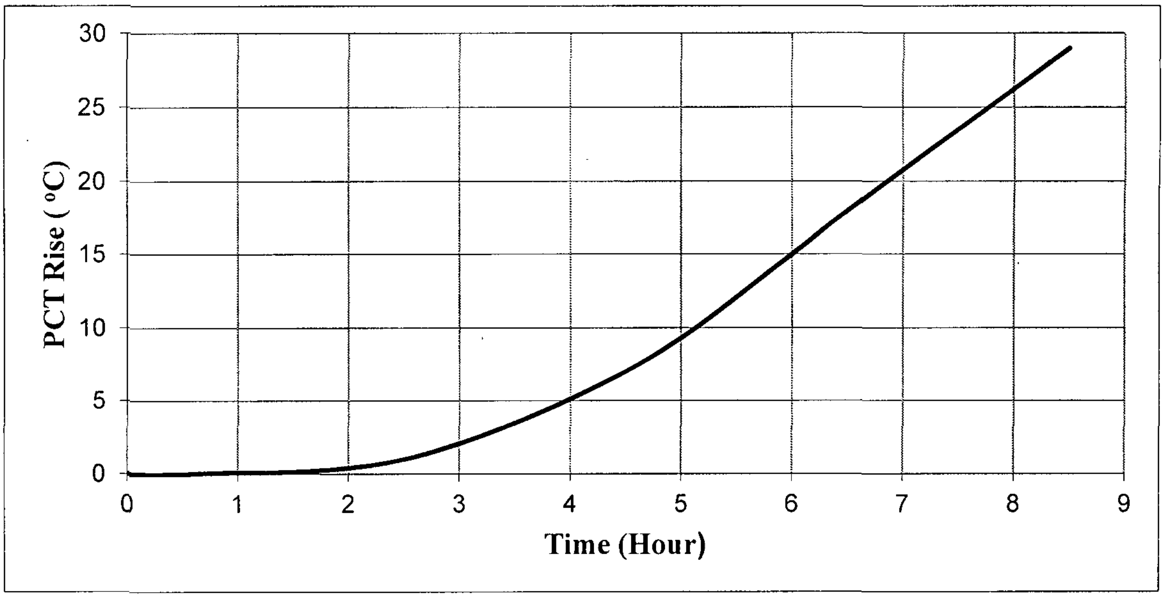

Figure 4.6.1: Rise of PCT during All Inlet Duck Blockage Accident Condition

4.7 REGULATORY COMPLIANCE

The thermal compliance pursuant to the provisions of NUREG [4.0.1] and ISG-11 [4.0.2] of the MPCs requested for certification (MPC-37 and MPC-89) in the HI-STORM UMAX system has been considered in this chapter. NUREG-1536 [4.0.1] and ISG-11 [4.0.2] define several thermal acceptance criteria that must be applied to evaluations of normal conditions of storage. These items are addressed in Sections 2.5 and 4.1. Each of the pertinent criteria and the conclusion of the evaluations are summarized here.

As required by ISG-11 [4.0.2], the fuel cladding temperature at the beginning of dry storage is maintained below the anticipated damage-threshold temperatures for normal conditions for the licensed life of the HI-STORM UMAX System. Maximum fuel cladding temperatures for long-term storage conditions are reported in Section 4.4.

As required by NUREG-1536 [4.0.1], the maximum internal pressure of the canister remains within its design pressure for normal conditions, assuming rupture of 1 percent of the fuel rods. Assumptions for pressure calculations include release of 100 percent of the fill gas and 30 percent of the significant radioactive gases in the fuel rods. Maximum internal pressures are reported in Section 4.4 and shown to remain below the normal design pressures specified in Table 2.3.5.

As required by NUREG-1536 [4.0.1], all VVM components and fuel materials are maintained within their minimum and maximum temperature for normal and off-normal conditions in order to enable components to perform their intended safety functions. Maximum and minimum temperatures for normal, off-normal and accident long-term storage conditions are reported in Sections 4.4 and 4.6 which are shown to be well below their respective Design temperature limits summarized in Table 2.3.7.

As required by NUREG-1536 [4.0.1], the system ensures a very low probability of cladding breach during long-term storage. For long-term normal conditions, the maximum CSF cladding temperature is shown to be below the ISG-11 [4.0.2] limit of 400°C (752°F).

As required by NUREG-1536 [4.0.1], the system is passively cooled. All heat rejection mechanisms described in this chapter, including conduction, natural convection, and thermal radiation, are completely passive.

As required by NUREG-1536 [4.0.1], the thermal performance of the system is within the allowable design criteria specified in SAR Chapters 2 and 3 for normal conditions. All thermal results reported in Section 4.4 are within the design criteria under all normal conditions of storage.

The thermal compliance of short term operations (such as MPC drying, lid welding and transport on the haul path) is demonstrated in the licensing-basis HI-STORM FW FSAR for the MPC-37 and MPC-89 [4.1.2].

As required by NUREG-1536 [4.0.1], the maximum internal pressure of the MPC is evaluated and shown to remain within its off-normal and accident design pressure, assuming rupture of 10 percent and 100 percent of the fuel rods, respectively. Assumptions for pressure calculations include release of 100 percent of the fill gas and 30 percent of the significant radioactive gases in the fuel rods.

It is therefore concluded that all applicable regulatory requirements and guidelines germane to the integrity of the stored fuel and the "UMAX" storage system have been addressed and satisfied in this chapter.

4.8 REFERENCES

[4.0.1] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," USNRC, Revision 1, (July 2010).

[4.0.2] "Cladding Considerations for the Transportation and Storage of Spent Fuel," Interim Staff Guidance – 11, Revision 3, USNRC, Washington, DC.

[4.1.1] "Holtec International Final Safety Analysis Report for the HI-STORM 100 Cask System", Holtec Report No. 2002444, Latest Revision, USNRC Docket No. 72-1014.

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CHAPTER 5: SHIELDING EVALUATION OF THE HI-STORM UMAX SYSTEM

5.0 INTRODUCTION

This chapter contains a shielding safety analysis of the loaded HI-STORM UMAX VVMs pursuant to the guidelines in NUREG-1536 [5.0.1]. The objective of the analyses summarized in this chapter is to demonstrate that the loaded underground VVM will provide sufficient dose blockage to enable an on-site ISFSI to be operated at a fraction of the controlled area boundary dose limits in 10CFR72. The analyses presented in this chapter focus on two representative multipurpose canisters, viz. MPC-37 and MPC-32, out of the population of MPCs listed in the Table 1.2.1. A technical justification of the basis for selecting these two representative canisters is provided later in this section. This chapter, however, only supports the certification of the MPC-37 and MPC-89. The analyses reported for the smaller diameter canister are for reference purposes only. The sections that follow demonstrate that the design of the HI-STORM UMAX dry cask storage system fulfills the following acceptance criteria outlined in the Standard Review Plan, NUREG-1536:

Acceptance Criteria

1. The minimum distance from each spent fuel handling and storage facility to the controlled area boundary must be at least 100 meters. The "controlled area" is defined in 10CFR72.3 as the area immediately surrounding an ISFSI or monitored retrievable storage (MRS) facility, for which the licensee exercises authority regarding its use and within which ISFSI operations are performed.

2. The system designer must show that, during both *normal operations and anticipated occurrences*, the radiation shielding features of the proposed dry cask storage system are sufficient to meet the radiation dose requirements in Section 72.104(a). Specifically, the vendor must demonstrate this capability for a typical array of casks in the most bounding site configuration. For example, the most bounding configuration might be located at the minimum distance (100 meters) to the controlled area boundary, without any shielding from other structures or topography.

3. Dose rates from the cask must be consistent with a well-established "as low as reasonably achievable" (ALARA) program for activities in and around the storage site.

4. After a design-basis accident, an individual at the boundary or outside the controlled area shall not receive a dose greater than the limits specified in 10CFR72.106.

5. The proposed shielding features must ensure that the dry cask storage system meets the regulatory requirements for occupational and radiation dose limits for individual members of the public, as prescribed in 10CFR Part 20, Subparts C and D.

Consistent with the guidelines provided in the Standard Review Plan, NUREG-1536, this chapter contains the following information:

- A description of the shielding features of the HI-STORM UMAX System.
- A description of the source terms.
- A general description of the shielding analysis methodology.
- A description of the analysis assumptions and results for the HI-STORM UMAX system.
- Analyses to show that the 10CFR72.106 controlled area boundary radiation dose limits are met during accident conditions of storage for non-effluent radiation at a minimum distance of 100 meters.

Since only representative dose rate values for normal conditions can be presented herein, compliance with the radiation and exposure objectives of 10CFR72.104, of necessity, must be performed as part of the site specific evaluations.

In this chapter, analyses are presented for two representative MPCs, namely MPC-32 and MPC-37, previously used to qualify peer-certified HI-STORM systems (MPC-32 in HI-STORM 100 in Docket Number 72-1014 [5.0.2], and MPC-37 in HI-STORM FW in Docket Number 72-1032 [5.0.3]), showing that the radiation dose rates follow As-Low-As-Reasonably-Achievable (ALARA) principle. MPC-32 and MPC-37 are selected as they represent two different classes of MPCs from the outer dimensions perspective. The smaller diameter of the MPC-32 compared to that of the MPC-37 results in a larger gap between the MPC enclosure shell and CEC. Additionally, MPC-32 is slightly longer than MPC-37. Both of these attributes may cause slightly higher dose rates for the HI-STORM UMAX system loaded with MPC-32 compared to MPC-37. As stated at the beginning of this section, the MPC-32 dose evaluations are for reference purpose only. Besides the MPC-37, this chapter also supports the certification of the MPC-89 in the HI-STORM UMAX system. However, the MPC-89 specific shielding analyses are not performed as the results presented in the HI-STORM FW FSAR show that results for the MPC-89 are similar to those for the MPC-37. Additionally, it is noted that site specific analyses need to use the site specific MPC (MPC-37 or MPC-89) for controlled area boundary dose calculations to show the site's compliance with 10 CFR 72.104 and 10 CFR 72.106.

The design basis zircaloy clad fuel assemblies used for calculating the dose rates presented in this chapter is the Westinghouse (W) 17x17 PWR fuel (see Table 5.0.1). The burnup and cooling times used for the shielding evaluation are consistent[‡‡] with those in [5.0.3]. Use of identical MPC and similar source term data enables a one-to-one comparison between the

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[‡‡] Only difference is the cooling time: FW uses 4.5 years which is more representative for the side of the MPC, whereas UMAX uses 5 years which is more representative for the top of the MPC.

shielding capacity of "HI-STORM UMAX" and its aboveground counterpart, the HI-STORM FW MPC storage system.

The principal sources of radiation in the HI-STORM UMAX System are:

- Gamma radiation originating from the following sources:

    1. Decay of radioactive fission products
    2. Secondary photons from neutron capture in fissile and non-fissile nuclides
    3. Hardware activation products generated during core operations

- Neutron radiation originating from the following sources:

    1. Spontaneous fission
    2. α,n reactions in fuel materials
    3. Secondary neutrons produced by fission from subcritical multiplication
    4. γ,n reactions (this source is negligible)

10CFR72 contains two sections that set down main dose requirements: §104 for normal and off-normal conditions, and §106 for anticipated occurrences and accident conditions. The relationship of these requirements to the safety analyses documented herein, are as follows:

- 10CFR72.104 specifies the dose limits from an ISFSI (and other operations) at a site boundary under normal and off-normal conditions. Compliance with §104 can therefore only be demonstrated on a site-specific basis, since it depends not only on the design of the cask system and the loaded fuel, but also on the ISFSI layout, the distance to the site boundary, and possibly other factors such as the terrain around the ISFSI. The purpose of this chapter is therefore to present the analysis methodology and illustrate its application to obtain the dose rates at locations of interest using a reference problem. The analysis carried out on the "HI-STORM UMAX" geometry is also intended to aid the user in applying the ALARA considerations and planning of the ISFSI. To accomplish the above objectives, it is appropriate to present reasonably conservative dose rate values, based on a reasonable conservative choice of burn-ups and cooling times of the assemblies (Table 5.0.1).
- For the accident dose limit in 10CFR72.106 it should be noted that the governing accident condition for the HI-STORM FW system, namely loss of shielding water in the Transfer cask, is analyzed in Reference [5.0.3]. Reference [5.0.3] contains the shielding analysis for accidental loss of water in HI-TRAC VW. Likewise, the HI-STORM 100 docket (Docket Number 72-1014) contains the equivalent accident analysis for HI-TRAC 125 and 100 models used to transfer MPC-32, MPC-68, and other models licensed in [5.0.2], which can be used as references for ISFSI planning. Therefore, the classical accident analysis considered in deploying the HI-STORM system are pre-empted by the evaluations in Reference [5.0.3], making it unnecessary and redundant to perform them in this FSAR. In addition, a Design Basis Missile (defined by Tables 2.3.3 and 2.3.4) strike to the exposed radiation protection space boundary (defined in Chapter 1), created by the excavation adjacent to it, has been analyzed in Chapter 3 and found to cause about 5.5 feet penetration

through the subgrade. It is to be noted that the optional enclosure wall was not considered in the missile penetration calculations, and while the radiation protection space provides at least 10.75 feet of subgrade in the radial direction from the outer metal surface of the VVM to the radiation protection space boundary, only 6.5 feet of subgarde is conservatively utilized for this accident condition dose calculation. Hence, the impact of a tornado missile penetrating a 6.5 feet subgrade creating a horizontal hole extending 5.5 feet from the external surface of the subgrade is considered as an accident condition for the shielding evaluations.

The shielding analyses were performed with MCNP5 [5.0.4] developed by Los Alamos National Laboratory (LANL). The source terms for the design basis fuels were calculated with the SAS2H and ORIGEN-S sequences from the SCALE 5 system [5.0.5][5.0.6]. A detailed description of the MCNP models and the source term calculations are presented in Sections 5.3 and 5.2, respectively.

To facilitate convenient access to the referenced material, the latest edition of the HI-STORM FW FSAR has been placed in this docket and a list of "FW" FSAR sections germane to this chapter is provided in a tabular form. The HI-STORM FW FSAR will be maintained in a configuration controlled status in this docket as a mandatory supplement to this FSAR. The table below provides a listing of the material adopted in this chapter by reference to the HI-STORM FW FSAR.

SECTIONS OF HI-STORM FW FSAR APPLICABLE TO THIS SAFETY EVALUATION [§§]

Location in the UMAX FSAR	**Subject of the Reference**	**Location in the HI-STORM FW FSAR, Revision 1**
Sections 5.0 and Sub-Section 5.1.1	Shielding safety analyses governing the HI-TRAC	Section 5.1 and 5.4
Section 5.2	The reference fuel and the Non-fuel hardware (BPRAs etc)	Section 5.2
Section 5.4	The axial distribution of the fuel source term	Table 2.1.5 Figures 2.1.3 and 2.1.4

[§§] For convenience of reference, the specific revision of the HI-STORM FW FSAR that is referenced in the safety analysis herein is placed in this docket. Updated versions of the HI-STORM FW FSAR shall be placed in this docket as necessary so as to ensure that the safety analyses on the "UMAX" docket (72-1040) remain aligned with the material referenced in the HI-STORM FW FSAR.

Table 5.0.1

DESIGN BASIS FUEL BURNUP, COOLING TIME, AND ENRICHMENT FOR DOSE EVALUATION

MPC TYPE	BURN- UP GWD/MTU	COOLING TIME YEARS	ENRICHMENT Wt % U-235
MPC-32 and MPC-37	45	5	3.6

5.1 SHIELDING FEATURES, DESIGN OBJECTIVE AND RESULTS

5.1.1 Shielding Features

The essentials of the HI-STORM UMAX System are described in Section 1.2. The design details are laid out in the licensing drawings in Section 1.5. As can be seen from the Licensing drawings, the underground HI-STORM UMAX System differs from all aboveground HI-STORM overpacks certified in Dockets 72-1014 and 1032 in that the used fuel is stored well below the ISFSI's top of grade (TOG). HI-STORM UMAX, however, is completely fungible with the HI-STORM FW overpack model in that it can store the MPC-37 and MPC-89 certified to be stored in the FW system. Furthermore, the HI-TRAC VW transfer cask used to perform the *short-term operations* to prepare and install the MPCs in the storage system is identical to that used in the HI-STORM FW system [5.0.3]. In fact, the MPC's content conditions and the loading operations up to the time the loaded transfer cask arrives at the ISFSI are identical to the HI-STORM FW system. Therefore, all shielding safety analyses governing the HI-TRAC VW transfer cask are already provided in Reference [5.0.3] and no further calculations involving the HI-TRAC VW transfer cask are necessary or presented in this chapter.

As shown in the Licensing drawings, the HI-STORM UMAX ISFSI consists of a set of vertically disposed thick-walled steel containers founded on a thick reinforced concrete pad (denoted as the Support Foundation pad, located over 20 feet below TOG) and embedded in a subgrade made of a Self-hardening Engineered Subgrade. The top region of the steel container is reinforced by a thick plate-type flange that rests on a reinforced concrete pad denoted as the ISFSI pad. The top opening in the container is the only location of access into the cavity and potential path of emission of radiation to the environment. To provide maximum blockage to the radiation issuing from the fuel, "HI-STORM UMAX" utilizes both mass and distance as barriers. The Closure Lid, made as an over-40 inch thick steel weldment filled with concrete, provides a massive body in the path of the radiation emanating from the fuel. The shielding action of the lid is further aided by ensuring that the top of the MPC (itself equipped with a > 9inch thick lid) is at least about 2 feet below the bottom of the VVM Closure lid. With such a massive blockage arrayed against the stored fuel, the dose levels at the top of the ISFSI pad are expected to be very low, which the analyses in this chapter will be seen to corroborate.

However, aside from the magnitude of shielding, the shielding mechanism in the HI-STORM UMAX VVM is similar to the aboveground overpack designs certified in [5.0.2] and [5.0.3] with gamma shielding provided by the concrete and the steel of the module, and neutron shielding provided by the ISFSI concrete. However, because the VVM is located below grade, a significant reduction in the dose at the directly accessible surface of the VVM compared to the aboveground storage modules is realized. Dose rates from a HI-STORM UMAX VVM at the site boundary are therefore significantly lower than, and bounded by, the corresponding dose rates from the peer aboveground HI-STORM systems.

5.1.2 Design Objective

In accordance with ALARA practices, design objective dose rates are established for the HI-STORM UMAX system and presented in Table 2.9.2.

Chapter 12 discusses the potential off-normal conditions and their effect on the HI-STORM UMAX system. None of the off-normal conditions have any impact on the shielding analysis. Therefore, off-normal and normal conditions are identical for the purpose of the shielding evaluation.

The 10CFR72.104 criteria for radioactive materials in effluents and direct radiation during normal operations are:

1. During normal operations and anticipated occurrences, the annual dose equivalent to any real individual who is located beyond the controlled area, must not exceed 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other critical organ.

2. Operational restrictions must be established to meet As-Low-as-Reasonably-Achievable (ALARA) objectives for radioactive materials in effluents and direct radiation.

10CFR20 Subparts C and D specify additional requirements for occupational dose limits and radiation dose limits for individual members of the public. Chapter 11 specifically addresses these regulations.

5.1.3 Results

Figure 5.1.1 identifies the locations of the dose points referenced in Tables 5.1.1 and 5.1.2 for HI-STORM UMAX loaded with MPC-32 and MPC-37, respectively. Dose Points #1 represents the side of the closure lid shell on top of the inlet plenum. Dose Point #1 is also the location of the highest dose rate on the lid in the final storage configuration. However, there is a substantial dose rate reduction at 1 meter from Dose Point #1. The maximum dose rate is reported for the side surface of the lid shell, while the dose rate value reported at 1 meter is taken at the middle of the lid shell. Dose Point #2 is the location of the surface of the outlet duct. Dose Point #3 is positioned on the closure lid cover plate. Dose Points # 4 and #5 (#5 not seen in Figure 5.1.1) are the locations of the outlet and inlet vents (top surface), respectively. Dose Point #6 is located over a tube that would be required for the ICCPS test station if an ICCPS is used. Dose Point #7 is located over an empty VVM located adjacent to a loaded VVM. Dose Point #7 is used to calculate the potential radiation streaming through an empty cavity surrounded by 4 loaded VVMs.

The tube for the ICCPS test station is modeled as a cylindrical hole that extends from the VIP down to the base plate of the MPC. The tube is modeled with a diameter of 4 inches, located about 5.5 feet from the center of the VVM. If the actual tube has characteristics that could result in higher dose rates, i.e. is larger or closer to the VVM than modeled here, the actual tube characteristics should be considered in the site specific dose calculations. Depending on the results of those calculations, additional measures, such as added shielding at the top of the tube, may be required.

A comparison between the dose rates in Table 5.1.2 and the corresponding dose rates presented in Section 5.1 of the HI-STORM FW FSAR [5.0.3] show that the maximum dose rate for the HI-STORM UMAX module with a loaded MPC is well below the maximum dose rate for the HI-STORM FW with the identically loaded MPC. The generally lower dose rate in HI-STORM UMAX compared to HI-STORM FW would suggest that the dose rate contribution at the site boundary will be accordingly exiguous. Nevertheless, calculations were performed for both MPC-32 and MPC-37 under normal condition to determine the annual dose rate from the HI-STORM UMAX system at a distance of 100 meters. These results, which are presented in Table 5.1.3, indicate that the HI-STORM UMAX meets the requirements of 10CFR72.104 at 100 meters with large margins. Comparing these results to the results in Section 5.1 of the HI-STORM FW FSAR demonstrates that the off-site dose from the HI-STORM UMAX is a small fraction of the off-site dose from an aboveground overpack.

The bounding accident condition is identified in Chapter 3 to be the impact of a tornado missile with a diameter of 8 inches. This missile would penetrate the soil about 5.5 ft. This is the bounding condition since smaller missiles have less energy, and larger missiles (automotive) have a much larger impact area thus resulting in a much smaller indentation of the soil. Under the bounding condition, the maximum dose over a period of 30 days at a distance of 100 m from the VVM is presented in Table 5.1.4. As discussed in Section 5.0, only 6.5 feet of subgrade in the radial direction from the outer metal surface of the VVM is applied for this accident condition dose evaluation. Table 5.1.4 demonstrates that the accident condition dose is in compliance with the 10CFR72.106 and much lower than the dose reported for HI-TRAC accident condition in Reference [5.0.3].

Table 5.1.1

DOSE RATES ADJACENT TO AND 1 METER FROM THE HI-STORM UMAX MODULE FOR NORMAL CONDITIONS
MPC-32 DESIGN BASIS ZIRCALOY CLAD FUEL

Dose Point[†] Location	**Fuel Gammas[††] (mrem/hr)**	**^{60}Co Gammas (mrem/hr)**	**Neutrons (mrem/hr)**	**Totals (mrem/hr)**	**Totals with BPRAs (mrem/hr)**
Surface of the overpack					
1	22.37	12.71	21.80	**56.88**	**66.04**
2	0.60	0.07	2.36	**3.03**	**3.10**
3	0.17	0.01	0.53	**0.72**	**0.73**
4	1.35	0.22	0.81	**2.37**	**2.55**
5	3.69	2.02	2.95	**8.65**	**10.11**
6	10.66	4.93	1.31	**16.90**	**20.28**
7[‡]	1.04	0.48	0.76	**2.24**	**2.56**
One meter from the overpack					
1	5.67	1.43	1.19	**8.29**	**9.56**
2	3.34	1.62	1.95	**6.91**	**8.14**
3	0.26	0.05	0.22	**0.53**	**0.57**
4	0.42	0.07	0.44	**0.93**	**0.99**
5	0.71	0.34	0.43	**1.48**	**1.72**

[†] Refer to Figure 5.1.1.

[††] Gammas generated by neutron capture are included with fuel gammas.

[‡] Calculated for an empty VVM surrounded by four loaded VVMs.

Table 5.1.2

DOSE RATES ADJACENT TO AND 1 METER FROM THE HI-STORM UMAX MODULE FOR NORMAL CONDITIONS

MPC-37 DESIGN BASIS ZIRCALOY CLAD FUEL

Dose Point[†] Location	Fuel Gammas[††] (mrem/hr)	^{60}Co Gammas (mrem/hr)	Neutrons (mrem/hr)	Totals (mrem/hr)	Totals with BPRAs (mrem/hr)
Surface of the overpack					
1	15.67	4.99	17.28	**37.93**	**41.47**
2	0.52	0.04	1.76	**2.32**	**2.35**
3	0.15	0.01	0.42	**0.57**	**0.57**
4	1.15	0.15	0.64	**1.94**	**2.08**
5	2.20	0.76	2.27	**5.24**	**5.77**
6	6.00	4.11	1.15	**11.27**	**13.87**
7[‡]	1.88	0.2	0.56	**2.64**	**2.8**
One meter from the overpack					
1	3.81	0.80	0.96	**5.58**	**6.14**
2	2.30	0.63	1.53	**4.45**	**4.92**
3	0.26	0.02	0.18	**0.47**	**0.53**
4	0.36	0.05	0.35	**0.76**	**0.80**
5	0.64	0.15	0.36	**1.14**	**1.27**

[†] Refer to Figure 5.1.1.

[††] Gammas generated by neutron capture are included with fuel gammas.

[‡] Calculated for an empty VVM surrounded by four loaded VVMs.

Table 5.1.3

ANNUAL DOSE AT 100 METERS FROM A SINGLE HI-STORM UMAX OVERPACK WITH MPC-32 AND MPC-37 WITH DESIGN BASIS ZIRCALOY CLAD FUEL[†]

Dose Component	**MPC-32 Dose Rates (mrem/yr)**	**MPC-37 Dose Rates (mrem/yr)**
Fuel gammas[††]	3.85	2.80
^{60}Co Gammas	1.23	0.61
Neutrons	2.54	2.10
Totals	7.62	5.43
Totals with BPRAs	**8.58**	**5.96**

[†] 8760 hour annual occupancy is assumed.

[††] Gammas generated by neutron capture are included with fuel gammas.

Table 5.1.4

DOSE AT 100 METERS FROM A SINGLE HI-STORM UMAX OVERPACK WITH MPC-32 AND MPC-37 LOADED WITH DESIGN BASIS FUEL FOR ACCIDENT CONDITION

MPC	**DOSE[§] (Rem)**
MPC-32	**0.12**
MPC-37	**0.13**

[§] Accident duration is assumed to be 30 days.

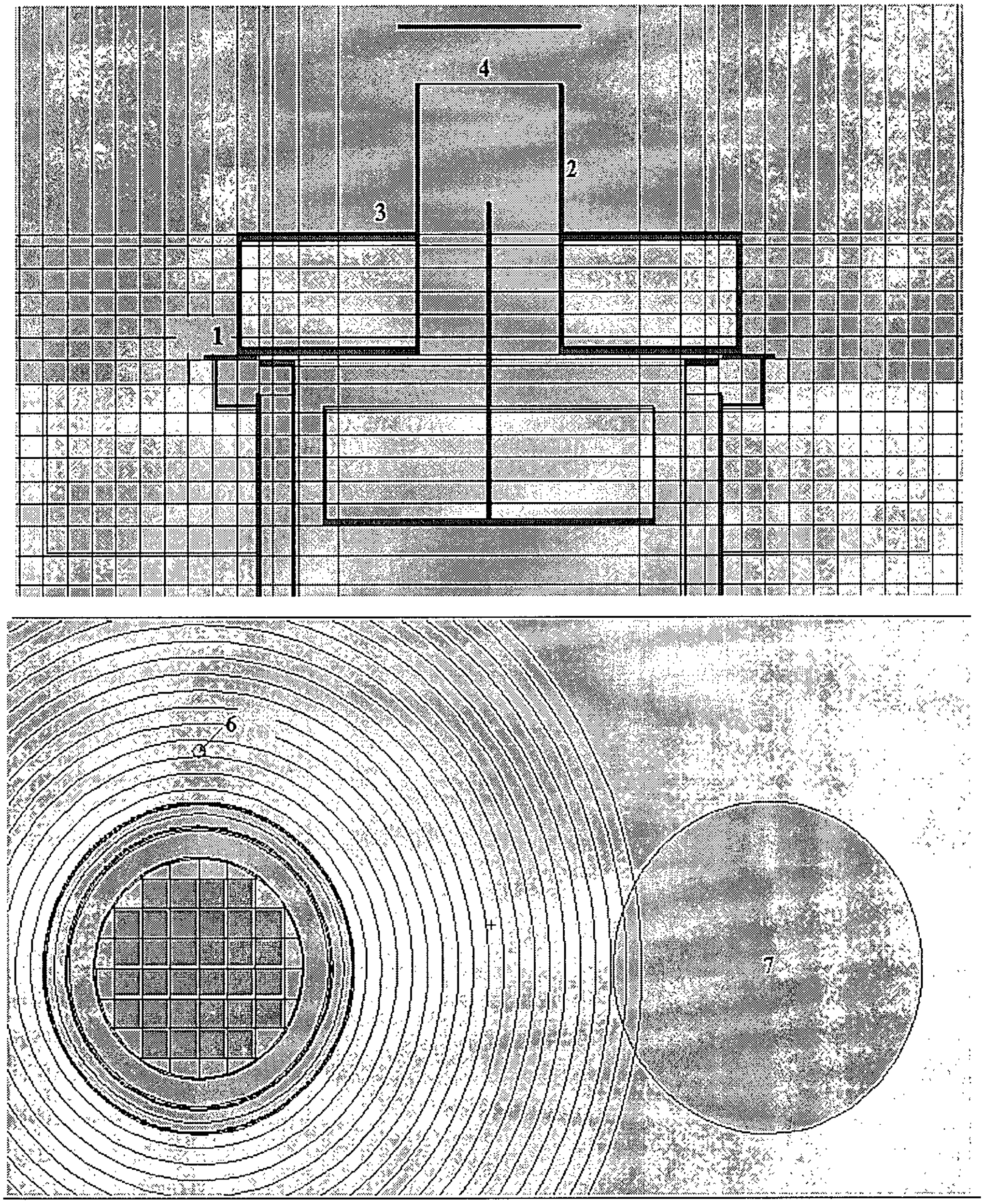

FIGURE 5.1.1: HI-STORM UMAX MODULE CROSS SECTIONAL VIEWS WITH DOSE POINT LOCATIONS
(SKY COLOR REPRESENTS CONCRETE, PINK REPRESENTS SUBGRADE AND ORANGE REPRESENTS AIR)

5.2 SOURCE SPECIFICATION

The design basis fuel used for the reference shielding analyses is identical, and the burnup, cooling time and enrichment combination is consistent** with what was used in the HI-STORM FW FSAR [5.0.3]. However, to enhance readability and to assist the reviewer, excerpt from the source specification section, Section 5.2 of Chapter 5, of the HI-STORM FW FSAR is presented here.

††The neutron and gamma source terms, decay heat values, and quantities of radionuclides available for release were calculated with the SAS2H and ORIGEN-S modules of the SCALE 5 system [5.0.5][5.0.6]. SAS2H has been extensively compared to experimental isotopic validations and decay heat measurements. References [5.2.1] through [5.2.8] present isotopic and decay heat comparisons for PWR and BWR fuels. All of these studies indicate good agreement between SAS2H and ORIGEN-S and measured data.

A description of the design basis fuel for the source term calculations is provided in Table 5.2.1. Subsection 5.2.4 discusses the rationale in the determination of the design basis fuel assemblies.

In performing the SAS2H and ORIGEN-S calculations, a single full power cycle was used to achieve the desired burnup. This assumption, in conjunction with the above-average specific powers listed in Table 5.2.1 resulted in a conservative source term calculation.

5.2.1 Gamma Source

Tables 5.2.2 provides the gamma source in MeV/s and photons/s as calculated with SAS2H and ORIGEN-S for the design basis zircaloy clad fuel at the burnups and cooling times used for the shielding analyses in this chapter.

Previous analyses were performed for the HI-STORM 100 system to determine the dose contribution from gammas as a function of energy [5.0.2]. The results of these analyses have revealed that, due to the magnitude of the gamma source at lower energies, photons with energies as low as 0.45 MeV must be included in the shielding analysis, but photons with energies below 0.45 MeV are too weak to penetrate the HI-STORM overpack or HI-TRAC. The effect of gammas with energies above 3.0 MeV, on the other hand, was found to be insignificant. This is due to the fact that the source of

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** Only difference is the cooling time: FW uses 4.5 years which is more representative for the side of the MPC, whereas UMAX uses 5 years which is more representative for the top of the MPC.

†† The text matter in the "Arial" font is excerpted from the HI-STORM FW FSAR with minor editorial changes, as appropriate.

gammas in this range (i.e., above 3.0 MeV) is extremely low. Therefore, all photons with energies in the range of 0.45 to 3.0 MeV are included in the shielding calculations.

The primary source of activity in the non-fuel regions of an assembly arises from the activation of ^{59}Co to ^{60}Co. The primary source of ^{59}Co in a fuel assembly is impurities in the steel structural material above and below the fuel. The zircaloy in these regions is neglected since it does not have a significant ^{59}Co impurity level. Reference [5.2.9] indicates that the impurity level in steel is 800 ppm or 0.8 gm/kg. Therefore, inconel and stainless steel in the non-fuel regions are both assumed to have the same 0.8 gm/kg impurity level.

Some of the PWR fuel assembly designs (B&W and WE 15x15) utilized inconel in-core grid spacers while other PWR fuel designs use zircaloy in-core grid spacers. In the mid 1980s, the fuel assembly designs using inconel in-core grid spacers were altered to use zircaloy in-core grid spacers. To take that into account, the gamma source for the PWR zircaloy clad fuel assembly includes the activation of the in-core grid spacers.

The masses in Table 5.2.1 were used to calculate a ^{59}Co impurity level in the fuel assembly material. The grams of impurity were then used in ORIGEN-S to calculate a ^{60}Co activity level for the desired burnup and decay time. The methodology used to determine the activation level was developed from Reference [5.2.10] and is described here.

1. The activity of the ^{60}Co is calculated using ORIGEN-S. The flux used in the calculation was the in-core fuel region flux at full power.

2. The activity calculated in Step 1 for the region of interest was modified by the appropriate scaling factors listed in Table 5.2.3. These scaling factors were taken from Reference [5.2.10].

Table 5.2.4 presents the ^{60}Co activity utilized in the shielding calculations for the non-fuel regions of the assemblies in the MPC-37 and the MPC-32.

In addition to the two sources already mentioned, a third source arises from (n,γ) reactions in the material of the MPC and the overpack. This source of photons is properly accounted for in MCNP when a neutron calculation is performed in a coupled neutron-gamma mode.

5.2.2 Neutron Source

It is well known that the neutron source strength increases as enrichment decreases, for a constant burnup and decay time. This is due to the increase in Pu content in the fuel, which increases the inventory of other transuranium nuclides such as Cm. The gamma source also varies with enrichment, although only slightly. Because of this effect and in order to obtain conservative source terms, low initial fuel enrichments of 3.6 wt% were chosen for the PWR design basis fuel assemblies under.

The neutron sources calculated for the design basis fuel assembly are listed in Tables 5.2.5 in neutrons/s for the selected burnup and cooling times used in the shielding evaluations. The neutron spectrum is generated in ORIGEN-S.

5.2.3 Non-Fuel Hardware

Burnable poison rod assemblies (BPRAs), thimble plug devices (TPDs), control rod assemblies (CRAs), axial power shaping rods (APSRs), and neutron source assemblies (NSAs)) are generally termed as non-fuel hardware and can be stored as an integral part of a PWR fuel assembly. Non-fuel hardware storage restrictions as applicable for a particular MPC in the certification of its host docket are also applicable in the HI-STORM UMAX system. Similar to HI-STORM FW FSAR [5.0.3], representative shielding analyses are performed in this chapter by only utilizing BPRAs in every PWR fuel location in the basket.

5.2.3.1 BPRAs

Burnable poison rod assemblies (BPRA) (including wet annular burnable absorbers) are an integral, yet removable, part of a large portion of PWR fuel. BPRAs are made of stainless steel in the region above the active fuel zone and may contain a small amount of inconel in this region. Within the active fuel zone the BPRAs may contain 2-24 rodlets which are burnable absorbers clad in either zircaloy or stainless steel. The stainless steel clad BPRAs create a significant radiation source (Co-60) while the zircaloy clad BPRAs create a negligible radiation source. Therefore, the stainless steel clad BPRAs are bounding.

The masses of this devise are listed in Table 5.2.6, while Table 5.2.7 presents the curies of Co-60 that were calculated for BPRAs in each region of the fuel assembly (e.g. incore, plenum, top). For specific site boundary evaluations, these levels/values can be used if they are bounding. Alternatively, more realistic values can be used.

5.2.4 Choice of Design Basis Assembly

The Westinghouse 17x17 assembly was selected as design basis assembly since it is been widely used throughout the industry. Site specific shielding evaluations should verify that those assemblies and assembly parameters are appropriate for the site-specific analyses.

Table 5.2.1
DESIGN BASIS PWR FUEL DATA

Item	Data
Assembly type/class	WE 17×17
Active fuel length (in.)	144
No. of fuel rods	2
Rod pitch (in.)	0.496
Cladding material	Zircaloy-4
Rod diameter (in.)	0.374
Cladding thickness (in.)	0.0225
Pellet diameter (in.)	0.3232
Pellet material	UO_2
Pellet density (gm/cc)	10.412 (95% of theoretical)
Enrichment (w/o ^{235}U)	3.6
Specific power (MW/MTU)	43.48
Weight of UO_2 (kg)[††]	532.150
Weight of U (kg)[††]	469.144
No. of Water Rods/ Guide Tubes	25
Water Rod/ Guide Tube O.D. (in.)	0.474
Water Rod/ Guide Tube Thickness (in.)	0.016
Lower End Fitting (kg)	5.9 (steel)
Gas Plenum Springs (kg)	1.150 (steel)
Gas Plenum Spacer (kg)	0.793 (inconel) 0.841 (steel)
Expansion Springs (kg)	N/A
Upper End Fitting (kg)	6.89 (steel) 0.96 (inconel)
Handle (kg)	N/A
Incore Grid Spacers (kg)	4.9 (inconel)

[††] Derived from parameters in this table.

Table 5.2.2

CALCULATED PWR FUEL GAMMA SOURCE PER ASSEMBLY FOR DESIGN BASIS BURNUP AND COOLING TIME

Lower Energy	**Upper Energy**	**45,000 MWD/MTU 5-Year Cooling**	
(MeV)	(MeV)	(MeV/s)	(Photons/s)
0.45	0.7	1.95E+15	3.40E+15
0.7	1.0	6.52E+14	7.67E+14
1.0	1.5	1.52E+14	1.22E+14
1.5	2.0	1.19E+13	6.79E+12
2.0	2.5	6.64E+12	2.95E+12
2.5	3.0	2.88E+11	1.05E+11
Total		2.78E+15	4.30E+15

Table 5.2.3

SCALING FACTORS USED IN CALCULATING THE ^{60}Co SOURCE

Region	**PWR**
Handle	N/A
Upper End Fitting	0.1
Gas Plenum Spacer	0.1
Expansion Springs	N/A
Gas Plenum Springs	0.2
Incore Grid Spacer	1.0
Lower End Fitting	0.2

Table 5.2.4

CALCULATED ^{60}Co SOURCE PER ASSEMBLY
FOR DESIGN BASIS
FUEL AT DESIGN BASIS BURNUP AND COOLING TIME

Location	**45,000 MWD/MTU and 5-Year Cooling (curies)**
Lower End Fitting	80.53
Gas Plenum Springs	15.70
Gas Plenum Spacer	11.15
Incore Grid Spacers	334.42
Upper End Fitting	53.57

Table 5.2.5

CALCULATED PWR NEUTRON SOURCE PER ASSEMBLY FOR 45,000 MWD/MTU BURNUP AND 5 YEAR COOLING

Lower Energy (MeV)	**Upper Energy (MeV)**	**45,000 MWD/MTU 5-Year Cooling (Neutrons/s)**
1.0e-01	4.0e-01	2.99E+07
4.0e-01	9.0e-01	6.52E+07
9.0e-01	1.4	6.51E+07
1.4	1.85	5.20E+07
1.85	3.0	9.69E+07
3.0	6.43	8.80E+07
6.43	20.0	8.40E+06
Totals		4.06E+08

Table 5.2.6
DESCRIPTION OF DESIGN BASIS BURNABLE POISON ROD ASSEMBLY

Region	BPRA
Upper End Fitting (kg of steel)	2.62
Upper End Fitting (kg of inconel)	0.42
Gas Plenum Spacer (kg of steel)	0.77488
Gas Plenum Springs (kg of steel)	0.67512
In-core (kg of steel)	13.2

Table 5.2.7
DESIGN BASIS COBALT-60 ACTIVITIES FOR BURNABLE POISON ROD ASSEMBLIES

Region	BPRA
Upper End Fitting (curies Co-60)	32.7
Gas Plenum Spacer (curies Co-60)	5.0
Gas Plenum Springs (curies Co-60)	8.9
In-core (curies Co-60)	848.4

5.3 MODEL SPECIFICATIONS

The shielding analyses of the HI-STORM UMAX module are performed with MCNP5 [5.0.4], which is a QA-validated code under Holtec International's quality program. A sample input file for MCNP is provided in Appendix 5.A.

Section 1.5 provides the drawings that describe the HI-STORM UMAX System. The nominal dimensions in these drawings were used to create the MCNP models used in the radiation transport calculations. Modeling deviations from these drawings are discussed below. Figure 5.3.1 shows cross sectional views of the HI-STORM UMAX module as it was modeled in MCNP for accident condition. Note that the inlet and outlet vents were modeled explicitly; therefore, streaming through these components is accounted for in the dose calculations. Figure 5.3.2 depicts the inlet plenum, part of the outlet and additionally the dose locations used to obtain a dose profile across the HI-STORM UMAX lid and surrounding ISFSI pad.

Since the HI-STORM UMAX models analyzed in this chapter use principally the same MPC models from the References [5.0.2][5.0.3], all figures, conservative modeling approximations, and modeling differences for the MPCs reported in the corresponding FSARs are applicable to the evaluations in this chapter. The differences between models and drawings for the module are listed and discussed here.

1. Minor penetrations in the body of the module (e.g. lift locations) are not modeled as these are small localized effects which will not affect the off-site dose rates.

2. The MPC supports and guides were conservatively neglected. The bottom pedestal was also neglected in the MCNP model.

3. The inlet plenum support plates and inlet plenum corner gussets were not included in the model.

4. The insulation installed on the divider shell was conservatively modeled as a void.

5. The cavities representing the optional ICCPS tube and the empty VVM are modeled as empty volumes surrounded by soil, i.e. any steel liner or other material in these areas, or any covers that would be located on top of those cavities, are conservatively neglected

6. The air inlets at the bottom of the divider shell were not modeled. This has negligible effect as most of the radiation is emanating from the top and side of the MPC.

5.3.1 Fuel Configuration

The active fuel region is modeled as a homogenous zone. Calculations were performed for the HI-STORM 100 [5.0.2] to determine the acceptability of homogenizing the fuel assembly versus explicit modeling. Based on these calculations it was concluded that it is acceptable to homogenize the fuel assembly without loss of accuracy. The width of the PWR homogenized fuel assembly is equal to 17 times the pitch. The end fittings and the plenum regions are also modeled as homogenous regions of steel. The masses of steel used in these regions are shown in Table 5.2.1. The axial description of the design basis fuel assemblies is provided in Table 5.3.1.

5.3.2 Regional Densities

Composition and densities of the various materials used in the HI-STORM UMAX system for shielding analyses are given in Table 5.3.2. All of the materials and their actual geometries are represented in the MCNP model.

Table 5.3.1

DESCRIPTION OF THE AXIAL MCNP MODEL OF THE FUEL ASSEMBLIES[†]

Region	Start (in.)	Finish (in.)	Length (in.)	Actual Material	Modeled Material
PWR					
Lower End Fitting	0.0	2.738	2.738	SS304	SS304
Space	2.738	3.738	1.0	zircaloy	void
Fuel	3.738	147.738	144.0	fuel & zircaloy	fuel & zircaloy
Gas Plenum Springs	147.738	151.916	4.178	SS304 & inconel	SS304
Gas Plenum Spacer	151.916	156.095	4.179	SS304 & inconel	SS304
Upper End Fitting	156.095	159.765	3.670	SS304 & inconel	SS304

[†] All dimensions start at the bottom of the fuel assembly. The length of the fuel shims must be added to the distances to determine the distance from the top of the MPC baseplate.

Table 5.3.2

COMPOSITION OF THE MATERIALS IN THE HI-STORM FW SYSTEM

Component	Density (g/cm^3)	Elements	Mass Fraction (%)
Metamic	2.642	B-10	4.388
		B-11	20.436
		Al	68.275
		C	6.901
Metamic-HT	**Withheld in Accordance with 10 CFR 2.390**	**Withheld in Accordance with 10 CFR 2.390**	
Carbon steel	7.82	Fe	99.0
		C	1.0
SS304	7.94	Cr	19.0
		Mn	2.0
		Fe	69.5
		Ni	9.5
Concrete	2.4 (150 lb/ft3)	O	53.2
		Si	33.7
		Ca	4.4
		Al	3.4
		Na	2.9
		Fe	1.4
		H	1.0
Soil	1.7	H	0.962
		O	54.361
		Al	12.859
		Si	31.818

Table 5.3.2 (continued)

COMPOSITION OF THE MATERIALS IN THE HI-STORM FW SYSTEM

Component	Density (g/cm^3)	Elements	Mass Fraction (%)
PWR Fuel Region Mixture	3.769 (5.0 wt% U-235)	^{235}U	3.709
		^{238}U	70.474
		O	9.972
		Zr	15.565
		Cr	0.016
		Fe	0.033
		Sn	0.230
Lower End Fitting (PWR)	1.849	SS304	100
Gas Plenum Springs (PWR)	0.23626	SS304	100
Gas Plenum Spacer (PWR)	0.33559	SS304	100
Upper End Fitting (PWR)	1.8359	SS304	100

Withheld in Accordance with 10 CFR 2.390

FIGURE 5.3.1: HI-STORM UMAX MODULE CROSS SECTIONAL ELEVATION VIEW WITH MISSILE PENETRATION. (SKY COLOR REPRESENTS CONCRETE, PINK REPRESENTS SUBGRADE, ORANGE REPRESENTS AIR AND YELLOW REPRESENTS MPC)

Withheld in Accordance with 10 CFR 2.390

FIGURE 5.3.2: HI-STORM UMAX MODULE CROSS SECTIONAL ELEVATION VIEW WITH DOSE POINT LOCATIONS

5.4 SHIELDING EVALUATION

Shielding analyses methodology applied to HI-STORM UMAX is identical with all the previous Holtec International's licensing applications. The MCNP5 code was used for all of the shielding analyses [5.0.4]. MCNP is a continuous energy, three-dimensional, coupled neutron-photon-electron Monte Carlo transport code. Continuous energy cross section data are represented with sufficient energy points to permit linear-linear interpolation between points. The individual cross section libraries used for each nuclide are those recommended by the MCNP manual. Cross section libraries are based on ENDF/B-V and ENDF/B-VI, except for Sn isotopes where the ENDL92 library is used, and uranium isotopes where LANL/T16 libraries are used. These are the default libraries for the MCNP code version used here [5.0.4]. MCNP has been extensively benchmarked against experimental data by the large user community. References [5.4.1], [5.4.2], and [5.4.3] are three examples of the benchmarking that has been performed.

The energy distribution of the source term, as described earlier, is used explicitly in the MCNP model. A different MCNP calculation is performed for each of the three source terms (neutron, decay gamma, and ^{60}Co). The axial distribution of the fuel source term is described in Table 2.1.5 and Figures 2.1.3 and 2.1.4 of the HI-STORM FW FSAR [5.0.3]. The PWR and BWR axial burn-up distributions were obtained from References [5.4.4] and [5.4.5], respectively, and have previously been utilized in the HI-STORM FSAR [5.0.2]. These axial distributions were obtained from operating plants and are representative of PWR and BWR fuel with burnups greater than 30,000 MWD/MTU. The ^{60}Co source in the hardware was assumed to be uniformly distributed over the appropriate regions.

It has been shown that the neutron source strength varies as the burnup level raised by the power of 4.2. Since this relationship is non-linear and since the burnup in the axial center of a fuel assembly is greater than the average burnup, the neutron source strength in the axial center of the assembly is greater than the relative burnup times the average neutron source strength. In order to account for this effect, the neutron source strength in each of the 10 axial nodes listed in Table 2.1.5 in [5.0.3] was determined by multiplying the average source strength by the relative burnup level raised to the power of 4.2. The peak relative burnups listed in Table 2.1.5, loc. cit., for the PWR fuel is 1.105. By employing the power of 4.2 relationship, the neutron source strength in the peak nodes for the PWR fuel increases by 37.6% ($1.105^{4.2}/1.105$). The total neutron source strength increases by 15.6%.

MCNP was used to calculate doses at the various desired locations. MCNP calculates neutron or photon flux and these values can be converted into dose by the use of dose response functions. This is done internally in MCNP and the dose response functions are listed in the input file in Appendix 5.A. The response functions used in these calculations are listed in Table 5.4.1 and were taken from ANSI/ANS 6.1.1, 1977 [5.4.6].

The dose rates at the various locations were calculated with MCNP using a two-step process. The first step was to calculate the dose rate for each dose location per starting particle for each neutron and gamma group in each basket region for each axial and azimuthal dose location. The second step is to multiply the dose rate per starting particle for each energy group and basket location (i.e., tally output/quantity) by the source strength (i.e., particles/sec) in that group and sum the resulting dose rates for all groups and basket locations in each dose location. The normalization of these results and calculation of the total dose rate from neutrons, fuel gammas or Co-60 gammas is performed with the following equation.

$$T_{final} = \sum_{j=1}^{M}\left[\sum_{i=1}^{N}\frac{T_{i,j}}{Fm_i} * F_{i,j}\right] \quad \text{(Equation 5.4.1)}$$

where,

T_{final} = Final dose rate (rem/h) from neutrons, fuel gammas, or Co-60
N = Number of groups (neutrons, fuel gammas) or Number of axial sections (Co-60 gammas)
M = Number of regions in the basket
$T_{i,j}$ = Tally quantity from particles originating in MCNP in group/section i and region j (rem/h)(particles/sec)
$F_{i,j}$ = Fuel Assembly source strength in group i and region j (particles/sec)
Fm_i = Source fraction used in MCNP for group i

Note that dividing by Fm_i (normalization) is necessary to account for the number of MCNP particles that actually start in group i. Also note that T_i is already multiplied by a dose conversion factor in MCNP.

The standard deviations of the various results were statistically combined to determine the standard deviation of the total dose in each dose location. The estimated variance of the total dose rate, S^2_{total}, is the sum of the estimated variances of the individual dose rates S^2_i. The estimated total dose rate, estimated variance, and relative error [5.0.4] are derived according to Equations 5.4.2 through 5.4.5.

$$R_i = \frac{\sqrt{S_i^2}}{T_i} \quad \text{(Equation 5.4.2)}$$

$$S_{Total}^2 = \sum_{i=1}^{n} S_i^2 \quad \text{(Equation 5.4.3)}$$

$$T_{Total} = \sum_{i=1}^{n} T_i \quad \text{(Equation 5.4.4)}$$

$$R_{Total} = \frac{\sqrt{S^2_{Total}}}{T_{Total}} = \frac{\sqrt{\sum_{i=1}^{n} S_i^2}}{T_{Total}} = \frac{\sqrt{\sum_{i=1}^{n} (R_i \times T_i)^2}}{T_{Total}} \qquad \text{(Equation 5.4.5)}$$

where,

i = tally component index

n = total number of components

T_{Total} = total estimated tally

T_i = tally i component

S^2_{Total} = total estimated variance

S^2_i = variance of the i component

R_i = relative error of the i component

R_{Total} = total estimated relative error

Note that the two-step approach outlined above allows the accurate consideration of the neutron and gamma source spectrum, and the location of the individual assemblies, since the tallies are calculated in MCNP as a function of the starting energy group and the assembly location, and then in the second step multiplied with the source strength in each group in each location. It is therefore equivalent to a one-step calculation where source terms are directly specified in the MCNP input files, except for the following approximations:

- Fuel is modeled as fresh UO_2 fuel (rather than spent fuel) in MCNP, with an upper bound (5%) enrichment.
- The axial burnup profile is modeled by assigning a source probability to each of the 10 axial sections of the active region, based on a representative axial burnup profile [5.0.2]. For fuel gammas, the probability is proportional to the burnup, since the gamma source strength changes essentially linearly with burnup. For neutrons, the probability is proportional to the burnup raised to the power of 4.2, since the neutron source strength is proportional to the burnup raised to about that power [5.4.7]. This is a standard approach that has been previously used in the licensing calculations for the HI-STAR cask models [5.4.8] and [5.4.9] and HI-STORM overpack models [5.0.2] and [5.0.3].

Tables 5.1.1 and 5.1.2 provide dose rates adjacent to and at 1 meter distance from the HI-STORM UMAX module during normal conditions for the MPC-32 and MPC-37, respectively. Table 5.1.3 provides the annual dose at 100 meters from a HI-STORM UMAX module for the MPC-32 and MPC-37 including the contribution from BPRAs. These results clearly demonstrate that the off-site dose from a HI-STORM UMAX is a small fraction of the off-site dose from the aboveground HI-STORM systems. In addition, Table 5.1.4 presents the dose for the accident condition caused by an impact of tornado borne missile on the radiation protection space boundary.

Soil is used to represent Self-hardening Engineering Subgrade in the models between the modules, with a composition and density shown in Table 5.3.2, representing typical soil conditions [5.4.10]. This is conservative, since the areas between and around the modules would contain engineered fill with a typical density higher than soil. Furthermore, the dose rates around the VVM are dominated by the streaming through the inlet and outlet vents, and not by direct radiation through the soil and concrete. To substantiate this, a complete dose rate profile across the lid and the ISFSI pad was determined. For the ISFSI pad, two conditions were evaluated, the normal condition and a condition where the streaming from the inlets and outlets were artificially blocked. For this second condition, dose rates were also calculated at a distance of 100 m from the VVM. This would indicate what portion of the dose rate results from direct radiation through the concrete and soil of the ISFSI pad as opposed to radiation from the streaming from the air inlet and outlet. The dose locations for the profile are shown in Figure 5.3.2, and are labeled alphabetically (A through X). The calculated dose rates are listed in Tables 5.4.2 and 5.4.3 for MPC-32 and MPC-37, respectively. The following conclusions can be drawn from the results:

- The profile did not reveal any locations with dose rates higher than those shown in Figure 5.1.1 and Tables 5.1.1 and 5.1.2.
- On the ISFSI pad, the dose rates are fairly low compared to other areas.
- At a distance of 100 m, the dose rate from the ISFSI pad surface contributes about 20% of the total dose rate.

It is to be noted that site specific analyses to demonstrate compliance with regulatory requirements should use appropriate site specific soil properties if these are substantially different from the properties used in this chapter.

The highest dose rate is observed for the side of the closure lid just above the inlet plenum zone. To investigate the effect of any streaming from the inlet plenum region, additional calculations were performed for dose locations above the plenum at various radial locations, on the level of dose point 2. Table 5.4.5 presents the calculated dose rates for those locations, as a function of the radial distance from dose location 2, for the MPC-37. The results show that the maximum dose rate occurs at a distance of about 4 feet from the surface point 2. This information should be used by the radiation protection team to ensure operational activities around the lid following ALARA principles.

5.4.1 Excavation Dose Analysis

ISFSIs with HI-STORM UMAX VVMs might be built in one stage or in several stages. If the ISFSI is built in several stages, then excavation work will be necessary in the vicinity of the section of the ISFSI that is already in operation and contains loaded modules. To protect workers from radiation from the loaded modules, a radiation protection space (RPS) boundary is defined around the ISFSI in the drawing in Section 1.5. The RPS boundary is placed so that in a radial direction, a minimum of 10.75 ft of engineered fill remains between the construction site and the closest loaded module. For a loaded module on the periphery of the ISFSI, this places the boundary at least 15 ft from the center of the module. For a loaded module not on the periphery of the ISFSI, this places the boundary at least 22 feet from the center of the module. Calculations were conservatively performed with the 6.5 ft remaining fill (soil is used in the model) around a loaded VVM instead of the 10.75 ft required by the RPS. The dose rates at the surface of the excavation are presented in table 5.4.4 for both MPC-32 and MPC-37. This dose rate is very low, specifically lower than the dose rates at 1 m from the inlet/outlet vents of the modules. The dose rates at a construction site might therefore be dominated by the dose rates from the inlet/outlet vents, and depending on the loading condition of the operating part of the ISFSI, temporary shielding might be used to reduce dose rates to the construction site. It is to be noted that 6.5 feet of soil is considered for this purpose without any concrete enclosure wall.

Table 5.4.1

FLUX-TO-DOSE CONVERSION FACTORS (FROM [5.4.6])

Gamma Energy (MeV)	**(rem/hr)/ (photon/cm^2-s)**
0.01	3.96E-06
0.03	5.82E-07
0.05	2.90E-07
0.07	2.58E-07
0.1	2.83E-07
0.15	3.79E-07
0.2	5.01E-07
0.25	6.31E-07
0.3	7.59E-07
0.35	8.78E-07
0.4	9.85E-07
0.45	1.08E-06
0.5	1.17E-06
0.55	1.27E-06
0.6	1.36E-06
0.65	1.44E-06
0.7	1.52E-06
0.8	1.68E-06
1.0	1.98E-06
1.4	2.51E-06
1.8	2.99E-06
2.2	3.42E-06

Table 5.4.1 (continued)

FLUX-TO-DOSE CONVERSION FACTORS (FROM [5.4.6])

Gamma Energy (MeV)	**(rem/hr)/ (photon/cm^2-s)**
2.6	3.82E-06
2.8	4.01E-06
3.25	4.41E-06
3.75	4.83E-06
4.25	5.23E-06
4.75	5.60E-06
5.0	5.80E-06
5.25	6.01E-06
5.75	6.37E-06
6.25	6.74E-06
6.75	7.11E-06
7.5	7.66E-06
9.0	8.77E-06
11.0	1.03E-05
13.0	1.18E-05
15.0	1.33E-05

Table 5.4.1 (continued)

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.6])

Neutron Energy (MeV)	Quality Factor	(rem/hr)[†]/(n/cm^2-s)
2.5E-8	2.0	3.67E-6
1.0E-7	2.0	3.67E-6
1.0E-6	2.0	4.46E-6
1.0E-5	2.0	4.54E-6
1.0E-4	2.0	4.18E-6
1.0E-3	2.0	3.76E-6
1.0E-2	2.5	3.56E-6
0.1	7.5	2.17E-5
0.5	11.0	9.26E-5
1.0	11.0	1.32E-4
2.5	9.0	1.25E-4
5.0	8.0	1.56E-4
7.0	7.0	1.47E-4
10.0	6.5	1.47E-4
14.0	7.5	2.08E-4
20.0	8.0	2.27E-4

[†] Includes the Quality Factor.

Table 5.4.2

DOSE RATES ADJACENT TO THE HI-STORM UMAX MODULE WITH MPC-32 AT DOSE LOCATIONS SHOWN IN FIGURE 5.3.2

Dose Location[††]	Dose Rate (mrem/hr unless noted)		Dose Location	Dose Rate (mrem/hr unless noted)	
	Inlet/Outlet Open	Inlet/Outlet Artificially Closed		Inlet/Outlet Open	Inlet/Outlet Artificially Closed
A	2.55	0.11	N	66.04	16.96
B	1.91	0.11	O	19.05	5.98
C	3.10	0.23	P	8.56	1.90
D	2.06	0.24	Q	4.61	0.78
E	1.67	0.32	R	1.44	0.31
F	1.49	0.28	S	1.29	0.28
G	1.25	0.32	T	1.18	0.28
H	0.73	0.32	U	1.10	0.27
I	0.36	0.16	V	1.03	0.26
J	0.59	0.31	W	0.88	0.26
K	0.92	0.49	X	0.80	0.23
L	0.52	0.37	Y	8.58 (mRem/year)	1.58 (mRem/year)
M	0.47	0.22			

[††] See Figure 5.3.2

Table 5.4.3

DOSE RATES ADJACENT TO THE HI-STORM UMAX MODULE WITH MPC-37 AT DOSE LOCATIONS SHOWN IN FIGURE 5.3.2

Dose Location[††]	Dose Rate (mrem/hr unless noted)		Dose Location	Dose Rate (mrem/hr unless noted)	
	Inlet/Outlet Open	Inlet/Outlet Artificially Closed		Inlet/Outlet Open	Inlet/Outlet Artificially Closed
A	2.08	0.10	N	41.47	13.73
B	1.52	0.09	O	12.13	4.82
C	2.35	0.20	P	5.24	1.50
D	1.73	0.21	Q	3.08	0.62
E	1.42	0.22	R	1.01	0.26
F	1.15	0.24	S	0.89	0.25
G	1.02	0.27	T	0.78	0.24
H	0.57	0.26	U	0.74	0.24
I	0.29	0.11	V	0.66	0.22
J	0.51	0.27	W	0.63	0.20
K	0.85	0.53	X	0.55	0.21
L	0.38	0.32	Y	5.96 mrem/year	1.31 (mRem/hr)
M	0.34	0.18			

[††] See Figure 5.3.2

Table 5.4.4

MAXIMUM DOSE RATES ON THE SURFACE OF THE RADIATION PROTECTION SPACE BOUNDARY

MPC-32 (mrem/hr)	MPC-37 (mrem/hr)
0.062	0.065

Table 5.4.5

DOSE RATE VALUES FOR LOCATIONS AT RADIAL DISTANCES FROM SURFACE LOCATION 2 FOR HI-STORM UMAX WITH MPC-37

Radial Distance from Surface Location 2 (cm)	Neutrons (mrem/hr)	Photons[§§§] (mrem/hr)	Total (mrem/hr)
61	0.12	0.32	0.44
100	1.53	3.39	4.92
130	2.55	7.09	9.64
161	1.47	4.28	5.75
191	0.95	3.15	4.10
222	0.63	2.51	3.14
252	0.45	2.15	2.60
283	0.33	1.64	1.97

[§§§] Photon dose rates include dose rates from fuel gammas, n-gamma reactions and Co-60 sources. In addition, BPRAs are included in the photon dose rate.

5.5 REGULATORY COMPLIANCE

Chapters 1, 2 and this chapter of this FSAR describe in detail the shielding structures, systems, and components (SSCs) important-to-safety.

The shielding-significant SSCs important-to-safety have been evaluated in this chapter and their impact on personnel and public health and safety resulting from operation of an independent spent fuel storage installation (ISFSI) utilizing the HI-STORM UMAX System has also been evaluated.

In summary it can be concluded that the shielding of the HI-STORM UMAX System is in compliance with 10CFR72 and satisfies the applicable design and acceptance criteria including 10CFR20. Thus, this shielding evaluation provides reasonable assurance that the HI-STORM UMAX system will allow safe storage of spent fuel in full conformance with 10CFR72.

5.6 REFERENCES

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[5.0.3] "Final Safety Analysis Report for the HI-STORM FW MPC Storage System", HI-2114830, Latest Revision.

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APPENDIX 5.A

SAMPLE INPUT FILE FOR MCNP

Withheld in Accordance with 10 CFR 2.390

CHAPTER 6: CRITICALITY EVALUATION

6.0 INTRODUCTION

This chapter discusses the criticality safety of the HI-STORM UMAX system. Criticality safety depends foremost on the MPC and fuel basket, and the MPC content. Those are identical between the HI-STORM UMAX and the HI-STORM FW. Criticality safety of the HI-STORM UMAX is therefore demonstrated in this chapter by reference to criticality evaluations documented in Chapter 6 of the HI-STORM FW FSAR [2.0.1], with appropriate recognition of the differences in the overpack configuration. As noted in other chapters, Revision 1 of the HI-STORM FW FSAR has been added to this docket to eliminate the need to consult the HI-STORM FW FSAR in another docket.

6.1 ACCEPTANCE CRITERIA

The acceptance criteria for criticality evaluations for the HI-STORM UMAX system are presented in Subsection 2.0 of this FSAR.

6.2 EVALUATION

During storage conditions in the HI-STORM UMAX system, the maximum k_{eff} will be significantly below the limiting maximum k_{eff} since the MPC is internally dry. Under this condition, the configuration is very similar in all HI-STORM models, which consists of an internally dry MPC, an air gap between the MPC and the overpack, a steel shell or shells and concrete (above-ground) or soil (underground). Results for the HI-STORM UMAX VVM would therefore be practically identical to the results listed for storage conditions in Chapter 6 of the HI-STORM FW FSAR [2.0.1]. Any small differences in results would not affect the principal conclusions, since the maximum k_{eff} under storage conditions (dry inert environment) is substantially below the regulatory limit. Note that the analysis for the MPCs in the HI-STORM documented in Chapter 6 of the HI-STORM FW FSAR [2.0.1] conservatively assume that the gap between the MPC and the HI-STORM is flooded with water, thus increasing the neutron reflection compared to a dry cavity [2.0.1, Section 6.1]. Flooding under accident conditions of the UMAX is therefore also covered by the calculations for the HI-STORM FW. All other normal, off-normal and accident conditions in the HI-STORM UMAX system are identical to those in the HI-STORM FW, since the MPCs, including content, and HI-TRAC are identical between the two systems.

In summary, the limiting condition for storage of MPCs in HI-STORM UMAX is identical to the limiting conditions for the HI-STORM FW from a criticality perspective, and all other normal, off-normal and accident conditions are identical or equivalent between the systems from a criticality perspective. All results and conclusions for criticality safety of the MPCs previously analyzed in Chapter 6 of the HI-STORM FW FSAR [2.0.1] remain applicable to the HI-STORM UMAX system, and no additional calculations to demonstrate criticality safety are required for the HI-STORM UMAX system.

CHAPTER 7: CONFINEMENT EVALUATION

7.0 INTRODUCTION

This chapter discusses the confinement safety of the HI-STORM UMAX System. Confinement of all radioactive materials in the HI-STORM UMAX system is provided by the MPC. MPCs are identical between the HI-STORM UMAX and the HI-STORM FW. All normal, off-normal and accident conditions relevant for confinement are identical between the HI-STORM UMAX and the HI-STORM FW, and there are no new conditions for the HI-STORM UMAX system that would require additional confinement analyses. Confinement safety of the HI-STORM UMAX is therefore demonstrated in this chapter by reference to confinement evaluations documented in Chapter 7 of the HI-STORM FW [2.0.1], with appropriate recognition of the differences in the overpack configuration. For ease of reference, the entire body of Revision 1 of the HI-STORM FW FSAR has been placed in this docket.

7.1 ACCEPTANCE CRITERIA

The acceptance criteria for confinement evaluations for the HI-STORM UMAX system are presented in Chapter 2 of this FSAR.

7.2 EVALUATION

The MPCs will be stored in the HI-STORM UMAX VVM in a passive state just as they are stored in the above ground overpacks described in the HI-STORM FW FSAR. Furthermore, as shown in Chapter 4, the temperature field in the MPC is engineered to be bounded by that determined in the HI-STORM FW FSAR. Therefore, the stress levels in the MPC pressure retaining boundary will be bounded by that in its certification basis value in the HI-STORM FW FSAR which leads to the axiomatic conclusion that the confinement integrity determinations reached in the HI-STORM FW MPC's also apply to storage in HI-STORM UMAX.

In summary, the storage configuration of MPCs in HI-STORM UMAX is identical to the storage configuration in the HI-STORM FW from a confinement perspective. Therefore, all descriptions and conclusions for the confinement system presented in Chapter 7 of the HI-STORM FW [2.0.1] remain applicable to the HI-STORM UMAX system, and no additional confinement evaluations are required for the HI-STORM UMAX system.

CHAPTER 8: MATERIAL EVALUATION

8.1 INTRODUCTION

This chapter presents an assessment of the materials selected for use in the HI-STORM UMAX system components identified in the licensing drawings in Section 1.5. The assessment of the materials selected for use in the MPC and HI-TRAC (i.e., components common to HI-STORM UMAX system and the previously licensed HI-STORM FW system) is provided in Chapter 8 of the HI-STORM FW FSAR. Material considerations pertaining to the components common to the "FW" and the "UMAX" systems, are referenced in this FSAR, as appropriate, to the HI-STORM FW FSAR. To facilitate convenient access to the referenced material, the latest edition of the HI-STORM FW FSAR has been placed in this docket and a list of "FW " FSAR sections germane to this chapter is provided in the (unnumbered) table below.

APPLICABLE SECTIONS OF HI-STORM FW FSAR

Location of UMAX FSAR	**Subject of the Reference**	**Location in HI-STORM FW FSAR, Revision 1**[*]
Section 8.1	Material evaluation for use in the MPCs and HI-TRAC	Paragraph 8.2.1.2, 8.2.1.2.i and 8.2.1.2.iii
Table 8.1.1	Performance of materials used in the MPC and HI-TRAC for short term operations	Table 8.1.1 and 8.1.3
Table 8.1.4	Failure and degradation mechanisms related to the performance of materials used in the MPCs and HI-TRAC for short term and storage operations	Table 8.1.4
Section 8.4	Material Properties for MPCs and HI-TRAC	Paragraph 8.4.4.1
Section 8.5	Welding material and welding specification for MPC and HI-TRAC	Section 8.5
Section 8.7	Coatings and corrosion mitigation techniques for MPC and HI-TRAC	Sub-Section 8.7.2 and 8.7.3
Section 8.8	Gamma and neutron shielding materials used in HI-TRAC	Section 8.8
Section 8.9	Neutron Absorbing Materials	Section 8.9
Section 8.10	Seals for the HI-TRAC bottom lid	Section 8.11
Section 8.11	Chemical and galvanic reactions related to the MPC and HI-TRAC	Section 8.12
Section 8.12	Fuel cladding integrity during short term operations	Section 8.13
Section 8.13	Examination and testing requirements for the MPC and HI-TRAC	Section 8.14.1

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[*] For convenience of reference, the specific revision of the HI-STORM FW FSAR that is referenced in the safety analysis herein is placed in this docket. Updated versions of the HI-STORM FW FSAR shall be placed in this docket as necessary so as to ensure that the safety analyses on the "UMAX" docket (72-1040) remain aligned with the material referenced in the HI-STORM FW FSAR.

In this chapter and in Chapters 2 and 3 of this FSAR, the significant mechanical, thermal, radiological, and metallurgical properties of materials identified for use in the components of the HI-STORM UMAX System VVM and ISFSI are presented.

The HI-STORM UMAX components must withstand the environmental conditions experienced during normal operation, off-normal conditions, and accident conditions for the entire service life. The major structural materials used in HI-STORM UMAX System are discussed in this chapter.

Chapter 1 provides a general description of the HI-STORM UMAX System including information on materials of construction. The ITS categories of the principal materials of construction in the HI-STORM UMAX VVM and ISFSI system are identified in the drawing package provided in Section 1.5.

The Materials selected for the HI-STORM UMAX VVM are the same as those used in its anatomically similar predecessor, HI-STORM 100U VVM, licensed in Docket number 72-1014. As such, the material considerations for HI-STORM UMAX are parallel to those for HI-STORM 100U.

Nevertheless, for completeness, it is necessary that the material considerations applicable to HI-STORM UMAX be independently evaluated for compliance with the ISG-15 [8.1.1] which contains the latest NRC position in this matter. The principal purpose of ISG-15 is to evaluate the dry cask storage system to ensure adequate material performance of components deemed to be important-to-safety at an independent spent fuel storage installation (ISFSI) under normal, off-normal, and accident conditions. Guidance on performing the safety evaluation of the materials is adopted directly from ISG-15.

ISG-15 sets down the following general acceptance criteria for material evaluation:

- The safety analysis report should describe all materials used for dry spent fuel storage components important-to-safety, and should consider the suitability of those materials for their intended functions in sufficient detail to evaluate their effectiveness in relation to all safety functions.

- The dry spent fuel storage system should employ materials that are compatible with wet and dry spent fuel loading and unloading operations and facilities. These materials should not degrade to the extent that a safety concern is created.

The information compiled in this chapter seeks to address the above acceptance criteria in full measure for the HI-STORM UMAX VVM and ISFSI. To perform the material suitability evaluation, it is necessary to characterize the following for each component: (i) the applicable environment, (ii) potential degradation modes and (iii) potential hazards to continued effectiveness of the selected material.

This FSAR seeks to qualify previously licensed MPCs (Table 1.2.1) in the HI-STORM FW docket for long-term storage in the HI-STORM UMAX modules The information required to address the short-term operations for the MPC and HI-TRAC are contained in Chapter 10 of the HI-STORM FW FSAR. The material evaluation effort, therefore, is directed towards the long-term storage and its consequences to the system's continued safety. Tables 8.1.1 and 8.1.2 provide a summary of the environmental states, potential degradation modes, and hazards applicable to the HI-STORM UMAX modules. Table 2.6.2 provides a listing of permissible materials used in the HI-STORM UMAX system. Table 8.1.3 provides the listing of material types that are important to safety and are subject to the ambient environmental of an ISFSI.

To provide a proper context for the subsequent evaluations, the potential degradation mechanisms applicable to the ventilated systems are summarized in Table 8.1.4. The degradation mechanisms listed in Table 8.1.4 are considered in the suitability evaluation presented in this chapter.

The material evaluation presented in this chapter is intended to be complete, even though *a' priori* conclusion of the adequacy of the materials can be made on the basis of the following facts:

i. The materials used in HI-STORM UMAX VVM are identical to those used in the widely deployed HI-STORM 100 System (Docket No. 72-1014) [8.1.2] including its underground VVM denoted as HI-STORM 100U and the HI-STORM FW system (Docket number 72-1032) [8.1.3].

ii. The thermal environment in the HI-STORM UMAX system emulates other HI-STORM models in all respects.

iii. The MPC transfer operations, described in Chapter 9 herein, are identical to those that have been practiced in the HI-STORM 100 system throughout the industry.

The organization of technical information in this chapter mirrors the format and content of Chapter 8 in the HI-STORM FW FSAR and complies with the guidance in NUREG-1536 [8.1.4]

Table 8.1.1

CONSIDERATIONS GERMANE TO PERFORMANCE OF MATERIALS USED IN THE MPCs IN LONG TERM STORAGE IN HI-STORM UMAX

Consideration	Environment
Environment	MPC's internal environment is hot (≤ 752°F), inertized and dry. Temperature of the MPC internals cycles vary gradually due to changes in the environmental temperature.
Potential degradation modes	Corrosion of the external surfaces of the MPC (stress, corrosion, cracking, pitting, etc.).
Potential hazards to effective performance	Blockage of ventilation ducts under an extreme environmental phenomenon leading to a rapid heat-up of the MPC internals.

Note that the considerations germane to the performance of materials used in the MPC and HI-TRAC for short term operations are addressed in Section 8.1 of the HI-STORM FW FSAR.

Table 8.1.2

CONSIDERATIONS GERMANE TO THE HI-STORM UMAX VVM MATERIAL PERFORMANCE

Consideration	Performance Data
Environment	Cool ambient air is progressively (but marginally) heated as it flows up the annulus between the Divider Shell and the MPC heating the inside surface of the cask and cooling the outside surface of the MPC. The heated air has reduced relative humidity the warmer it gets. As a result, the bottom external surface of the Closure Lid is heated and the top external surfaces are in contact with ambient air, rain, and snow, as applicable. The exterior surfaces of the CEC are in contact with either engineered fill or concrete (concrete encasement or "free-flow "concrete) and may be subjected to cathodic protection, as applicable.
Potential degradation modes	Peeling or perforation of surface preservatives on steel surfaces and corrosion of exposed steel surfaces.
Potential hazards to effective performance	Blockage of ducts by debris leading to overheating of the concrete in the overpack, scorching of the cask by proximate fire, lightning.

Table 8.1.3
MATERIAL TYPES IN THE HI-STORM UMAX SYSTEM COMPONENTS EXPOSED TO THE LONG-TERM AMBIENT ENVIRONMENT

	Material Type	**Components and Their Surfaces Exposed to Ambient Environment**
1.	Low carbon steel	• All surfaces of the closure lid • Internal surfaces of the CEC (expose to air) • External surfaces of the CEC (exposed to buffer concrete) or subgrade • Internal and External surfaces of the Divider shell
2.	Shielding concrete	The outside surface of the ISFSI pad
3.	Alloy X Austenitic Stainless Steel	• External surfaces of the stored MPC • MPC Guides and MPC support surfaces inside the CEC. • Divider shell leaf spring gasket
4.	Elastomeric Gasket	Closure Lid Gasket

Table 8.1.4

FAILURE AND DEGRADATION MECHANISMS[*]

	Mechanism	Area of Performance Affected	Vulnerable Parts
1.	General Corrosion	Structural capacity	All carbon steel parts
2.	Stress Corrosion Cracking	Structural	Austenitic Stainless Steel
3.	Galling	Equipment handling and deployment	Threaded Fasteners
4.	Fatigue	Structural Integrity	Fuel Cladding & Bolting
5.	Brittle Fracture	Structural Capacity	Thick Steel Parts
6.	Boron Depletion	Criticality Control	Neutron Absorber

Note that the failure and degradation mechanisms related to the performance of materials used in the MPC and HI-TRAC for short term and storage operations are addressed in Section 8.1 of the HI-STORM FW FSAR.

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[*] This table lists all potential (generic) mechanisms, whether they are credible for the HI-STORM UMAX System or not. The viability of each failure mechanism is discussed later in this chapter.

8.2 MATERIAL SELECTION

The acceptance criteria for the materials subject to long-term storage conditions in HI-STORM UMAX are extracted from ISG-15[8.1.1] as follows:

a. The material properties of a dry spent fuel storage component should meet its service requirements in the proposed cask system for the duration of the licensing period.

b. The materials that comprise the dry spent fuel storage should maintain their physical and mechanical properties during all conditions of operations. The spent fuel should be readily retrievable without posing operational safety problems.

c. Over the range of temperatures expected prior to and during the storage period, any ductile-to-brittle transition of the dry spent fuel storage materials, used for structural and nonstructural components, should be evaluated for its effects on safety.

d. Dry spent fuel storage gamma shielding materials should not experience slumping or loss of shielding effectiveness to an extent that compromises safety. The shield should perform its intended function throughout the licensed service period.

e. Dry spent fuel storage materials used for neutron absorption should be designed to perform their safety function.

f. Dry spent fuel storage protective coatings should remain intact and adherent during all loading and unloading operations within wet or dry spent fuel facilities, and during long-term storage.

It is recognized that the qualification of the materials used in the MPC types and the HI-TRAC transfer cask is documented in Section 8.2 of the HI-STORM FW FSAR. The material selection opportunities for the HI-STORM UMAX system, therefore, are limited to the VVM module assembly components and the reinforced concrete structures that support or surround them.

However, to obviate any new material qualification effort, the materials permitted for the HI-STORM UMAX system *are limited to those certified in other HI-STORM 100 and HI-STORM FW dockets*. The material qualification information presented in this chapter is accordingly adopted from Docket Number 72-1032.

8.2.1 Structural Materials

8.2.1.1 Cask Components and Their Constituent Materials

The major structural material that is used in the HI-STORM UMAX VVM is carbon steel. The concrete in the VVM Closure Lid does not play a major structural role but is present in large quantity for the main purpose of shielding. The major structural materials in the ISFSI structures are the concrete and rebars in the Support Foundation Pad, the ISFSI Pad, and the Self-hardening Engineered Subgrade (SES).

8.2.1.2 Synopsis of Structural Materials

i. Carbon Steel, Low-Alloy Steel

Materials for the HI-STORM UMAX VVM are selected to preclude brittle fracture. Details of discussions are provided in Section 3.1 and Section 8.4, as applicable. The fracture toughness test requirements specified in Table 3.1.9 apply to the HI-STORM UMAX Closure Lid ferritic structural steels including any "significant-to-handling" (STH) parts of the Closure Lid.

ii. Reinforced Concrete

All reinforced concrete load bearing structures (concrete and rebar) in the HI-STORM UMAX ISFSI will conform to stress criteria of ACI-318(2005) [8.2.1]. Section 3.3 provides properties for reinforced concrete to be used for the HI-STORM UMAX interfacing ISFSI structures. The service life of the ISFSI structures is specified to be the same as that of the HI-STORM UMAX VVM.

Chapter 3 discusses the structural evaluations of the HI-STORM UMAX System components and ISFSI structures. It is demonstrated that the structural steel components of the HI-STORM UMAX VVM and the SFP concrete meet the allowable stress limits for normal, off-normal, and accident loading conditions as applicable.

iii. Self-hardening Engineered Subgrade

SES materials used in the HI-STORM UMAX ISFSI will conform to the stress criteria of ACI-318(2005) or ACI-229(1999). Section 3.3 provides the properties for the SES material used for HI-STORM UMAX ISFSI. The service life for the SES is the same as that of the VVM and ISFSI reinforced concrete.

Chapter 3 discusses the structural evaluations of the HI-STORM UMAX System components and ISFSI structures. It is demonstrated that the structural steel components of the HI-STORM UMAX VVM and the SFP concrete meet the allowable stress limits for normal, off-normal, and accident loading conditions as applicable.

8.2.2 Non-Structural Materials

i. Plain Concrete

Plain concrete is specified for the VVM Closure Lid for its shielding properties and also as an encasement around the exterior of the VVM CEC shell, if required, for its corrosion mitigation properties. The requirements on the shielding concrete are specified in Table 2.3.2 in Chapter 2.

The shielding performance of the plain concrete is maintained by ensuring that the minimum concrete density is met during construction and the allowable concrete temperature limits are not exceeded. The thermal analyses for normal and off-normal conditions are carried out in this FSAR to insure that the plain concrete does not exceed the allowable long term temperature limit provided in Table 2.3.7.

ii. Insulation

The Divider Shell is lined with insulation on its outer surface to prevent excessive heating of the ISFSI pad. 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 Chapter 4. The high zinc content present in the coating of the Divider Shell provides protection for the jacketing or foil from the potential of galvanic corrosion. To ensure adequate 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. 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 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 VVM assembly and ranks them in order of importance.

Acceptance Criteria for the Selection of the Insulation Material	
Rank	**Criteria**
1	Adequate thermal resistance (See Table 4.1.1)
2	Adequate high temperature resistance (See Table 2.3.7)
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 [8.2.2] 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 above acceptance criteria may be used.

8.2.3 Critical Characteristics and Equivalent Materials*

As defined in the Glossary, the *critical characteristics* of a material are the properties that the material must possess to enable the part in which it is used to render its intended design function. However, 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 equivalent materials explained above has been previously used in the HI-STORM 100 FSAR [8.1.2] to qualify four different austenitic stainless steel alloys (ASME SA240 Types 304, 304LN, 316, and 316LN) to serve as candidate MPC 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, properties such as Yield Strength, Ultimate Strength, and Elongation must be specified as minimum guaranteed values. However, there are certain properties where both minimum and maximum acceptable values are required (in this category lies specific gravity and thermal expansion coefficients).

Table 8.2.1 lists the array of 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 needs, 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:

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* Materials in this section have been adapted from HI-STORM FW FSAR and therefore in Arial font [8.1.3]

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

The properties listed in Table 8.2.1 are the ones that may apply in a dry storage or transport application.

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 analyes 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. For ITS materials used with the HI-STORM UMAX VVM, 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 HI-STORM UMAX System, therefore, are:

- Material yield strength, σ_y
- Material ultimate strength, σ_u
- Elongation, ε

- Charpy impact strength at the lowest service temperature for the part, C_i (Unless exempted by other provisions in the governing code)

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 their minimum values used in the qualifying analyses used in this FSAR.

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 shall be necessary to ensure that all regulaory predicates for the material substitution are fully satisfied.

Table 8.2.1

TYPICAL 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 δ_{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.	Minimim Emmissivity	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.

8.3 APPLICABLE CODES AND STANDARDS

The principle codes and standards applied to the HI-STORM UMAX System components are the ASME Code Section II [8.3.1], the ACI code [8.2.1], the ASTM Standards, and the ANSI standards. Chapter 1 provides details of the specific applications of these codes and standards along with the other codes and standards that are applicable. The principle codes and standards applied to the MPC and HI-TRAC are described in Section 8.3 of the HI-STORM FW FSAR and are not repeated here.

Chapter 2 discusses factored load combinations for ISFSI pad design per NUREG-1536 [8.1.4]. Codes ACI 360R-92, "Design of Slabs on Grade"; ACI 302.1R, "Guide for Concrete Floor and Slab Construction"; and ACI 224R-90, "Control of Cracking in Concrete Structures" are also used in the design and construction of the concrete pad, as appropriate. Section 2.2 elaborates on the specific applications of the ASME Boiler and Pressure Vessel code for the HI-STORM UMAX System.

Chapter 3 provides allowable stresses and stress intensities for various materials extracted from applicable ASME code sections for various service conditions. This chapter also provides discussions on fracture toughness test requirements per ASME code sections. Mechanical properties of materials are extracted from applicable ASME sections [8.3.1], [8.3.2] and are tabulated for various materials used in HI-STORM UMAX System. Concrete properties are from ACI 318-2005 code.

In order to meet the requirements of the codes and standards the materials must conform to the minimum acceptable physical strengths and chemical compositions and the fabrication procedures must satisfy the prescribed requirements of the applicable codes.

Additional codes and standards applicable to welding are discussed in Section 8.5 and those for the bolts and fasteners are discussed in Section 8.6.

Review of the above shows that the identified codes and standards are appropriate for the material control of major components. Additional material control is identified in material specifications. Material selections are appropriate for environmental conditions to be encountered during loading, unloading, transfer, and storage operations. The materials and fabrication of major components are suitable based on the applicable codes of record.

8.4 MATERIAL PROPERTIES

This section provides discussions on material properties that mainly include mechanical and thermal properties. Additional discussions related to materials used in the MPC and HI-TRAC are presented in Section 8.4 of the HI-STORM FW FSAR. The material properties used in the design and analysis of the HI-STORM UMAX System are obtained from established industry sources such as the ASME Boiler and Pressure Vessel Code [8.3.1], ASTM publications, handbooks, textbooks, other NRC-reviewed SARs, and government publications, as appropriate.

8.4.1 Mechanical Properties

Section 3.3 presents mechanical properties of all ITS materials used in the HI-STORM UMAX System. The structural materials include Alloy X, carbon steel, low-alloy and nickel-alloy steel, bolting materials, and weld materials. The properties include yield stress, mean coefficient of thermal expansion, ultimate stress, and Young's modulus of these materials and their variations with temperature. Certain mechanical properties are also provided for nonstructural materials such as concrete used for shielding.

The discussion on mechanical properties of materials in Chapter 3 provides reasonable assurance that the class and grade of the structural materials are acceptable under the applicable construction code of record. Selected parameters such as the temperature dependent values of stress allowables, modulus of elasticity, Poisson's ratio, density, thermal conductivity, and thermal expansion have been appropriately defined in conjunction with other disciplines. The material properties of all code materials are guaranteed by procuring materials from Holtec-approved vendors through the so-called "material dedication" process*, if necessary.

8.4.2 Thermal Properties

Section 4.2 presents thermal properties of materials used in the MPC such as Alloy X, Metamic-HT, aluminum shims and helium gas; materials present in HI-STORM UMAX such as carbon steel and concrete; and materials present in HI-TRAC transfer cask that include carbon steel, lead and demineralized water. The properties include density, thermal conductivity, heat capacity, viscosity, and surface emissivity/absorptivity. Variations of these properties with temperature are also provided in tabular forms.

The thermal properties of fuel (UO_2) and fuel cladding are also reported in Section 4.2. Thermal properties are obtained from standard handbooks or established text books (see Table 4.2.1).

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* Dedication is a term of art in nuclear quality assurance.

8.4.3 Low Temperature Ductility of Ferritic Steels[*]

The risk of brittle fracture in the HI-STORM UMAX components is eliminated by utilizing materials that maintain high fracture toughness under "cold" conditions (temperatures < -40 degrees F)

The MPC canister is constructed from a menu of stainless steels termed Alloy X. These stainless steel materials do not undergo a ductile-to-brittle transition in the minimum service temperature range of the HI-STORM UMAX system. Therefore, brittle fracture is not a concern for the MPC components. Such an assertion cannot be made *a' priori* for the HI-STORM storage overpack and HI-TRAC transfer cask that contain ferritic steel parts. In general, the impact testing requirement for the HI-STORM overpack and the HI-TRAC transfer cask is a function of two parameters: the Lowest Service Temperature (LST)[†] and the normal stress level. The significance of these two parameters, as they relate to impact testing of the VVM is discussed below.

In normal storage mode, the LST of the HI-STORM storage overpack structural members may reach -40°F in the limiting condition wherein the spent nuclear fuel (SNF) in the contained MPCs emits no (or negligible) heat and the ambient temperature is at -40°F (design minimum per Chapter 2: Principal Design Criteria). During the heavy load handling operations at an ISFSI, the applicable lowest service temperature in the MPC's in FW docket is limited to a threshold ambient temperature below which lifting and handling of the HI-TRAC transfer cask is not permitted by the Technical Specification. Therefore, two distinct LSTs are applicable to load bearing metal parts within the HI-STORM UMAX overpack and the HI-TRAC transfer cask; namely,

LST = 0°F for the HI-STORM overpack during handling operations and for the HI-TRAC transfer cask during all normal operating conditions.

LST = -40°F for the HI-STORM overpack during all non-handling operations (i.e., normal and off-normal storage mode).

Parts used to lift the overpack or the transfer cask, which include the top flange in HI-TRAC, are referred to as "significant-to-handling" (STH) parts. All other parts of the overpack and the transfer cask will be referred to as "NF" components. It is important to ensure that all materials designated as "NF" or "STH" parts possess sufficient fracture toughness to preclude brittle fracture. For the STH parts, the necessary level of protection against brittle fracture is deemed to exist if the NDT (nil ductility transition) temperature of the part is at least 40°F below the LST.

It is well known that the NDT temperature of steel is a strong function of its composition, manufacturing process (viz., fine grain vs. coarse grain practice), thickness, and heat treatment.

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[*] This subsection has been copied from the HI-STORM 100 FSAR (Section 3.1) without any substantive change.

[†] LST (Lowest Service Temperature) is defined as the daily average for the host ISFSI site when the outdoors portions of the "short-term operations" are carried out.

For example, it is well known that increasing the carbon content in carbon steels from 0.1% to 0.8% leads to the change in NDT from -50°F to approximately 120°F. Likewise, lowering of the normalizing temperature in the ferritic steels from 1200°C to 900°C may lower the NDT from 10°C to -50°C. It therefore follows that the fracture toughness of steels can be varied significantly within the confines of the ASME Code material specification set forth in Section II of the Code. For example, SA516 Gr. 70 can have a maximum carbon content of up to 0.3% in plates up to four inches thick. Section II further permits normalizing or quenching followed by tempering to enhance fracture toughness. Manufacturing processes that have a profound effect on fracture toughness, but little effect on tensile or yield strength of the material, are also not specified with the degree of specificity in the ASME Code to guarantee a well-defined fracture toughness. In fact, the Code relies on actual coupon testing of the part to ensure the desired level of protection against brittle fracture. For Section III, Subsection NF Class 3 parts, the desired level of protection is considered to exist if the lowest service temperature is equal to or greater than the NDT temperature (per NF 2311(b)(10)). Accordingly, the required NDT temperature for all load bearing metal parts in the HI-STORM UMAX overpack (NF and STH) is set at -40°F below the LST.

The STH components (Closure Lid strong backs) have thicknesses less than or equal to 1". The strong backs are fabricated from normalized SA516 Gr.70 material which is exempted from impact testing at lowest service temperatures above -30°F per ASME Section III, Subsection NF. Because the HI-TRAC Transfer Cask operations are limited to a minimum service temperature of 0°F for handling, the lid will also not be handled at temperatures below 0°F and the strong back material is thereby exempt from testing.

All other steel structural materials in the HI-STORM UMAX are made of SA516 Gr. 70, SA515 Gr. 70, SA36 or austenitic stainless steel. The SA516 Gr. 70 material used to fabricate the HI-STORM UMAX is exempt from impact testing per NF-2311(b), because:

i. The LST for handling operations is above the Minimum Design Temperature of SA516 Gr. 70 (for thickness less than 2-1/2") per Figure NF-2311(b)-1, and;

ii. During non-handling operations (i.e., <u>normal</u> storage mode), the maximum tensile stress in the HI-STORM overpack is less than the threshold limit of 6,000 psi specified in NF-2311(b)(7).

If the SA516 Gr. 70 plate is as-rolled (i.e., not normalized), then impact testing is required except when the maximum stress under normal conditions, including handling operations, does not exceed 6,000 psi tension (see NF-2311(b)(7)) or is non-tensile (compressive).

Table 3.1.9 provides a summary of impact testing requirements to ensure prevention of brittle fracture.

8.4.4 Creep Properties of Materials

Creep, a visco-elastic and visco-plastic effect in metals, manifests itself as a monotonically increasing deformation if the metal part is subjected to stress under elevated temperature. Since certain parts of the HI-STORM UMAX system, notably the fuel basket, operate at relatively high temperatures, creep resistance of the fuel basket is an important property. Creep resistance of the MPC internals is discussed in the HI-STORM FW FSAR. Creep is not a concern in the Enclosure Vessel, the HI-STORM UMAX, or the HI-TRAC steel weldment because of the operating metal temperatures, stress levels and material properties. Steels used in ASME Code pressure vessels have a high threshold temperature at which creep becomes a factor in the equipment design. The ASME Code Section II material properties provide the acceptable upper temperature limit for metals and alloys acceptable for pressure vessel service. In the selection of steels for the HI-STORM UMAX system, a critical criterion is to ensure that the sustained (normal) metal temperature of the part made of the particular steel type shall be less than the Code permissible temperature for pressure vessel service. This criterion guarantees that excessive creep deformation will not occur in the steels used in the HI-STORM UMAX system.

8.5 WELDING MATERIAL AND WELDING SPECIFICATION

Welds in the HI-STORM UMAX system are divided into two broad categories:

i. Structural welds
ii. Non-structural welds

Structural welds are those that are essential to withstand mechanical and inertial loads exerted on the component under normal storage and handling.

Non-structural welds are those that are subject to minor stress levels and are not critical to the safety function of the part. Non-structural welds are typically located in the redundant parts of the structure. The guidance in the ASME Code Section NF-1215 for secondary members may be used to determine whether the stress level in a weld qualifies it to be categorized as non-structural.

Both structural and non-structural welds must satisfy the material considerations listed in Tables 8.1.1 and 8.1.2 for the MPC and the HI-STORM UMAX VVM, respectively. In addition, the welds must not be susceptible to any of the applicable failure modes listed in Table 8.1.4
The welding material and welding specification considerations for the MPC and HI-TRAC are discussed in Section 8.5 of the HI-STORM FW FSAR.

To ensure that all structural welds in the HI-STORM UMAX system shall render their intended function, the following requirements are observed:

i. The welding procedure specifications comply with ASME Section IX for every Code material used in the system.

ii. The quality assurance requirements applied to the welding process correspond to the highest ITS classification of the parts being joined.

iii. The non-destructive examination of every weld is carried out using quality procedures that comply with ASME Section V.

The welding operations are performed in accordance with the requirements of codes and standards depending on the design and functional requirements of the components.

The selection of the weld wire, welding process, range of essential and non-essential variables,[*] and the configuration of the weld geometry has been carried out to ensure that each weld will have:

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[*] Please refer to Section IX of the ASME Code for the definition and delineation of essential and non-essential variables.

i. Greater mechanical strength than the parent metal.
ii. Acceptable ductility, toughness, and fracture resistance.
iii. Corrosion resistance properties comparable to the parent metal.
iv. No risk of crack propagation under the applicable stress levels.

The welding procedures implemented in the manufacturing of HI-STORM UMAX components are intended to fulfill the above performance expectations.

The inspection and testing requirements of the HI-STORM UMAX System component welds are provided in Section 10.1.

The weld filler material shall comply with requirements set forth in the applicable Welding Procedure Specifications qualified to ASME Section IX at the manufacturer's facility. Only those Welding Procedures that have been qualified to the Code are permitted in the manufacturing of HI-STORM UMAX components.

The weld procedure qualification record specifies the requirements for fracture control (e.g., post weld heat treatment). The HI-STORM UMAX module assembly does not require any post weld heat treatment due to the material combinations and provisions in the applicable codes and standards.

Non-structural welds shall meet the following requirements:

1. The welding procedure shall comply with Section IX of the ASME Code or AWS D1.1.

2. The welder shall be qualified, at minimum, to the commercial code such as ASME Section VIII, Div.1, or AWS D1.1.

3. The weld shall be visually examined by the weld operator or a Q.C. inspector qualified to Level 1 (or above) per ASNT designation.

8.6 BOLTS AND FASTENERS

The HI-STORM UMAX VVM assembly does not employ any ITS bolts or fasteners. However, during the MPC transfer into the HI-STORM UMAX, the HI-TRAC and mating device may be attached to the VVM assembly to prevent tip-over during a seismic event. If bolts are used to secure the HI-TRAC against tip-over, the bolts and anchor location material would be considered ITS and would be procured in accordance with the Holtec QA program. Bolt and anchor location material would be selected from the list of materials identified in ASME Section II. The bolting materials used for the HI-TRAC are evaluated in section 8.6 of the HI-STORM FW FSAR.

The only bolts employed in the HI-STORM UMAX VVM system are those used to secure the vent flue to the inlet and outlet plenums. All bolts and fasteners are made of alloy materials which are not expected to experience any significant corrosion in the operating environment. The ISFSI operation and maintenance program shall call for coating of bolts and fasteners if the ambient environment is aggressive.

All threaded surfaces are treated with a preservative to prevent corrosion. The O&M program for the storage system calls for all bolts to be monitored for corrosion damage and replaced, as necessary.

8.7 COATINGS AND CORROSION MITIGATION

In order to provide reasonable assurance that the VVM will meet its intended Design Life of 60 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. Coatings and corrosion mitigation techniques related to the MPC and HI-TRAC are discussed in Section 8.7 of the HI-STORM FW FSAR.

It should be noted that, although the CEC is a buried steel structure it is substantially sequestered from the native soil through two engineered features:

a. A thick reinforced concrete Enclosure Wall surrounds the VVM array and, along with the Support Foundation pad, provides a physical separation (water intrusion protection) to the CECs.

b. The subgrade in contact with the CECs is either a "free flow" concrete or an engineered fill selected to provide a non-aggressive environment around the CECs.

The above engineered features provide an environmentally benign condition for the CECs. The above said, although the CEC is not a part of the MPC confinement 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 [8.1.1] are summarized.

All VVM components are protected from galvanic corrosion by appropriate designs. Except for the CEC exterior surfaces (exterior CEC surface coating requirements discussed separately), all steel surfaces of the VVM are lined and coated with the same or equivalent surface preservative that is used in the aboveground HI-STORM FW and HI-STORM 100 overpacks. The pre-approved surface preservative is a proven zinc-rich inorganic/metallic (may also be an organic zinc rich coating) material that protects galvanically and has self-healing characteristics for added protection. All exposed surfaces interior to the VVM are accessible for the reapplication of surface preservative, if necessary.

Additional preemptive measures to prevent corrosion are essential, if the substrate is of aggressive chemistry. A description of corrosion mitigation measures proposed to protect the HI-STORM UMAX systems and which are also approved for use in HI-STORM 100U VVM in Docket Number 72-1014, are presented in the following.

The native soil excavated at the ISFSI site shall preferably not be used as subgrade unless it has the requisite density and low corrosivity. To evaluate soil corrosivity, a "10 point" soil-test evaluation procedure, in accordance with the guidelines of Appendix A of ANSI/AWWA C105/A21 [8.7.1] 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.[8.7.1] , 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 necessary if the native soil is used as the subgrade:

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. Exterior Coating

The CEC exterior 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. Organic coatings such as epoxy, however, must have proven radiation resistance 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 [8.7.6] or equivalent. The coating should be conservatively treated as a Service Level II coating as described in Reg. Guide 1.54 [8.7.3]. As such, the coating shall be subjected to appropriate quality assurance in accordance with the applicable guidance provided by ASTM D 3843-00 [8.7.4]. The coating should preferably be shop-applied in accordance with manufacturer's instructions and, if appropriate, applicable guidance from ANSI C 210-03 [8.7.5]. 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
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 required 5-inch minimum thickness is more conservative than that recommended in ACI Codes, such as ACI 318, 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, an approximately 5-inch thick concrete encasement is considered more than sufficient to provide reasonable assurance that the design basis service life can be achieved. The lowest part of the CEC sits in a recessed region of the Support Foundation Pad with an annular gap normally filled with substrate. If present, the CEC concrete encasement slurry will fill this annular gap during construction.

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 that utilize applicable guidance from the ACI codes (e.g., ACI 318 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)

If the aggressiveness of the subgrade around the CEC is highly aggressive and warrants an ICCPS then the user may choose to either extend an existing ICCPS to protect the installed ISFSI, or to establish an autonomous system. 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 [8.7.7].

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. Alternatively, the system shall be designed to mitigate corrosion of the CEC for its License Life with due consideration to provisions that would allow system upgrades or maintenance for extended service as required for potential future license extensions.

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 [8.7.8]
   - NACE Standard RP0285-2002 "Corrosion Control of Underground Storage Tank Systems by Cathodic Protection" [8.7.7]

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"
- NACE RP0169-96, "Control of External Corrosion on Underground or Submerged Piping Systems"
- 49CFR192 Subpart I "Requirements for Corrosion Control", Oct. 1, 2004 edition
- 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.

8.8 GAMMA AND NEUTRON SHIELDING MATERIALS

Gamma and neutron shield materials in the HI-STORM UMAX VVM system are discussed in Section 1.2. The gamma and neutron shielding materials used in the MPC and HI-TRAC are discussed in Sections 8.8 and 8.9 of the HI-STORM FW FSAR. The primary shielding materials used in the HI-STORM UMAX VVM system, as listed in Table 8.1.3, are plain concrete, reinforced concrete, and steel.

The plain concrete provides the main shielding function in the HI-STORM UMAX lids to minimize sky shine.

8.8.1 Plain Concrete

Unlike the above ground HI-STORM models, the use of plain concrete for shielding purposes in the underground VVMs is limited to the VVM Closure Lid. The *critical characteristics* of concrete used in the Closure Lid are its density and compressive strength. Table 2.3.2 provides reference properties of plain concrete used in the Closure Lid. The temperature limits in Table 2.3.7 are adopted from the HI-STORM 100 FSAR where the bases for the thermal limits are documented.

The density of plain concrete within the HI-STORM UMAX overpack is subject to a minor decrease due to long-term exposure to elevated temperatures. The reduction in density occurs primarily due to liberation of unbonded water by evaporation.

The shielding analysis in Section 5.3 considers the density of concrete in the Closure Lid as an explicit input item in the computation of dose above the HI-STORM UMAX ISFSI structure.

8.8.2 Steel

Section 5.3 provides a discussion on steel as a shielding material and its composition used in the evaluation of its shielding characteristics.

8.9 NEUTRON ABSORBING MATERIALS

The discussion related to the selection and use of neutron absorbing materials used in the MPC and HI-TRAC are discussed in Section 8.9 of the HI-STORM FW FSAR and are not repeated here.

8.10 SEALS

The HI-STORM UMAX VVM assembly does not utilize any gaskets that seal against a large pressure differential.

The only external gasket used in the system is the soft gasket at the Closure lid-CEC Flange interface that helps prevent the ingress of moisture and insects (through the small crack that may exist due to weld distortion in the fabrication of interfacing fabricated steel weldment surfaces) into the module cavity space.

The Divider shell is sealed against the Closure lid using a pliable, non-organic seal material that is suitable for long-term ambient air application up to 300 deg. F.

The seals used with the HI-TRAC bottom lid are discussed in Section 8.11 of the HI-STORM FW FSAR.

8.11 CHEMICAL AND GALVANIC REACTIONS

The materials used in the HI-STORM UMAX System are examined to establish that these materials do not participate in any chemical or galvanic reactions when exposed to the various environments during all normal operating conditions and off-normal and accident events. Chemical and galvanic reactions related to the MPC and HI-TRAC are discussed in Section 8.12 of the HI-STORM FW FSAR.

The following acceptance criteria for chemical and galvanic reactions are extracted from ISG-15 [8.1.1] for use in HI-STORM UMAX VVM components.

a. The DCSS should prevent the spread of radioactive material and maintain safety control functions using, as appropriate, noncombustible and heat resistant materials.

b. A review of the DCSS, its components, and operating environments (wet or dry) should confirm that no operation (e.g., short-term loading/unloading or long-term storage) will produce adverse chemical and/or galvanic reactions, which could impact the safe use of the storage cask.

c. Components of the DCSS should not react with one another, or with the cover gas or spent fuel, in a manner that may adversely affect safety. Additionally, corrosion of components inside the containment vessel should be effectively prevented.

d. Potential problems from general corrosion, pitting, stress corrosion cracking, or other types of corrosion, should be evaluated for the environmental conditions and dynamic loading effects that are specific to the component.

The materials and their ITS pedigree are listed in the drawing package provided in Section 1.5. The compatibility of the selected materials with the operating environment and to each other for potential galvanic reactions is discussed in this section.

- External atmosphere – During long-term storage the casks are exposed to outside atmosphere, air with temperature variations, solar radiation, rain, snow, ice, etc.

As discussed herein, the components of the HI-STORM UMAX System have been engineered to ensure that the environmental conditions expected to exist at nuclear power plant installations do not prevent the cask components from rendering their respective intended functions.

The principal operational considerations that bear on the adequacy of the storage overpack for the service life are addressed as follows:

<u>Exposure to Environmental Effects</u>

All exposed surfaces of the HI-STORM UMAX VVM components are made from ferritic steels that are readily painted. Concrete, which serves strictly as a shielding material in the VVM Closure Lid, is encased in steel. Therefore, the potential of environmental vagaries such as spalling of concrete are ruled out for HI-STORM UMAX VVM. Under normal storage conditions, the bulk temperature of the HI-STORM UMAX storage overpack will change very gradually with time because of its large thermal inertia. Therefore, material degradation from rapid thermal ramping conditions is not credible for the HI-STORM UMAX VVM. Similarly, corrosion of structural steel embedded in the concrete structures due to salinity in the environment at coastal sites is not a concern for HI-STORM UMAX VVM because it does not rely on rebars (indeed, it contains no rebars). The configuration of the storage VVM assures resistance to freeze-thaw degradation. In addition, the storage system is specifically designed for a full range of enveloping design basis natural phenomena that could occur over the service life of the storage system as catalogued in Section 2.2 and evaluated in Chapter 11.

The ISFSI pad, which is exposed to the elements, shall be subject to a surveillance program to monitor its potential degradation, as discussed in Chapter 10.

Material Degradation

The relatively low neutron flux to which the storage overpack is subjected cannot produce measurable degradation of the cask's material properties and impair its intended safety function. Exposed carbon steel components are coated to prevent corrosion. The ambient environment of the ISFSI storage pad mitigates damage due to exposure to corrosive and aggressive chemicals that may be produced at other industrial plants in the surrounding area.

Maintenance and Inspection Provisions

The requirements for periodic inspection and maintenance of the storage overpack throughout its service life are defined in Section 10.4. These requirements include provisions for routine inspection of the storage overpack exterior and periodic visual verification that the ventilation flow paths of the storage overpack are free and clear of debris. ISFSIs located in areas subject to atmospheric conditions that may degrade the storage cask or canister should be evaluated by the licensee on a site-specific basis to determine the frequency for such inspections to assure long-term performance. In addition, the HI-STORM UMAX system is designed for easy retrieval of the MPC from the storage overpack should it become necessary to perform more detailed inspections and repairs on the storage system.

The above findings are consistent with those of the NRC's Waste Confidence Decision Review [8.11.1], which concluded that dry storage systems designed, fabricated, inspected, and operated in accordance with such requirements are adequate for a 60-year Design and a 100-year service life while satisfying the requirements of 10CFR72.

8.12 FUEL CLADDING INTEGRITY

The discussion related to the fuel cladding integrity during short term operations is presented in Section 8.13 of the HI-STORM FW FSAR and are not repeated here.

8.13 EXAMINATION AND TESTING

Examination and testing are integral parts of manufacturing of the HI-STORM UMAX System components. Examination and testing requirements for the MPC and HI-TRAC are described in Section 8.14 of the HI-STORM FW FSAR. A comprehensive discussion on the examinations and testing that are conducted during the manufacturing process for the HI-STORM UMAX VVM is provided in Chapter 10 wherein the applicable codes and standards are also cited along with the acceptance criteria derived from them.

Post-fabrication inspections are discussed in Section 10.4 as part of the HI-STORM UMAX VVM System maintenance program. Inspections are conducted prior to fuel loading or prior to each fuel handling campaign. Other periodic inspections are conducted during storage.

The HI-STORM UMAX VVM is a passive device with no moving parts. Overpack vent screens are inspected on scheduled intervals for damage, holes, etc. The VVM's external surface, including identification markings, is visually examined on a periodic basis in accordance with the ISFSI's surveillance plan. The temperature monitoring system, if used, is inspected per the licensee's QA program and manufacturer's recommendations.

8.14 REGULATORY COMPLIANCE

The preceding sections describe the materials used in important-to-safety SSCs and the suitability of those materials for their intended functions in the HI-STORM UMAX System.

The requirements of 10CFR72.122(a) are met: The material properties of SSCs important to safety conform to quality standards commensurate with their safety functions.

The requirements of 10CFR72.104(a), 106(b), 124, and 128(a)(2) are met: Materials used for shielding are adequately designed and specified to perform their intended function.

The requirements of 10CFR72.122(h)(1) and 236(h) are met: The design of the DCSS and the selection of materials adequately protect the spent fuel cladding against degradation that might otherwise lead to gross rupture of the cladding by ensuring that the cladding temperature remains below the ISG-11 Rev 3 limits..

The requirements of 10CFR72.236(h) and 236(m) are met: The material properties of SSCs important-to-safety will be maintained during normal, off-normal, and accident conditions of operation as well as short-term operations so the spent fuel can be readily retrieved without posing operational safety problems.

The requirements of 10CFR72.236(g) are met: The material properties of SSCs important-to-safety will be maintained during all conditions of operation so the spent fuel can be safely stored for the specified service life and maintenance can be conducted as required.

The requirements of 10CFR72.236(h) are met: The HI-STORM UMAX System employs materials that are not vulnerable to degradation over time or react with one another during long-term storage.

8.15 REFERENCES

[8.1.1] ISG-15, "Materials Evaluation," U.S. Nuclear Regulatory Commission, Washington, DC, Revision 0, January 2001.

[8.1.2] USNRC Docket No. 72-1014, "HI-STORM 100 Final Safety Analysis Report", Holtec Report HI-2002444, latest revision,.

[8.1.3] "Final Safety Analysis Report on the HI-STORM FW System", Holtec Report No. HI-2114830, latest revision.

[8.1.4] NUREG-1536, "Standard Review Plan for Spent Fuel Dry Storage Systems at a General License Facility", Rev 1, U.S. Nuclear Regulatory Commission, Washington, DC.

[8.1.5] Craig and Anderson, "Handbook of Corrosion Data," ASM International, First Ed., 1995.

[8.2.1] ACI 318-2005, "Building Code Requirements for Structural Concrete," American Concrete Institute, Ann Arbor, MI.

[8.2.2] Morgan Thermal Ceramics Inc., Product Data Sheet for Blanket Products (Kaowool® Blanket).

[8.3.1] ASME Boiler and Pressure Vessel Code, Section II, Part A – Ferrous Material Specifications," American Society of Mechanical Engineers, New York, NY, 2010 Edition.

[8.3.2] ASME Boiler and Pressure Vessel Code, Section III, Appendices, 2010 edition.

[8.7.1] ANSI/AWWA C105/A21.5 "AWWA Standard for Polyethylene Encasement for Ductile Iron Pipe Systems."

[8.7.2] 49CFR Part 192 Subpart I "Requirements for Corrosion Control, Title 49 of the Code of Federal Regulations, Oct, 1 2004 Edition (or latest), Office of the Federal Register, Washington, D.C.

[8.7.3] Reg. Guide 1.54, "Service Level I, II, and III Protective Coatings Applied to Nuclear Power Plants", Revision 2, US Nuclear Regulatory Commission, Washington, DC.

[8.7.4] ASTM D 3843-00, "Standard Practice for Quality Assurance for Protective Coatings Applied to Nuclear Facilities", ASTM International, West Conshohocken, PA.

[8.7.5] ANSI C 210-03, “Liquid Epoxy Coating Systems for the Interior and Exterior of Steel Water Pipes”.

[8.7.6] ASTM D4082-10, “Standard Test Method for Effects of Gamma Radiation on Coatings for use in Nuclear Power Plants”, ASTM International, West Conshohocken, PA.

[8.7.7] NACE Standard RP0285-2002, “Standard Recommended Practice-Corrosion Control of Underground Storage Tank Systems by Cathodic Protection”.

[8.7.8] 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.

[8.11.1] 10CFR, Waste Confidence Decision Review, USNRC, September 18, 1990.

CHAPTER 9: OPERATING PROCEDURES

9.0 INTRODUCTION

The operations associated with the use of the HI-STORM UMAX System are quite similar to the operations for the HI-STORM 100U system certified in Docket Number 72-1014. Because the HI-STORM UMAX System's scope of certification is limited to loading pre-certified MPCs (Table 1.2.1) using pre-certified transfer cask (Table 1.2.2), the operations culminating in the arrival of the MPC-bearing HI-TRAC VW transfer cask at the ISFSI are governed by the HI-STORM FW System FSAR [9.6.1]. The description of the operations governed by this FSAR | pertains to staging the HI-TRAC transfer cask on the VVM cavity and ends with the removal of the empty transfer cask and replacement of the Closure Lid and installation of other appurtenances to place the storage system in a long-term storage configuration. The necessary information for executing the reverse set of steps to retrieve an MPC from a storage cavity is likewise provided. The guidance provided in this chapter shall be used as an aid to develop the short-term operations procedure specific to a host site that elects to deploy the HI-STORM UMAX system. The procedures provided in this chapter are prescriptive to the extent that they provide the basis and general guidance for plant personnel in preparing detailed written, site-specific, loading, handling, storage, and unloading procedures. Users may add, modify the sequence of, perform in parallel, or delete steps as necessary provided that the intent of this guidance is met and the requirements of the Certificate of Compliance (CoC) are complied within a *literal manner*. The information provided in this chapter complies with the provisions of NUREG-1536.

The information presented in this chapter along with the technical basis of the system design described in this SAR will be used to develop detailed operating procedures. In preparing the site-specific procedures, the user must consult the conditions of the CoC, equipment-specific operating instructions, and the plant's working procedures as well as the information in this chapter to ensure that the short-term operations shall be carried out with utmost safety and ALARA.

The following generic criteria shall be used to determine whether the site-specific operating procedures developed pursuant to the guidance in this chapter are acceptable for use:

- All heavy load handling instructions are in keeping with the guidance in industry standards and Holtec-provided instructions.
- The procedures are in conformance with this FSAR and its CoC.
- The procedures are in conformance with the HI-STORM FW System FSAR [9.6.1].
- The operational steps are ALARA.
- The procedures contain provisions for documenting successful execution of all safety significant steps for archival reference.

- Procedures contain provisions for classroom and hands-on training and for a Holtec-approved personnel qualification process to ensure that all operations personnel are adequately trained.
- The procedures are sufficiently detailed and articulated to enable craft labor to execute them in *literal compliance* with their content.

ISFSI owners are required to develop or modify existing programs and procedures to account for the implementation of the HI-STORM UMAX system. Written procedures are required to be developed or modified to account for such items as handling and storage of systems, structures and components (SSCs) identified as *important-to-safety*, heavy load handling, specialized instrument calibration, special nuclear material accountability, fuel handling procedures, training, equipment, and process qualifications. Users shall implement controls to ensure that all critical set points (e.g., Lift Weights) do not exceed the design limit of the specific equipment.

Control of the operation shall be performed in accordance with the user's Quality Assurance (QA) program to ensure critical steps are not overlooked and that the cask has been confirmed to meet all requirements of the CoC before being released for on-site storage under 10 CFR Part 72.

ALARA warnings highlighted in this chapter are included to alert users to radiological issues. Actions identified with these items are of an advisory nature and shall be implemented based on site-specific determination by the plant's radiation protection personnel.

Section 9.1 provides the technical basis for loading and unloading procedures. Section 9.2 provides the guidance for loading the HI-STORM UMAX system. Section 9.3 provides the procedures for ISFSI operations and general guidance for performing maintenance and for responding to abnormal events that may occur during normal loading operations. Section 9.4 provides the procedure for unloading the HI-STORM UMAX System. The loading steps and the illustrations, are illustrative (rather than definitive) because the architecture of a particular plant and its ISFSI may require significant adaptations for a safe and ALARA loading program.

Because the MPCs and transfer casks utilized in the HI-STORM UMAX system are originally certified in the HI-STORM FW docket, there is a close informational nexus between the two dockets with respect to the components common to both systems. Table 9.0.1 provides a matrix of the information in this FSAR that is supplemented by the corresponding material from the HI-STORM FSAR.the latest QA validated version of which (Rev 1) is placed in this docket for reference purposes.

TABLE 9.0.1: APPLICABLE SECTIONS OF HI-STORM FW FSAR*

Location of UMAX FSAR	Subject of the reference	Location in HI-STORM FW FSAR, Revision 1
Section 9.0	The operations culminating in the arrival of the MPC-bearing HI-TRAC at the ISFSI	Sections 9.1 and 9.2
Sub-Section 9.2.3	Loading of MPC	Sub-Sections 9.2.1 and 9.2.3
Sub-Section 9.4.1	Direction on further action such as return MPC to the fuel pool or loading in a transport cask for off-site shipment	Section 9.4
Sub-Section 9.4.2	HI-TRAC receipt inspection and cleanliness inspection	Table 9.2.5
Section 9.5	Steps to remove an MPC from a loaded VVM	Sub-Sections 9.4.3 and 9.4.4

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* For convenience of reference, the specific revision of the HI-STORM FW FSAR that is referenced in the safety analysis herein is placed in this docket. Updated versions of the HI-STORM FW FSAR shall be placed in this docket as necessary so as to ensure that the safety analyses on the "UMAX" docket (72-1040) remain aligned with the material referenced in the HI-STORM FW FSAR.

9.1 TECHNICAL AND SAFETY BASIS FOR LOADING AND UNLOADING PROCEDURES

The procedures herein are developed for the loading, storing, and unloading of a loaded MPC in the HI-STORM UMAX System. The design of the HI-STORM UMAX System, along with the implementation procedures, the ancillary equipment, and the Technical Specifications, collectively serve to achieve ALARA, minimize risks to the operational staff, and mitigate consequences of potential adverse events.

The primary objective of the information presented in this chapter is to identify and describe the sequence of significant operations and actions that are important-to-safety for canister loading, canister handling, storage operations, and canister unloading to adequately protect crew health and to eliminate any conceivable danger to life or property, to protect the MPC's contents from dispersal, and to provide for the safe execution of tasks and operations.

In the event of an extreme environmental condition, the appropriate procedural guidance to respond to the situation must be available and ready for implementation at the nuclear plant. As a minimum, the procedures shall address establishing emergency action levels, implementation of emergency action program, establishment of personnel exclusions zones, monitoring of radiological conditions, actions to mitigate or prevent the release of radioactive materials, recovery planning and execution, and reporting to the appropriate regulatory agencies, as required.

9.2 PROCEDURE FOR PLACING THE LOADED MPC IN THE HI-STORM UMAX VVM

9.2.1 Overview of Loading Operations

The HI-STORM UMAX System differs from the HI-STORM FW System in that the vertical ventilated module (VVM) is an integral part of the ISFSI and is therefore immovable (cannot be transported on-site). Therefore, the transfer of the MPC from the transfer cask to the storage module cannot occur within the plant's Part 50 structure. Like the HI-STORM 100U the underground module (in Docket Number 72-1014), the transfer of the MPC occurs by staging the HI-TRAC transfer cask over the CEC cavity. The loaded HI-TRAC transfer cask is transported between the ISFSI and the Part 50 facility where the MPC is loaded using a heavy haul vertical cask transporter, heavy haul transfer trailer, a rail car, air pads and the like that have been previously used for such applications. In what follows, the acronym VCT (for vertical cask transporter) is used to denote the hauling machinery. The operational steps required to prepare, load the MPC, and transport it to the ISFSI using the HI-TRAC transfer cask are governed by the HI-STORM FW System FSAR [9.6.1]. The detailed operational steps presented in this chapter, therefore, start with the preparation to stage the loaded HI-TRAC over the recipient storage cavity.

Prior to the start of MPC transfer at the ISFSI, the VVM lid is removed and the storage cavity is inspected for absence of foreign matter. The Mating Device is positioned on top of the VVM. The outlet flue installed on other VVMs on the path to the recipient CEC cavity may need removal to enable the VCT to reach the target cavity. If used, the Supplemental Cooling System (SCS) is disconnected from the HI-TRAC, the HI-TRAC annulus is drained, and the HI-TRAC is placed on top of the Mating Device (Figure 9.2.1). The MPC may be downloaded using the vertical cask crawler, the MPC downloader attached to the transfer cask, or other suitable lifting device. The MPC lifting device is attached to the MPC. The bottom lid is removed and the Mating Device drawer is opened. Optional temporary shielding may be installed, as guided by the licensee's Radiation Protection program, on or around the Mating Device. The MPC is lowered into the VVM (Figure 9.2.2). Following verification that the MPC is fully lowered, the MPC slings are disconnected from the lifting device and lowered onto or removed from the MPC lid. Alternately, the MPC lifting device may be removed. Any temporary shielding is removed, if necessary. The HI-TRAC and bottom lid may be reattached while on the VVM or may be removed and then reattached. HI-TRAC is removed from on top of the VVM. The MPC lift device is removed as necessary. Plugs are installed in the empty MPC lifting holes to fill the voids left by the removal of the lift cleat studs. The Mating Device is removed and the VVM lid is installed. Finally, the temperature monitoring elements and their instrument connections, if used at the ISFSI, are installed, and post-loading performance verification specified in the site loading procedures is performed.

Because the HI-STORM UMAX VVM is an integral part of the ISFSI itself, there is no handling of the VVM. For an example of the rigging required to handle the HI-STORM UMAX VVM

Closure Lid, see Figure 9.2.3.

9.2.2 Preparation for MPC Transfer

The required equipment/devices that participate in the transferring of the MPC into dry storage are, as a minimum:

1. Equipment to remove and install the VVM Closure Lid;
2. The vertical cask transporter (VCT) or equivalent load handling devices with redundant drop protection features;
3. The loaded transfer cask containing the MPC;
4. The Mating Device; and
5. MPC lifting and handling devices.

Prior to staging the Mating Device and the transfer cask on the recipient VVM cavity, the storage cavity shall be inspected for absence of debris, water, animals or insect nests, and the like. A general checklist for performing the pre-staging inspection of the VVM cavities is provided below:

1. The painted surfaces shall be inspected for corrosion and chipped, cracked, or blistered paint.
2. All lid surfaces shall be relatively free of dents, scratches, gouges, or other damage.
3. Lid lifting points shall be inspected for dirt, debris, and general condition.
4. Vent openings shall be free from obstructions.
5. Vent screens shall be available, intact, and free of holes and tears.
6. Temperature monitoring elements, if used, shall be inspected for availability, function, calibration, and provisions for mounting to the VVM outlet air passage.

HI-STORM UMAX VVM Main Body

1. Cooling passages shall be free from obstructions.
2. The interior cavity shall be free of debris, litter, tools, and equipment.
3. Painted surfaces shall be inspected for corrosion, and chipped, cracked or blistered paint.

VERTICAL CASK TRANSPORTER (VCT)

The VCT shall be serviced before the beginning of a dry storage campaign and all VCT checks are performed in accordance with its manufacturer's O&M manual. The quantity of fuel and other combustibles in the VCT shall be confirmed to be within the limits specified in the site's 72.212 safety evaluation report. The VCT shall be operated only if the ambient temperature is within the specified limit in the VCT's O&M manual. The VCT operator must have received training in the use of the VCT as specified in its O&M manual.

Finally, the Mating Device shall be inspected for any loose paint, scale, or other adherent debris and cleaned appropriately to eliminate the risk of foreign materials adhering to it that fall into the VVM cavity. The smooth operation of the lid drawer traction system shall be confirmed and moving surfaces lubricated, as specified in the applicable Holtec International Purchasing Specification.

The MPC transfer shall not occur if the meteorological forecast indicates a credible chance of adverse weather activity such as lightning, snow fall, rain, or heavy winds at the ISFSI during the planned transfer operation.

All slings and fasteners shall be inspected for general condition and indication of wear and degradation (such as a cut or nick in the sling) before accepting them for use.

9.2.3 Placement of the MPC into Storage

The operational steps presented in the following are intended to provide guidance to the user in preparing site-specific loading procedures that must be prepared with due consideration of the particular site's physical characteristics, its rigging plan, and its safety/ALARA practices. Figure 9.2.4 provides a pictorial overview of the loading steps.

Loading Steps

1. Load the MPC in accordance with Chapter 9 of the HI-STORM FW System FSAR [9.6.1]
2. Remove the Closure Lid using a crane or other equivalent lifting device.
3. Install the Mating Device on the VVM.
4. Place the loaded HI-TRAC transfer cask recipient on the Mating Device using the vertical cask crawler (or other suitable transportation device).
5. Rig the MPC to the lift components of the cask transporter or other suitable downloading device. Raise the MPC slightly to remove the weight of the MPC from the HI-TRAC Bottom lid (also called the Pool lid).
6. Unbolt the Bottom lid from the HI-TRAC body and lower the lid into the Mating Device.
7. Open the Mating Device drawer.

ALARA Warning:

Temporary shielding may be used to reduce personnel dose during transfer operations. If ALARA considerations dictate that temporary shielding not be used, personnel must remain clear of the immediate area around the Mating Device drawer during MPC downloading.

8. At the user's discretion, install temporary shielding to cover the potential streaming paths around the Mating Device drawer.
9. Lower the MPC into the VVM.
10. Verify that the MPC is fully seated in the VVM.

Caution:

Operations steps that occur with the MPC in the VVM with the Mating Device installed and the drawer closed must be performed in an expeditious manner to avoid excessive heating of the MPC and fuel. The Mating Device must be removed or the drawer opened to establish air cooling within the time limits described in Section 4.5. In the event of equipment malfunction that results in the blockage of air flow, corrective actions must occur within the time limits of the 100% blocked duct accident condition.

11. Disconnect the MPC rigging from the downloading device and lower them onto the MPC lid or remove them from the MPC.
12. Remove any temporary shielding and close the Mating Device drawer.
13. Reinstall the HI-TRAC Bottom lid.

ALARA Warning:

Personnel should remain clear (to the maximum extent practicable) of the VVM annulus when HI-TRAC is being removed to comply with ALARA requirements.

14. Remove the HI-TRAC transfer cask from the top of the VVM.
15. Partially open the Mating Device drawer and remove any MPC rigging.
16. Install hole plugs in the empty MPC bolt holes.
17. Close the Mating Device drawer and remove the Mating Device from on top of the VVM.

Guidance:

The lid shall be preferably kept less than 2 feet above the top surface of the VVM while over the MPC. This lift limit action is purely a defense-in-depth measure because the Closure Lid cannot fall and impact the MPC because of geometric constraints.

18. Install the VVM lid. Check that the rigging (in its specific configuration) is rated to lift the load (rated to lift two times the load per NUREG 0612).
19. Remove the VVM lid rigging equipment and re-install the outlet vent cover (if previously removed).
20. Install the VVM temperature monitoring elements (if used).
21. Install the flue extensions (that were removed to avoid interference with the VCT).
22. Perform shielding effectiveness testing, if required by the Technical Specification..

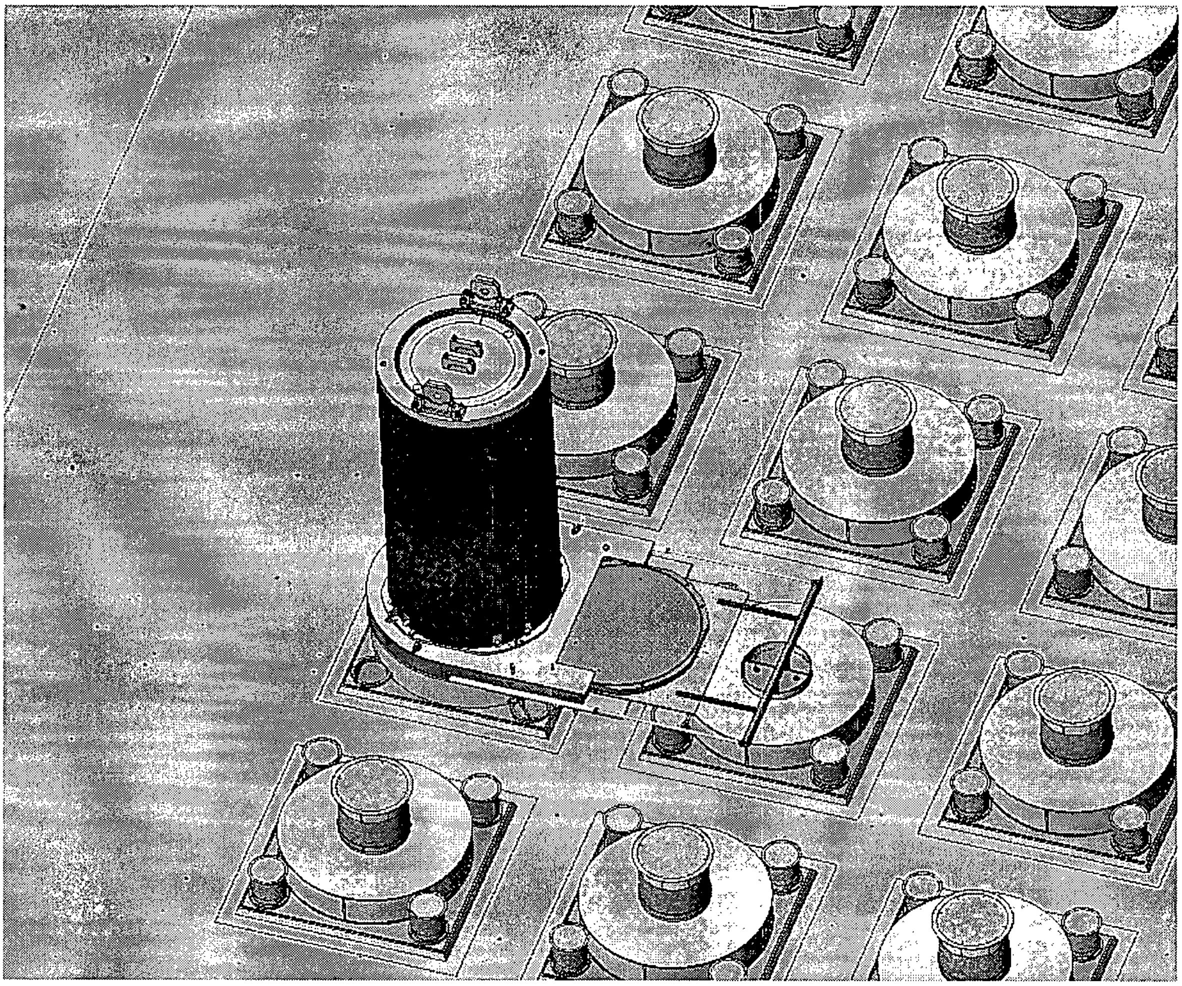


FIGURE 9.2.1: HI-TRAC ALIGNMENT AND PLACEMENT ON MATING DEVICE AND HI-STORM UMAX VVM

Note: The design features of the HI-STORM UMAX System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM UMAX depicted here and other figures in this FSAR may vary slightly from the licensing drawings in Section 1.5.

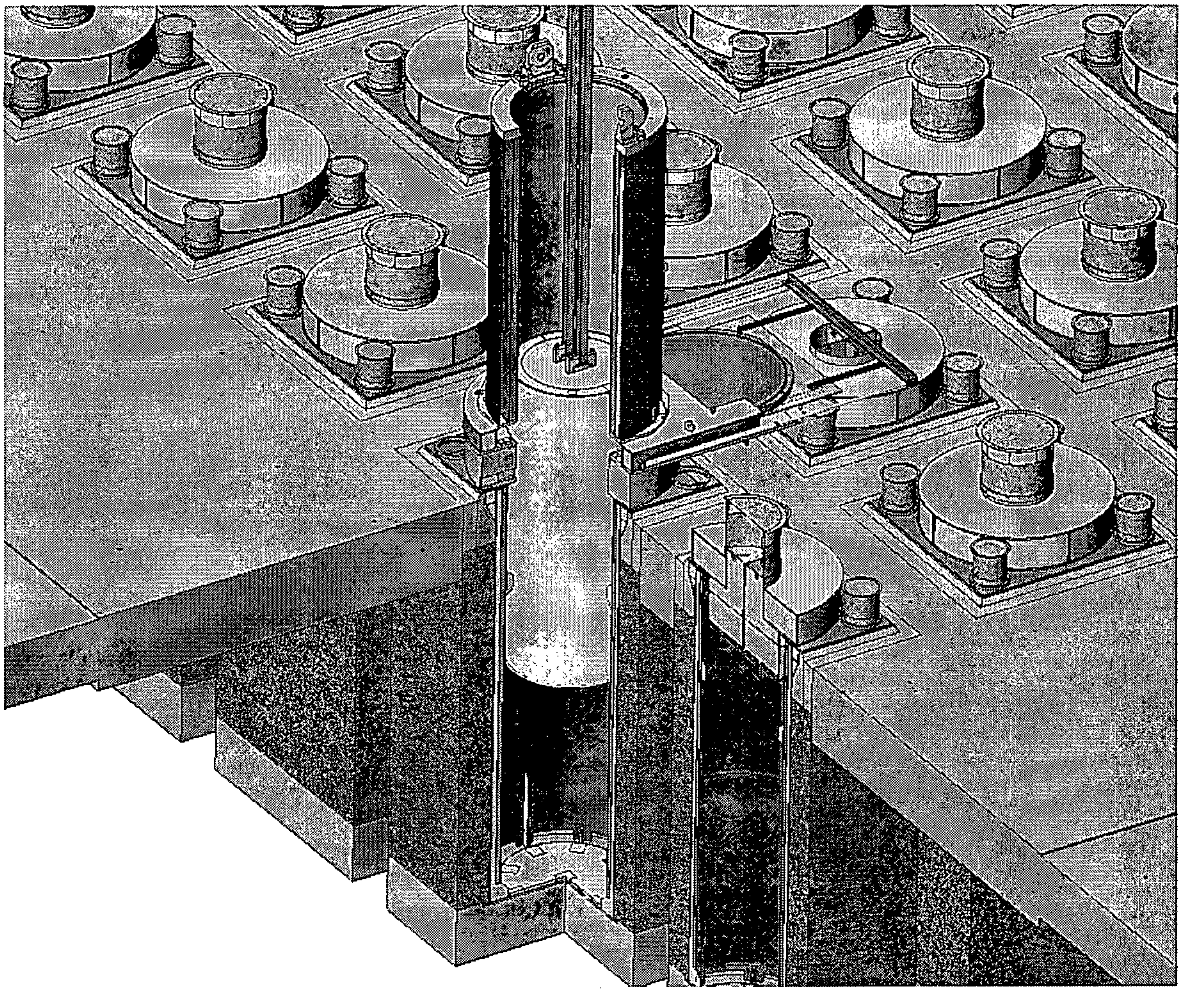


FIGURE 9.2.2: DOWNLOADING MPC INTO HI-STORM UMAX VVM

Note: The design features of the HI-STORM UMAX System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM UMAX depicted here and other figures in this FSAR may vary slightly from the licensing drawings in Section 1.5.

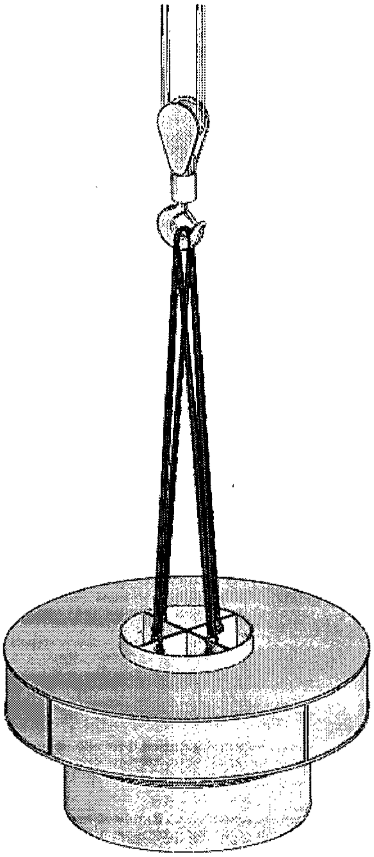
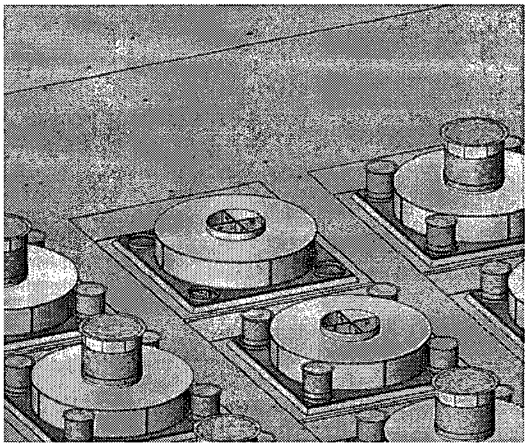


FIGURE 9.2.3: ILLUSTRATIVE RIGGING CONFIGURATION FOR THE HI-STORM UMAX VVM LID

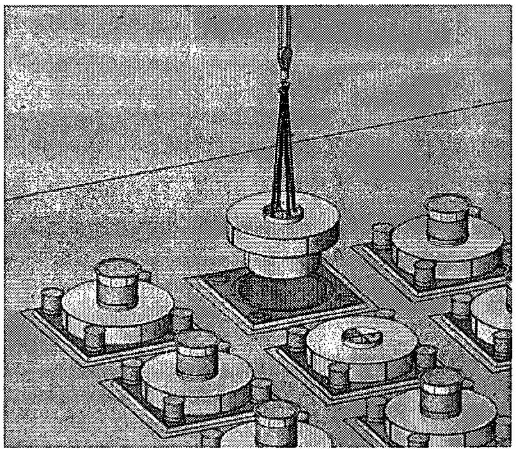
Note: The design features of the HI-STORM UMAX System are the exclusive intellectual property of Holtec International under U.S. and international patent right laws. Minor details of the HI-STORM UMAX depicted here and other figures in this FSAR may vary slightly from the licensing drawings in Section 1.5.

A.



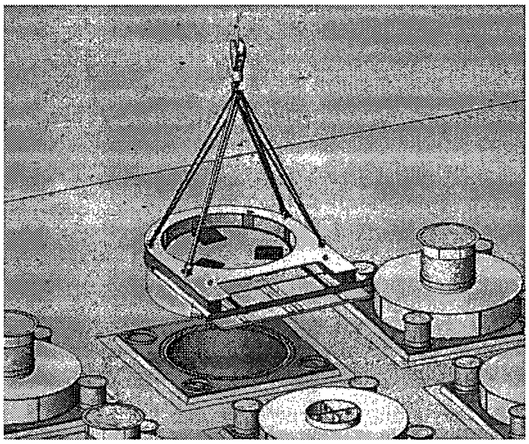
Remove the flue extensions to access the lid lifting features.

B.



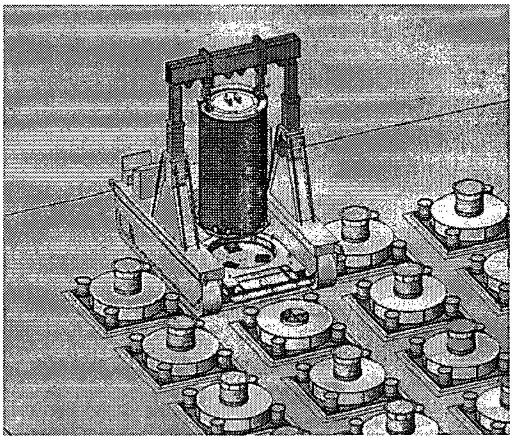
Remove the UMAX lid from the VVM to be loaded.

C.



Install the mating device on the VVM to be loaded.

D.



Align the HI-TRAC to the mating device using the vertical cask transporter.

FIGURE 9.2.4: PICTORIAL OVERVIEW OF THE LOADING STEPS (SHEET 1 OF 3)

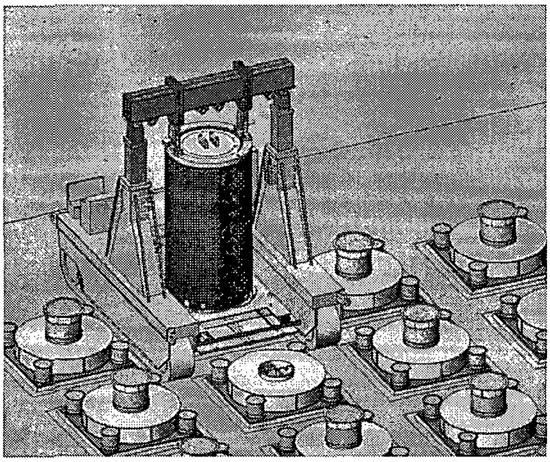
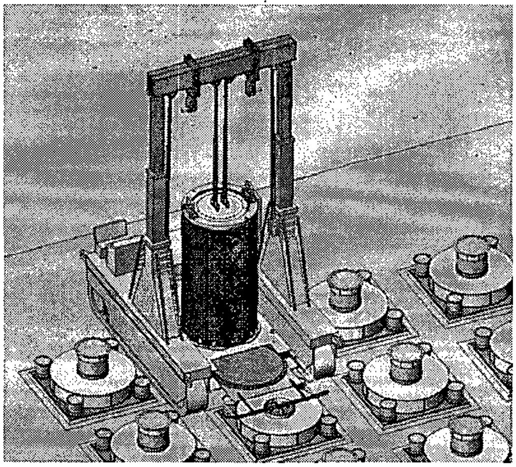
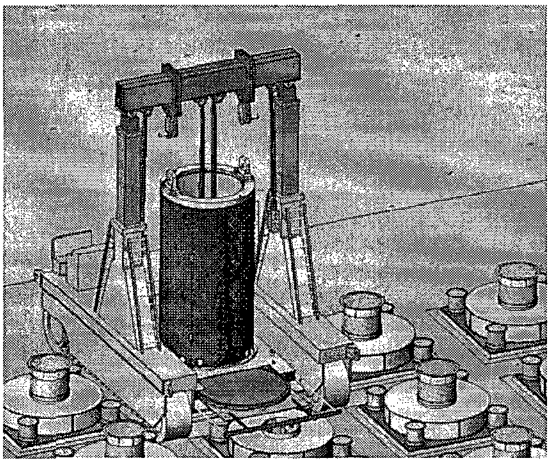
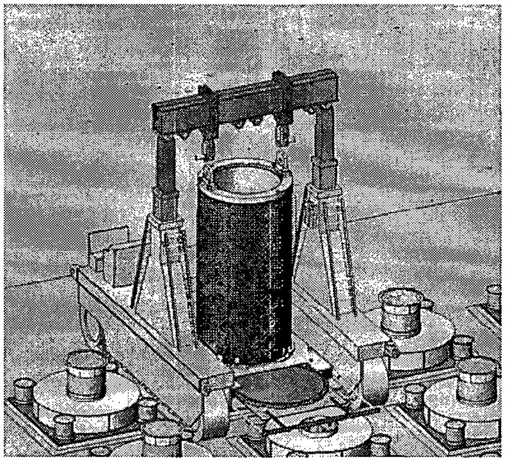
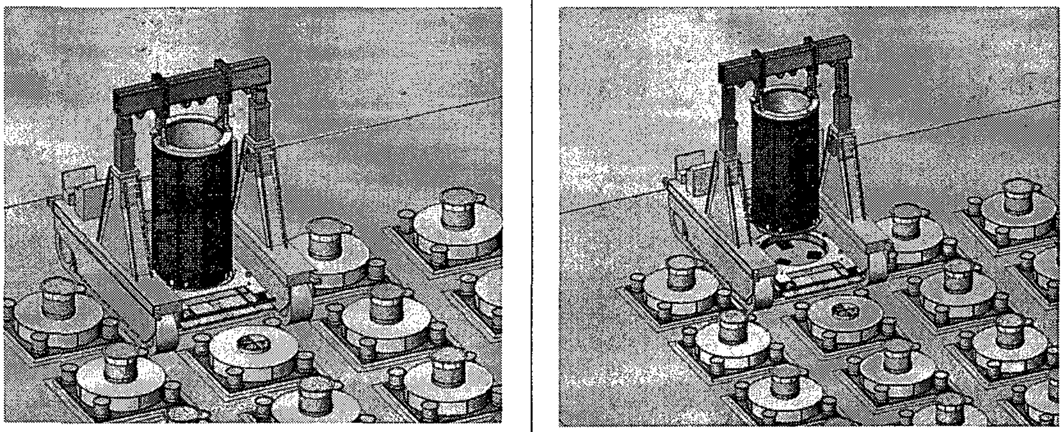
E.  **Mate the HI-TRAC to the VVM.**	**F.**  **Attach the MPC rigging to the vertical cask transporter.** **Raise the MPC slightly.** **Remove the HI-TRAC bottom lid bolts.** **Open the mating device.**
G.  **Lower the MPC into the VVM.**	**H.**  **Disconnect the rigging from the vertical cask transporter and lower it onto the MPC lid.**

FIGURE 9.2.4: PICTORIAL OVERVIEW OF THE LOADING STEPS (SHEET 2 OF 3)

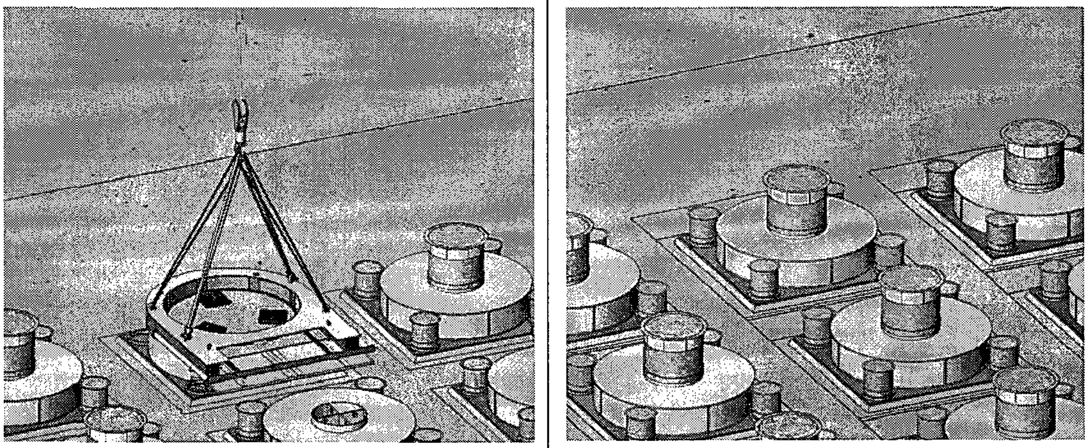
I. **J.**



I. Reconnect the HI-TRAC to the vertical cask transporter.
Close the mating device.
Reinstall the HI-TRAC bottom lid.

J. Remove the vertical cask transporter from the mating device.
Remove the MPC lid rigging from the MPC lid.

K. **L.**



K. Remove the mating device from the VVM.

L. Reinstall the VVM lid flue extensions.

FIGURE 9.2.4: PICTORIAL OVERVIEW OF THE LOADING STEPS (SHEET 3 OF 3)

9.3 ACTIVITIES PERTAINING TO ISFSI OPERATIONS

The HI-STORM UMAX System heat removal is by totally passive means. As discussed in Chapter 10, surveillance of the HI-STORM VVM assembly to ensure its continued effectiveness involves the following principal activities:

1. Check for intrusion of foreign objects that may impair the system's thermal performance during normal operations and in the wake of an extreme environmental phenomenon including severe flood.
2. Check for corrosion damage to the steel parts, namely the CECs (oldest or most vulnerable VVM shall be inspected).
3. Check for structural damage to the ISFSI after an earthquake.
4. Perform the heat removal operability surveillance as specified the CoC.
5. Perform ISFSI Security Operations in accordance with the host site's security plan.

Routine maintenance on the HI-STORM UMAX System will typically be limited to cleaning and touch-up painting of the exposed steel surfaces, repair, and replacement of damaged vent screens, and removal of vent blockages (e.g., leaves, debris), if any (See Table 10.4.1 and 10.4.2 for specific requirements). The heat removal system operability surveillance should be performed after any event that may have an impact on the safe functioning of the HI-STORM UMAX system. These include, but are not limited to, wind storms, heavy snow storms, fire inside the ISFSI, seismic activity, flooding of the ISFSI, and/or observed animal, bird, or insect infestations. The responses to these conditions involve first assessing the dose impact to perform the corrective action (inspect the HI-STORM VVM cavity, clear the debris, check for any structural damage of the ISFSI pad, and/or replace damaged vent screens); perform the corrective action; and verify that the system is operable (check ventilation flow paths and radiation blockage capability). In the unlikely event of significant damage to the ISFSI, possibly from a Beyond-the-Design Basis earthquake, the situation may warrant removal of the MPC, and repair or replacement of the damaged ISFSI areas. Section 9.4 may be used as guidance for unloading the MPC from the HI-STORM UMAX.

9.4 PROCEDURE FOR REMOVING THE MPC FROM THE HI-STORM UMAX VVM CAVITY

9.4.1 Overview of HI-STORM UMAX System Unloading Operations

The MPC is recovered from the HI-STORM UMAX VVM at the ISFSI using the same set of steps as described in Section 9.2, except that the order is basically reversed. The VVM temperature monitoring elements (if used) and lid are removed. The flue extensions are removed as necessary to allow the VCT to access the target cavity. The Mating Device is installed and the Mating Device drawer is partially opened. The MPC lift rigging is attached to the MPC. The MPC rigging is attached to the MPC lift device and positioned on the MPC lid. The Mating Device drawer is closed and the HI-TRAC is positioned on top of the Mating Device and VVM. The HI-TRAC's Bottom lid is unbolted from the HI-TRAC and the Mating Device drawer is opened. The MPC slings are brought through the HI-TRAC and connected to the lift device. The MPC is raised into HI-TRAC and the Mating Device drawer is closed. The bottom lid is bolted to the HI-TRAC. The HI-TRAC is removed from on top of the VVM and transported out of the ISFSI area for further processing. The scope of this FSAR ends with the loaded HI-TRAC suspended from the VCT for further processing. Chapter 9 of the HI-STORM FW System FSAR [9.6.1] for the host MPC provides the direction on further action such as return to the fuel pool or loading in a transport cask for off-site shipment.

9.4.2 MPC Recovery from the HI-STORM UMAX VVM

PRINCIPAL OPERATING STEPS

1. If necessary, perform a transport route walkdown to ensure that the cask transport conditions are met for transporting the loaded HI-TRAC transfer cask. Remove all physical obstructions (e.g., flue extensions) that may interfere with the movement of the VCT.

2. Perform a HI-TRAC receipt inspection and cleanliness inspection in accordance with a written inspection checklist in accordance with the HI-STORM FW System FSAR [9.6.1]. Transport the HI-TRAC to the ISFSI using the cask transporter or other suitable device.

3. Remove the VVM temperature monitoring equipment (if used) from the (MPC donor) VVM cavity.

4. Remove the VVM Closure lid from the donor VVM cavity, preferably keeping its height above the top of the CEC Flange to under 2 feet. See Figure 9.2.3 for a rigging illustration.

Caution:

Operations steps that occur with the MPC in the VVM with the Mating Device installed and the drawer closed must be performed in an expeditious manner to avoid excessive heating of the MPC and fuel. The Mating Device must be removed or the drawer opened to establish air cooling within the time limits described in Section 4.5. In the event of equipment malfunction that results in the blockage of air flow, corrective actions must occur within the time limits of the 100% blocked duct accident condition.

5. Install the Mating Device on the VVM.
6. Partially open the Mating Device drawer.
7. Remove the MPC lift cleat hole plugs and install the MPC rigging on the MPC lid..
8. Close the Mating Device drawer.
9. If previously drained, fill the neutron shield jacket with plant demineralized water or an approved antifreeze solution as necessary. Ensure that the fill and drain plugs are installed.
10. Align HI-TRAC over the Mating Device and VVM and mate the casks.
11. Unbolt the bottom lid from the HI-TRAC and lower into the Mating Device.
12. Open the Mating Device drawer.
13. At the user's discretion, install temporary shielding to cover the gap above and below the Mating Device drawer.
14. Raise the MPC rigging up through the HI-TRAC and attach them to the lifting device.
15. Raise the MPC into HI-TRAC.
16. Verify the MPC is in the full-up position.
17. Close the Mating Device drawer.
18. Reinstall the bottom lid to the HI-TRAC.
19. Lower the MPC onto the bottom lid.
20. Disconnect the slings from the lifting device and the MPC lift cleats.
21. Remove HI-TRAC from the top of the VVM.

22. Transport the HI-TRAC to the designated location using the cask transporter or other suitable device.

23. Remove the Mating Device from the VVM.

24. Install the VVM lid and vent flue assemblies on all storage cavities, where they were removed, to prevent entry of foreign objects into the VVM.

9.5 REGULATORY COMPLIANCE:

The operational steps required to place a loaded MPC into a HI-STORM UMAX VVM cavity have been described in this chapter. The steps to remove an MPC from a loaded VVM, which are essentially reverse of the steps in the loading sequence, have been provided in Chapter 9 of the HI-STORM FW System FSAR [9.6.1]. These loading steps are, of necessity, generic in their description and may require adaptation to a specific ISFSI. The implementation steps are nevertheless sufficiently detailed to lead to the conclusion that the guidelines of safety and ALARA set down in NUREG-1536 are fully satisfied. In particular, it can be concluded that:

i. There are no radiation streaming paths from the MPC during its transfer operation.
ii. The Mating Device handling operations occur near grade level thus eliminating the need for ladders/platforms and improving the human factors aspects.
iii. There are no freestanding structures in the MPC transfer operations and thus there is no risk of uncontrolled load movement under a (hypothetical) extreme environmental event such as tornado or high winds.
iv. The ventilation paths to passively cool the canister using ambient air during the transfer operation is maintained at all times (except during brief operations as mentioned above) thus protecting the fuel cladding from overheating and eliminating any thermally guided time limit on the duration for implementing the transfer steps.
v. All heavy load handling is carried out by handling devices that are equipped with redundant load drop protection features.
vi. Each storage cavity is independently accessible. Installation or removal of any MPC does not have to contend with other stored MPCs.
vii. Because the MPC insertion (and withdrawal) occurs in the vertical configuration with ample lateral clearances, there is no risk of scratching or gouging of the MPC's external surface (Confinement Boundary). Thus the ASME Section III Class 1 prohibition against damage to the pressure retaining boundary is maintained.

It is thus concluded that the HI-STORM UMAX ISFSI is engineered to meet the safety and ALARA imperatives contemplated in 10CFR 72 in full measures.

9.6 REFERENCES:

[9.6.1] "Final Safety Analysis Report on the HI-STORM FW System", Holtec Report No. HI-2114830, latest revision.

CHAPTER 10: ACCEPTANCE CRITERIA AND MAINTENANCE PROGRAM

10.0 INTRODUCTION

This chapter addresses the fabrication, inspection, test, and maintenance programs for the HI-STORM UMAX VVM assemblies. In particular, this chapter identifies the fabrication, inspection, test, and maintenance programs to be conducted on the HI-STORM UMAX VVM to verify that the structures, systems, and components (SSCs) classified as important-to-safety have been fabricated, assembled, inspected, tested, accepted, and maintained in accordance with the requirements set forth in this FSAR, the applicable regulatory requirements, and the Certificate of Compliance (CoC). The acceptance criteria and maintenance program requirements specified in this chapter apply to each HI-STORM UMAX system fabricated, assembled, inspected, tested, and accepted for use under the purview of the system's CoC. The assessment of the fabrication, inspection, test, and maintenance programs for the MPC and HI-TRAC used with the HI-STORM UMAX is described in Chapter 10 of the HI-STORM FW FSAR, a QA validated copy of which is placed in this docket for reference. The material in the HI-STORM FW FSAR which is relied upon to articulate the acceptance criteria and maintenance program of components that the "UMAX" system shares with "FW" is provided in a matrix form in Table 10.0.1 for ease of reference.

The controls, inspections, and tests set forth in this chapter, in conjunction with the design requirements described in previous chapters, ensure that the HI-STORM UMAX system will reject the decay heat of the stored radioactive materials in the MPCs to the environment by passive means and maintain radiation doses within regulatory limits. The controls, inspections, and tests set forth in Chapter 10 of the HI-STORM FW along with the MPC and HI-TRAC design requirements described in the HI-STORM FW, ensure that the system will maintain confinement of radioactive material and will maintain subcriticality control under normal, off-normal, and hypothetical accident conditions, including short term operations. The aforementioned design, controls, inspections, and tests described in the HI-STORM FW also ensure that the MPC and HI-TRAC will reject the decay heat of the stored radioactive materials to the environment by passive means and maintain radiation doses within regulatory limits.

Both pre-operational and operational tests and inspections are performed throughout HI-STORM UMAX system operations to assure that the system is functioning within its design parameters. These include receipt inspections, nondestructive weld examinations, thermal performance tests, and others. "Pre-operation", as referred to in this chapter, defines that period of time from acceptance inspection of a HI-STORM UMAX system until the loaded MPC is placed in the CEC cavity.

The HI-STORM UMAX system is classified as important-to-safety. Therefore, the individual structures, systems, and components (SSCs) that make up the HI-STORM UMAX system shall be designed, fabricated, assembled, inspected, tested, accepted, and maintained in accordance with a quality program commensurate with the particular SSC's graded quality category. The licensing drawings identify all important-to-safety subcomponents of the HI-STORM UMAX system.

The acceptance test requirements on the manufactured welds in the HI-STORM UMAX system are contained in the component licensing drawings in Section 1.5. Additional details on the requirements in the drawings are provided in this chapter or in Chapter 10 of the HI-STORM FW FSAR for MPC and HI-TRAC, which will be incorporated in the shop manufacturing documents (viz., weld procedures, shop travelers, inspection procedures, and fabrication procedures) to ensure full compliance with this FSAR.

The VVM consists of a shop-fabricated CEC (Cavity Enclosure Container) installed below grade and a removable Closure Lid. The CEC is a welded shell-type structure made of low carbon steel plate and bar (or forging) stock. Likewise, the Closure Lid is made of welded and formed steel plates and bar (or forging) stock. However, unlike the CEC, the Closure Lid also contains shielding concrete.

By virtue of its underground configuration, the CEC is interfaced by the subgrade along its lateral surface, by the ISFSI pad near its flanged upper region and by the Support Foundation Pad (SFP) along its bottom surface. The requirements on these interfacing bodies, to the extent they are needed to enable the CEC to render its intended function, are provided in Chapter 2. All requirements pertaining to the manufacturing, inspection, testing, and maintenance of the VVM SSCs are presented in this chapter to comply with the provisions of 10CFR72.24(p).

The user of the HI-STORM UMAX system should consult this chapter and the Technical Specification to ensure that the site's acceptance criteria and maintenance program are consistent with the representations made herein. The user's maintenance program should also utilize the information that will be gathered and disseminated by Holtec International through the Company's "lessons learned" data base and other means that are intended to help ensure maximum shielding effectiveness and a long service life of the ISFSI .

TABLE 10.0.1: APPLICABLE SECTIONS OF HI-STORM FW FSAR[1]

Location of UMAX FSAR	**Subject of the Reference**	**Location in Chapter 10 of the HI-STORM FW FSAR, Revision 1**
Section 10.0	Fabrication, inspection, test, and maintenance programs for the MPC and HI-TRAC	Table 10.2.1 for maintenance for HI-TRAC Sub-Sections 10.2.1, 10.2.4, and 10.2.5
Section 10.1	Inspection and acceptance tests for MPCs and HI-TRAC	Section 10.1
Section 10.1	The testing and inspection acceptance criteria applicable to the MPC, including the MPC Lid-to-Shell weld, and the HI-TRAC	Table 10.1.1 and 10.1.3
Subsection 10.1.1	Fabrication controls and required inspections	Sub-Section 10.1.1
Subsection 10.1.1	Weld examination requirements for the MPCs and HI-TRAC	Sub-Section 10.1.1;.4 Tables 10.1.4 and 10.1.5
Sub-Section 10.1.2	Structural and pressure test requirements for the MPC and HI-TRAC	Sub-Section 10.1.2
Sub-Section 10.1.3	Material testing requirements for the MPC and HI-TRAC	Sub-Section 10.1.3 Tables 10.1.6,10.1.7 and 10.1.8
Sub-Section 10.1.4	Leakage testing of MPC	Sub-Section 10.1.4
Subsection 10.1.5	Requirements for component tests of valves, pressure relief device and fluid transport devices associated with the MPC and HI-TRAC	Sub-Section 10.1.5
Sub-Section 10.1.6	The shielding integrity testing requirements for the MPC and HI-TRAC	Sub-Section 10.1.6
Sub-Section 10.1.7	The thermal test requirement for the first manufactured MPC, either MPC-37 or MPC-89	Sub-Section 10.1.7

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[1] For convenience of reference, the specific revision of the HI-STORM FW FSAR that is referenced in the safety analysis herein is placed in this docket. Updated versions of the HI-STORM FW FSAR shall be placed in this docket as necessary so as to ensure that the safety analyses on the "UMAX" docket (72-1040) remain aligned with the material referenced in the HI-STORM FW FSAR.

10.1 ACCEPTANCE CRITERIA

This section provides the workmanship inspections and acceptance tests to be performed on the HI-STORM UMAX ISFSI and VVM prior to and during loading of the system. Information on the workmanship inspections and acceptance tests to be performed on the MPC and HI-TRAC components are provided in Section 10.1 of the HI-STORM FW FSAR. These inspections and tests provide the assurance that all components of the HI-STORM UMAX system are fabricated, assembled, inspected, tested, and accepted for use under the conditions specified in this FSAR and the Certificate of Compliance issued by the NRC in accordance with the provisions of 10CFR72.

The testing and inspection acceptance criteria applicable to HI-STORM UMAX VVM are listed in Table 10.1.1 and discussed in more detail in the sections that follow. The testing and inspection acceptance criteria applicable to the MPC, including the MPC Lid-to-Shell weld, and the HI-TRAC are listed in Table 10.1.1 and 10.1.3 of the HI-STORM FW FSAR and are discussed in more detail in the HI-STORM FW FSAR. Chapter 9 from both this FSAR and the HI-STORM FW FSAR provide operating guidance. Chapter 13 of this FSAR provides the bases for the Technical Specifications. These inspections and tests are intended to demonstrate that the HI-STORM UMAX system has been fabricated, assembled, and examined in accordance with the design criteria contained in Chapter 2 of the HI-STORM UMAX FSAR. Identification and resolution of manufacturing non-compliances, if any, shall be performed in accordance with the Holtec International Quality Assurance Program approved by the USNRC (Docket Number 71-0784).

The material on testing and maintenance of system components in this FSAR governs the content of the daughter documents such as the Manufacturing Manual and the O&M Manual for the system components used in the manufacturing and long-term maintenance of the system components.

10.1.1 Fabrication and Nondestructive Examination (NDE)

This subsection summarizes the test program required for the HI-STORM UMAX system.

10.1.1.1 Fabrication Requirements

The manufacturing of UMAX VVM components shall be carried out in accordance with the CoC holder's NRC-approved QA program. All elements of the manufacturing cycle will be established to accord with the Important-to-Safety (ITS) designation of the specific part (indicated in the Licensing drawings) and the applicable provisions of the referenced codes and standards. The acceptance criteria for the manufactured components apply to each step of the manufacturing evolution, namely (a) supplier selection, (b) preparation of material procurement specifications, (c) preparation of the shop traveler and fabrication procedures, (d) fabrication activities such as forming, bending, plasma cutting, and welding, (e) in-process inspections, (f) final inspection, (g) packaging for shipment, and (h) assembling of the documentation package to serve as the archival evidence of adherence to the quality requirements.

In order to receive the Certificate-of-Compliance under the CoC holder's QA program, the manufacturing of the HI-STORM UMAX VVM components must meet all of the technical, quality control, procedural (quality assurance) and administrative requirements set forth in the manufacturing program.

Similarly, the low carbon steel plates, bars, and forgings, as applicable, used in the construction of the HI-STORM UMAX VVM shall be dimensionally inspected to assure compliance with the requirements on the drawings. Test results shall be documented and become part of the quality documentation package. Dimensional inspections of the Closure Lid and its weight measurement after placement of the shielding concrete shall assure that the required amount of shielding material has been incorporated in the lid.

The fabrication controls and required inspections detailed in Section 10.1 of the HI-STORM FW FSAR shall be performed on the MPCs and HI-TRAC transfer casks, in order to assure compliance with the HI-STORM FW FSAR, the HI-STORM UMAX FSAR and the Certificate of Compliance. Specifically, the following fabrication controls and required inspections shall be performed on the HI-STORM UMAX system in order to assure compliance with this FSAR and the Certificate of Compliance.

i. Materials of construction specified for the HI-STORM UMAX system are identified in the drawings in Chapter 1. Materials for ITS Components shall be procured with certification and supporting documentation as required by the ASME Code, Section II, where applicable [10.1.1], Holtec procurement specifications, and 10CFR72, Subpart G. ITS materials and components shall be receipt inspected for visual and dimensional acceptability, material conformance to specification requirements, and traceability markings, as applicable. Controls shall be in place to ensure that material traceability is maintained throughout fabrication.

ii. Structural welds shall be performed using welders and weld procedures that have been qualified in accordance with ASME Code Section IX and ASME Section III, Subsection NF. Non-structural welds shall be performed using welders and weld procedures that have been qualified in accordance with ASME Code Section IX or AWS D1.1.

iii. Structural welds shall be visually examined in accordance with ASME Code, Section V, Article 9. NDE inspections of structural welds shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A [10.1.2] or other site-specific, NRC-approved program for personnel qualification. Non-structural welds shall be visually examined by qualified welders or weld inspectors for cracks and other linear indications which must be repaired when identified.

iv. Single pass welds identified on the HI-STORM UMAX VVM drawing shall be made using a prequalified weld procedure. In addition to the normal procedure qualifications required by ASME Section IX or AWS D1.1, the weld procedure shall define limits on essential variables such that the weld produced will be guaranteed to have a minimum fillet size of 1/8". Upon qualification of the weld procedure, the single pass welds identified on the licensing drawing can be fabricated and verification of use of proper essential variables for welding can be substituted for examination for proper weld size. Single pass welds shall be visually examined by qualified welders or weld inspectors for cracks and other linear indications which must be repaired when identified.

v. The HI-STORM UMAX system shall be inspected for cleanliness and proper packaging for shipping in accordance with written and approved procedures.

vi. Each VVM shall be durably marked with the appropriate model number, a unique identification number, and its empty weight per 10CFR72.236(k) at the completion of the acceptance test program.

vii. A documentation package shall be prepared and maintained during fabrication of each HI-STORM UMAX system to include detailed records and evidence that the required inspections and tests have been performed. The completed documentation package shall be reviewed to verify that the HI-STORM UMAX system components have been properly fabricated and inspected in accordance with the design and Code construction requirements. The documentation package shall include, as applicable, but not be limited to:

- Completed Shop Weld Records
- Inspection Records
- Nonconformance Reports
- Material Test Reports
- NDE Reports
- Dimensional Inspection Report

10.1.1.2 Visual Inspections and Measurements

The HI-STORM UMAX system components shall be assembled in accordance with the licensing drawing package in Section 1.5. The drawings provide dimensional tolerances that define the limits on the dimensions used in licensing basis analysis. Fabrication drawings provide additional dimensional tolerances necessary to ensure fit-up of parts. Visual inspections and measurements shall be made and controls shall be exercised to ensure that the cask components conform to the dimensions and tolerances specified on the licensing and fabrication drawings. These dimensions are subject to independent confirmation and documentation in accordance with the Holtec QA program approved in NRC Docket Number 71-0784.

The HI-STORM UMAX VVM, except for its Closure Lid, does not require unique marking other than that required for fuel ISFSI configuration management because it is not a transportable structure. The module is essentially an integral portion of the ISFSI, not a separate cask structure that can be moved by the user. As such, the markings provided on the MPC alone are sufficient to meet the requirements of 10CFR72.236(k). Nevertheless, it is required that each VVM cavity be labeled with an identifier that is unique for the specific site. Further, because the Closure Lid will be subject to handling, consistent with defense-in-depth guidelines for handling heavy loads at nuclear plants, its unique identifier and its bounding weight shall be permanently marked on a readily visible location.

The following shall be verified as part of visual inspections and measurements:

- Visual inspections and measurements shall be made to ensure that the systems' effectiveness is not significantly reduced as a result of manufacturing deviations. Any *important-to-safety* component found to be under the specified minimum thickness shall be justified under the rules of 10CFR72.48 or repaired or replaced, as appropriate.

- The HI-STORM UMAX CEC and Closure Lid shall be inspected to confirm that the labeling is complete and legible.

- The system components shall be inspected for cleanliness and prepared for shipment in accordance with written and approved procedures.

- Visual inspections shall be made to verify that neutron absorber panels, basket shims and anti-rotation bars are present as required by the MPC basket design.

The visual inspection and measurement results for the HI-STORM UMAX system shall become part of the final quality documentation package.

10.1.1.3 Weld Examination

The examination of the HI-STORM UMAX system welds shall be performed in accordance with the drawing package in Section 1.5 and the applicable codes and standards.

Weld examination requirements for the MPC and HI-TRAC are described in Section 10.1 of the HI-STORM FW FSAR. All structural weld inspections shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A. Structural welds for the VVM shall meet the acceptance criteria of ASME Section III, Subsection NF. All required inspections, examinations, and tests shall become part of the final quality documentation package. Non-structural weld inspections shall be performed by welders or weld inspectors qualified in accordance with written procedures. Non-structural welds shall be free of cracks and other linear indications.

10.1.2 Structural and Pressure Tests

The structural and pressure test requirements for the MPC and HI-TRAC are described in Section 10.1 of the HI-STORM FW FSAR. The following subparagraphs provide the structural and pressure test requirements for the HI-STORM UMAX VVM.

10.1.2.1 Lifting Locations

Because the HI-STORM UMAX system is immovable, it does not utilize any lifting appurtenances.

The only removable component in the HI-STORM UMAX system is the Closure Lid which features four lift lugs (see drawing in Section 1.5). Because the lugs are integral to the component, they possess high ductility and, as shown in Chapter 3, meet the factor of safety of 6 to yield and 10 to ultimate, as required by ANSI N14.6 [10.1.3]. The requirements for testing and inspection of the load handling equipment related to the HI-TRAC and MPC are covered in the governing license document for the respective component and are not repeated here.

Section 5 of NUREG-0612 [10.1.4] calls for measures to "provide an adequate defense-in-depth for handling of heavy loads...". The NUREG-0612 guidelines cite four major causes of load handling accidents, of which rigging failure is one:

i. operator errors
ii. rigging failure
iii. lack of adequate inspection
iv. inadequate procedures

The cask loading and handling operations program shall ensure maximum emphasis to mitigate the potential load drop accidents by implementing measures to eliminate shortcomings in all aspects of the operation including the four aforementioned areas.

Each lifting lug will be subjected to a dimensional test in the shop to ensure that it meet the dimensional requirements. The lift lugs will be load tested per ANSI 14.6 -1993 prior to the shipping of the Closure Lid to the ISFSI site.

10.1.3 Materials Testing

The materials testing requirements for the MPC and HI-TRAC are described in Section 10.1 of the HI-STORM FW FSAR. The following paragraphs provide the materials testing requirements for the HI-STORM UMAX VVM.

The steel materials used in the HI-STORM VVM will be tested in accordance with the requirements of the applicable material code.

The concrete utilized in the construction of the HI-STORM UMAX ISFSI shall be mixed, poured, and tested in accordance with the applicable code using written and approved procedures. Testing shall verify the material properties meet design requirements. Tests required shall be performed at a frequency as defined in the applicable ACI code.

10.1.4 Leakage Testing

The leakage testing requirements for the MPC are described in Section 10.1 of the HI-STORM FW FSAR. There is no leakage testing required for the HI-STORM UMAX VVM.

10.1.5 Component Tests

10.1.5.1 Valves, Pressure Relief Devices, and Fluid Transport Devices

There are no valves, pressure relief device and fluid transport devices associated with the HI-STORM UMAX VVM. The requirements for component tests of valves, pressure relief device and fluid transport devices associated with the MPC and HI-TRAC are described in Section 10.1 of the HI-STORM FW FSAR.

10.1.5.2 Seals and Gaskets

There are no confinement seals or gaskets included in the HI-STORM UMAX system.

10.1.6 Shielding Integrity

The shielding integrity testing requirements for the MPC and HI-TRAC are described in Section 10.1 of the HI-STORM FW FSAR. There is no criticality control testing required for the HI-STORM UMAX VVM. The shielding integrity testing for the HI-STORM UMAX VVM is limited to dimensional checks of the steel components and concrete forming and to confirmation of the correct density for the concrete used in the Closure Lid and ISFSI pad.

10.1.7 Thermal Acceptance Tests

The thermal performance of the HI-STORM UMAX system, including the MPCs and HI-TRAC transfer cask, is demonstrated through analysis in Chapter 4 of this FSAR and the HI-STORM FW FSAR. Dimensional inspections to verify the item has been fabricated to the dimensions provided in the drawings shall be performed prior to system loading.

The thermal test requirement for the first manufactured MPC, either MPC-37 or MPC-89 is described in Section 10.1 of the HI-STORM FW FSAR.

Table 10.1.1

HI-STORM UMAX VVM ASSEMBLY INSPECTION AND TEST ACCEPTANCE CRITERIA

Function	Fabrication	Pre-operation	Maintenance and Operations
Visual Inspection and Nondestructive Examination (NDE)	Structural Steel Components: a) All structural welds shall be visually examined per ASME Section V, Article 9 with acceptance criteria per ASME Section III, Subsection NF, NF-5360. b) All structural welds requiring MT examination as shown on the drawings shall be MT examined per ASME Section V, Article 7 with acceptance criteria per ASME Section III, Subsection NF, NF-5340. c) NDE of weldments shall be defined on design drawings using ANSI NDE symbols and/or notations.	a) The VVM shall be visually inspected for general condition of coatings and insulation and for presence of FME prior to placement in service. b) Fit-up with mating components (e.g., lid) shall be performed directly whenever practical or using templates or other means. c) VVM Assembly protection at the licensee's facility shall be verified. d) Exclusion of foreign material shall be verified prior to placing the VVM Assembly in service at the licensee's facility.	a) Indications identified during visual inspection shall be corrected, reconciled, or otherwise dispositioned. b) Exposed surfaces shall be monitored for coating deterioration and repair/recoat as necessary.

Table 10.1.1 (continued)

HI-STORM UMAX VVM ASSEMBLY INSPECTION AND TEST ACCEPTANCE CRITERIA

Function	**Fabrication**	**Pre-operation**	**Maintenance and Operations**
Visual Inspection and Nondestructive Examination (NDE) (continued)	General: a) Cleanliness of the VVM Assembly shall be verified upon completion of fabrication. b) Packaging of the VVM Assembly at the completion of shop fabrication shall be verified prior to shipment. c) Labeling of the CEC and the Closure Lid	General: a) Labeling of the CEC and the Closure Lid	
Structural	a) Verification of structural materials shall be performed through receipt inspection and review of certified material test reports (CMTRs) obtained in accordance with the item's quality category. b) Load testing of Closure Lid lift points	a) No structural or pressure tests are required for the VVM during pre-operation.	a) No structural or pressure tests are required for the VVM during operation.
Leak Tests	a) None.	a) None.	a) None.
Shielding Integrity	a) Concrete density shall be verified per Appendix 1.D of [10.1.4], at time of placement. b) Shell thicknesses and dimensions between inner and outer shells shall be verified as conforming to design drawings prior to concrete placement in the Closure Lid.	a) None	a) None.

Table 10.1.1 (continued)

HI-STORM UMAX VVM ASSEMBLY INSPECTION AND TEST ACCEPTANCE CRITERIA

Function	Fabrication	Pre-operation	Maintenance and Operations
Thermal Acceptance	a) Inner shell I.D. and vent size, configuration and placement shall be verified.	a) Visual examination of the insulation and coatings will be performed to verify that they are in good condition b) Air flow paths will be visually inspected to ensure they are clear and free of FME.	a) MPC lid temperature test shall be performed as discussed in Section 10.3 b) Periodic surveillance shall be performed by either (1) or (2) below, at the licensee's option. (1) Inspection of VVM inlet and outlet air vent openings for debris and other obstructions. (2) Temperature monitoring.
Cask Identification	a) Verification that the VVM identification is present in accordance with the drawings shall be performed upon completion of assembly.	a) The VVM identification shall be checked prior to loading.	a) The VVM identification shall be periodically inspected per licensee procedures and repaired or replaced if damaged.
Fit-up Tests	a) Lid fit-up with the VVM shall be verified following fabrication.	a) Lid fit-up with the VVM shall be verified following placement of concrete around the VVM.	a) None.

10.2 SITE CONSTRUCTION

Like the aboveground HI-STORM overpacks, the site construction activities on the HI-STORM UMAX VVM components and ISFSI structures (namely, the Support Foundation Pad, the ISFSI Pad Subgrade, the ISFSI Pad, and the Enclosure Wall) shall be carried out to demonstrate compliance with the technical criteria set forth in this FSAR. The specific requirements, to ensure that the required *critical characteristics** of the VVM and the interfacing SSCs are realized, are summarized below.

a. All site construction processes shall be proceduralized, reviewed, and approved in accordance with the CoC holder's NRC-approved QA program.

b. All HI-STORM UMAX VVM components and structures designated as ITS shall be subject to the necessary quality assurance regimen established in accordance with the Company's QA program. The major NITS components in the ISFSI are the inlet and outlet flue extensions including the chimney cover and the concrete casement around the CEC shell, the cathodic protection system (if used) and the engineered fill.

c. Compliance with the requirements in this FSAR shall be demonstrated by appropriate testing and the results documented for archival reference. For example, the strength properties of the subgrade can be established using the classical "plate test" or an equivalent method endorsed by a national consensus standard.

d. The density and compressive strength of the ISFSI concrete and the yield strength of the re-bars used in the ISFSI structures shall be confirmed to comply with the Purchasing Specification prepared by the cask designer for the particular site.

e. The insulation installed on the Divider shell shall be subject to visual examination to ensure that it is undamaged and properly secured.

f. The coating on the exterior surface of the CEC shall be inspected for absence of gross damage before the surface becomes inaccessible.

g. The concrete encasement, if used, shall be installed in accordance with the provisions of Chapter 8.

h. The dimensional compliance of the CEC, including its verticality, shall be inspected to establish compliance with the governing construction documents.

i. The installation of the corrosion barriers shall be in accordance with written procedures.

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* See Glossary for definition.

j. All VVM surfaces that become inaccessible shall be photographed with sufficient resolution to provide a clear archive of their in-situ state at installation.

10.3 INSPECTIONS AND TESTING

i. Post-Construction Inspection:

Each as-built HI-STORM UMAX VVM shall be inspected for final acceptance before it is loaded with fuel. The following inspections define minimum acceptance requirements:

a. The as-installed CEC shall be inspected to ensure that it will not hinder installation of the Closure Lid.

b. The CEC Flange Shell gasket/seal bearing surfaces shall be inspected for its horizontal alignment (within specified tolerance). The seals shall be inspected for general condition (lack of cuts, tears, or degradation that could lead to poor sealing).

c. The Closure Lid skirt shall be checked for fit-up with the CEC Flange.

d. The outlet air passage in the Closure Lid shall be inspected for absence of obstruction such as debris and extensive weld spatter.

e. The results of the post-construction inspection shall be incorporated in the VVM's Documentation Package.

f. The impressed current cathodic protection system (ICCPS), if used, shall be tested for operability using Holtec provided procedures.

ii. Shielding Integrity and Effectiveness Test:

Operational neutron and gamma shielding effectiveness tests shall be performed after the first fuel loading at the host plant site using written and approved procedures. Calibrated neutron and gamma dose rate meters shall be used to measure the actual neutron and gamma dose rates at the accessible surface of the HI-STORM UMAX VVM. Measurements shall be taken at the locations specified in the Radiation Protection Program for comparison against the prescribed limits. The test is performed to identify the expected dose levels around the VVM in order to plan for appropriate radiation protection measures for future cask loadings. Dose rate measurements shall be documented and shall become part of the quality record of the loaded cask.

iii. Thermal Acceptance Test

The thermal performance of the HI-STORM UMAX system is demonstrated through analysis in Chapter 4 of this FSAR.

However, a thermal acceptance test shall be performed on the first fully loaded VVM assembly whose aggregate MPC heat load is at least 50% of the Design Basis maximum heat load per the system CoC. (Because of its in-ground installation, a thermal test at a lower heat load is apt to be too inaccurate to provide meaningful information.)

After the system has been in storage for at least one week (to reach steady state) and when the ambient is relatively quiescent and the solar heat deposition rate is minimal, the surface temperature of the top of the MPC lid shall be measured at the center and 4 orthogonally disposed peripheral locations.

The measured lid temperature data (at designated measurement points) shall be compared with the results predicted by the FLUENT analysis.

The measured temperatures (in Deg. F) must be no greater than 5% over the corresponding analytically predicted temperatures to be acceptable. Otherwise, the Design Basis heat load capacity of the VVM assembly will be downgraded by incorporating a penalty factor in the FLUENT model and the USNRC so informed. The reduced heat load values will become the *de facto* limits for all VVMs at the site until a root cause evaluation indicates extenuating circumstances unique to the site.

The heat load anomaly must be resolved by additional testing: until then, the reduced heat load limit will apply to all HI-STORM UMAX sites.

The technical specifications require periodic surveillance of the system air inlet and outlet vents or, optionally, implementation of a HI-STORM UMAX VVM air temperature monitoring program to provide continued assurance of the operability of the HI-STORM UMAX heat removal system.

iv. Storm Water Control Test

The HI-STORM UMAX VVM is designed to direct storm water and snow/ice melt-off away from the CEC Flange and the Closure Lid where the air passages are located. The engineered rain caps installed on the inlet and outlet serve to keep rain and snow away from the VVM cavity. Moreover, any minor amount of moisture that may intrude into the MPC cavity due to wind-driven rain will evaporate in a short period of time due to the continuous movement of heated air in the MPC storage cavity. To verify the effectiveness of the storm water drainage design, a one-time test shall be performed after construction of the first VVM to ensure that the design is effective in directing storm water away from the VVM to the ISFSI's drainage system. The VVM shall be subjected to a water spray that simulates exposure to rainfall of at least 2 inches per hour for at least one hour. At the conclusion of the water spray, the depth of the water (if any) in the bottom of the module cavity shall be measured. Any amount of water accumulation beyond wetting of the Bottom Plate indicates an inadequacy in rain diversion features of the VVM and shall be appropriately corrected. It should be noted that accumulation of water is not injurious to the thermal performance of the system. The only deleterious effect of prolonged exposure to water is the potential for reducing the service life of the preservative on the wetted surface of the Bottom Plate, CEC shell, and other interfacing components.

10.4 MAINTENANCE PROGRAM

An ongoing maintenance program shall be defined and incorporated into the HI-STORM UMAX system Operations and Maintenance Manual, which shall be prepared and issued prior to the first use of the system by a user. This document shall delineate the detailed inspections, testing, and parts replacement necessary to ensure continued structural, thermal performance, and radiological safety in accordance with 10CFR72 regulations, the conditions in the Certificate of Compliance, and the design requirements and criteria contained in this FSAR.

This section addresses the maintenance program for the HI-STORM UMAX VVM. The HI-STORM UMAX system does not require any changes to the maintenance requirements for the MPC described in its governing FSARs.

The HI-STORM UMAX system is totally passive by design and requires minimal preventive maintenance to ensure that it will render its intended design functions satisfactorily. Periodic surveillance (via temperature monitoring or visual or camera-aided inspection of air passages) is required to ensure that the air passage in the VVM is not blocked. Preventive or remedial painting of the exposed steel surfaces as part of the user's preventive maintenance program is recommended to mitigate corrosion. Such preventive maintenance activities are typical in scope and complexity to other standard maintenance activities at nuclear power plants.

In-service inspection for long-term interior and below-grade degradation shall be performed on a site-specific basis in accordance with Holtec specified long-term maintenance guidelines and the licensee's preventive maintenance program. At most potential ISFSI sites, visual inspection of accessible areas of the HI-STORM UMAX VVM is expected to be sufficient to detect in-service degradation. The frequency of this visual in-service inspection should be in performed in accordance with Table 10.4.1

Additional in-service inspection activities may include more thorough inspections for foreign material accumulation, corrosion (CEC wall thinning) and insulation degradation as warranted by site-specific conditions. In-service inspections for evaluating foreign material accumulation, corrosion (CEC wall thinning) and/or insulation degradation are not required if it is determined that the applicable degradation actuating mechanisms do not exist. A VVM with a loaded MPC may be inspected using remote devices such as a boroscope. The oldest VVM or VVM considered to be most vulnerable to corrosion degradation shall be selected for inspection.

As is true for all components certified pursuant to this FSAR, the maintenance activities on the HI-STORM UMAX VVM shall be performed in accordance with a written program that fulfills the requirements of the CoC holder's 10CFR72 Subpart G compliant QA program; the owner site's Safety Plan and corrective action program; and the system's Technical Specification.

Among the QA commitments are performance of maintenance by trained personnel by written procedures and written documentation of the maintenance work performed and of the results obtained. Table 10.4.2

provides a listing of the minimum maintenance activities on the HI-STORM UMAX VVM.

In summary, the HI-STORM UMAX System is totally passive by design: There are no active components or monitoring systems required to assure the performance of its safety functions. As a result, only minimal maintenance will be required over its lifetime, and this maintenance would primarily result from the effects of weather. Typical of such maintenance would be the reapplication of corrosion inhibiting materials on accessible external surfaces. Visual inspection of the vent screens is required to ensure the air flow passages are free from obstruction. Such maintenance requires methods and procedures that are far less demanding than those currently in use at power plants.

Maintenance activities shall be performed under the licensee's NRC-approved quality assurance program. Maintenance activities shall be administratively controlled and the results documented.

10.4.1 Structural and Pressure Parts

Prior to each MPC loading, a visual examination in accordance with a written procedure shall be required of the Closure Lid lift lugs and the HI-TRAC Tapped Anchor Locations (TALs), bottom lid bolts, and bolt holes. The examination shall inspect for indications of overstress such as cracks, deformation, wear marks, corrosion, etc. Repairs in accordance with written and approved procedures shall be required if an unacceptable condition is identified.
As described in Chapters 7 and 12 of this FSAR, there are no credible normal, off-normal, or accident events which can cause the structural failure of the MPC. Therefore, periodic structural or pressure tests on the MPCs following the initial acceptance tests are not required as part of the storage maintenance program.

10.4.2 Leakage Tests

There are no seals or gaskets used on the fully-welded MPC confinement system. As described in Chapters 7 and 12, there are no credible normal, off-normal, or accident events which can cause the failure of the MPC Confinement Boundary welds. Therefore, leakage tests are not required as part of the storage maintenance program.

10.4.3 Subsystem Maintenance

The HI-STORM UMAX System does not include any active subsystems that provide auxiliary cooling. If the cask user chooses to use an air temperature monitoring system in lieu of visual inspection of the air inlet and outlet vents, the thermocouples and associated temperature monitoring instrumentation shall be maintained and calibrated in accordance with the user's QA program commensurate with the equipment's safety classification and designated QA category.

10.4.4 Pressure Relief Devices

The pressure relief devices used on the water jackets for the HI-TRAC transfer cask shall be confirmed to have been calibrated as specified in the licensing basis FSAR for the HI-TRAC to ensure pressure relief settings are accurate prior to the cask's use at a HI-STORM UMAX ISFSI.

10.4.5 Shielding

The gamma and neutron shielding materials in the HI-TRAC and MPC are not subject to measurable degradation over time or as a result of usage. The radiation shielding capacity of the HI-STORM UMAX System is expected to remain undiminished over time. Therefore, unless the VVM is subjected to an extreme environmental event that imparts stresses or temperatures beyond-the-design-basis limits for the system (i.e., prolonged fire or impact from a beyond-the-design basis large energetic projectile) with the plausible potential to degrade the shielding effectiveness of the VVM, no shielding effectiveness tests beyond that required by the plant's Radiation Protection Program are required over the life of the HI-STORM UMAX System.

Radiation monitoring of the ISFSI by the licensee in accordance with 10CFR72.104(c) provides ongoing evidence and confirmation of shielding integrity and performance. If increased radiation doses are indicated by the facility monitoring program, additional surveys of the ISFSI shall be performed to determine the cause of the increased dose rates.

The water level in the HI-TRAC water jacket shall be verified during each loading campaign in accordance with the licensee's approved operations procedures.

The neutron absorber panels installed in the MPC baskets are not expected to degrade under normal long-term storage conditions. Therefore, no periodic verification testing of neutron poison material is required on the HI-STORM UMAX System.

10.4.6 Thermal

In order to assure that the HI-STORM UMAX System continues to provide effective thermal performance during storage operations, surveillance of the air vents (or alternatively, by temperature monitoring) shall be performed in accordance with written procedures.

For those licensees choosing to implement temperature monitoring as the means to verify VVM Assembly heat transfer system operability, a maintenance and calibration program shall be established in accordance with the plant-specific Quality Assurance Program, the equipment's quality category, and manufacturer's recommendations.

Table 10.4.1

HI-STORM SYSTEM MAINTENANCE PROGRAM SCHEDULE

Task	Frequency
VVM cavity visual inspection	Prior to MPC loading
Divider shell visual inspection	Prior to MPC loading
Closure Lid visual inspection	Prior to MPC loading
VVM external surface (accessible) visual examination	Annually, during storage operation
VVM inlet and outlet vent screen visual inspection for damage, holes, etc.	Monthly
VVM inlet and outlet vent inspection for blockage	Daily unless monitoring is performed using temperature monitoring equipment
HI-TRAC cavity visual inspection	Prior to each handling campaign
HI-TRAC TAL visual inspection	Prior to each handling campaign
HI-TRAC bottom lid bolts and bolt holes	Prior to each handling campaign
HI-TRAC pressure relief device calibration	Per the device manufacturer's recommendation.
HI-TRAC water jacket water level visual examination	During each handling campaign in accordance with licensee approved operations procedures
VVM visual inspection of identification markings	Annually
VVM Air Temperature Monitoring System	Per licensee's QA program and manufacturer's recommendations
VVM inlet plenum inspection for accumulation of FME.	Every five years or following a severe weather event that may introduce significant FME material.

Table 10.4.2

MAINTENANCE ACTIVITIES FOR THE HI-STORM UMAX VVM

	Activity	Frequency	Comment
1.	CEC cavity is visually inspected	Prior to MPC installation	To ensure that VVM internal components are properly aligned, the surface preservatives on all exposed surfaces are undamaged, the insulation on the Divider Shell is undamaged and the cavity is free of visible foreign material.
2.	Lid Examination	Prior to MPC installation	Ensure that the preservatives on the external surfaces are in good condition and the lid is free of dents and rust stains.
3.	Screen Inspection	Prior to installation of the flanged screen assembly and monthly when in use	Ensure that the screen is undamaged.
4.	ISFSI pad	Annually	Ensure that the ISFSI Pad (raised areas near the VVM) is free of visible cracks or repaired as appropriate, the interface between the ISFSI Pad and the CEC Flange is grouted (or caulked) if necessary, the ISFSI drain system is functional, the ground water collection and removal system (if used) is in working order. Ensure that the subgrade settlement is minimal and unsightly surface cracks in the ISFSI pad have not developed. Implement counter measures to prevent the opening of surface cracks and excessive pad settlement, if observed. The cathodic protection system shall be routinely verified as operable in accordance with the guidance set forth in this FSAR and the CoC.
5.	Shielding Effectiveness Test	As required by the Radiation Protection Program	—

Table 10.4.2 (continued)

MAINTENANCE ACTIVITIES FOR THE HI-STORM UMAX VVM

	Activity	**Frequency**	**Comment**
6.	ISFSI Settlement	Every five years	Confirm that the VVM settlement is within the range of the Plant's "best estimate". Implement countermeasures if the settlement is determined to be excessive by the CoC holder.
7.	VVM Air Temperature Monitoring System (if used)	Per Licensee's QA Program and manufacturer's recommendations	—
8.	VVM In-Service Inspection	Annually	Ensure that the vent screen assembly fasteners or weldments remain coated with preservative, the screen is undamaged, all visible external surfaces are free from significant corrosion, and the air passages are not degraded.
10.	Additional VVM In-Service Inspection for Long-Term Interior and Below-grade Degradation: a) Visual inspection of accessible areas for long-term degradation. b) Additional in-service inspection activities include inspection for foreign material accumulation, corrosion (CEC thinning) and insulation degradation	a) Monthly visual inspection of accessible areas. b) Frequencies for additional in-service inspections are determined on a site-specific basis.	Inspection activities shall be commensurate with site-specific conditions. Under site conditions existing at most ISFSI sites, visual inspection of accessible areas is sufficient to determine the general condition of the system.

10.5 CASK IDENTIFICATION

The HI-STORM UMAX VVM and Closure Lids shall be marked with a durable unique identifier to comply with the provisions of 10CFR72.236(k). Each MPC and HI-TRAC transfer cask shall be marked with a model number, identification number (to provide traceability back to documentation), and the empty weight of the item in accordance with the marking requirements specified in 10 CFR 72.236(k).

10.6 REGULATORY COMPLIANCE

The information presented in this chapter fulfills the regulatory requirements pertaining to the testing and maintenance of the HI-STORM UMAX System, resolution of issues concerning adequacy and reliability, and cask identification. This section demonstrates the corresponding compliance information on the HI-STORM UMAX VVM.

a. The program for pre-operational testing and initial operations, as required by 10CFR72.24(p) for the HI-STORM UMAX VVM, is provided in Section 10.3 herein.

b. The maintenance protocol for the HI-STORM UMAX VVM, as specified in §72.236(g), is provided in Section 10.4 herein.

c. The quality assurance requirements on the design, fabrication, and on-site construction of the HI-STORM UMAX VVM commensurate with its ITS designation (as defined in Section 1.5) are invoked through Chapter 14 of this FSAR and summarized in Sections 10.1, 10.2, and 10.3 herein as called for in §72.24(c), §72.122(a), §72.122(f), §72.128(a)(1) and §72.236(l).

d. The provisions of §72.82(d) and §72.162 with respect to acceptance criteria and the appropriate test program to ensure compliance with the acceptance criterion are fulfilled by Section 10.1, et seq., herein.

e. The quality requirements with respect to inspection, testing, and documentation, as set down in §72.212(b)(8), are provided in Section 10.1 herein.

f. The provisions of §72.236(k) with respect to labeling is met as provided in Section 10.1 here-in.

g. The quality requirements with respect to design and testing for methods of criticality control and confinement effectiveness as set down in §72.124(b), §72.236(c), and §72.236(j) are provided in the governing licensing documents applicable to the MPC type to be stored in the UMAX and are not part of the scope of this application.

10.7 REFERENCES

[10.1.1] American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code," Sections II, III, V, IX, and XI, 2010 Edition.

[10.1.2] American Society for Nondestructive Testing, "Personnel Qualification and Certification in Nondestructive Testing," Recommended Practice No. SNT-TC-1A, December 1992.

[10.1.3] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials - Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kilograms) or More", ANSI N14.6, September 1993.

[10.1.4] "NUREG-0612, Control of Heavy Loads at Nuclear Power Plants", US Nuclear Regulatory Commission, 1980.

CHAPTER 11: RADIATION PROTECTION

11.0 INTRODUCTION

This chapter contains the design considerations and operational features that are incorporated in the HI-STORM UMAX system to protect plant personnel and the public from exposure to radioactive contamination and ionizing radiation during handling of the loaded MPCs at the ISFSI. Occupational exposure estimate for typical canister handling operations described in Chapter 9 is discussed in this chapter. Chapter 5 presents dose evaluations at 100 m from a single HI-STORM UMAX system. This 100 m dose information from Chapter 5 can be used for ISFSI planning purposes. The information provided in this chapter meets the requirements of NUREG-1536 [11.0.1].

The HI-STORM UMAX is an underground vertical ventilated module (VVM) designed to accommodate all MPC models listed in Table 1.2.1 for storage at an ISFSI. However, this chapter only supports the certification of the MPC-37 and MPC-89. Because of its underground disposition, the radiological dose to plant personnel as well as members of the general public from an operating ISFSI with HI-STORM UMAX VVM assembly is well below those of its aboveground counterpart. Since the determination of off-site doses is necessarily site-specific, similar dose assessment shall be prepared by the licensee as part of implementing the HI-STORM UMAX System in accordance with 10CFR72.212 [11.0.2].

11.1 ENSURING THAT OCCUPATIONAL RADIATION EXPOSURES ARE AS-LOW-AS-REASONABLY-ACHIEVABLE (ALARA)

11.1.1 Policy Considerations

The HI-STORM UMAX has been designed in accordance with 10CFR72 [11.0.2] and maintains radiation exposures ALARA-consistent with 10CFR20 [11.1.1] and the guidance provided in Regulatory Guides 8.8 [11.1.2] and 8.10 [11.1.3]. Licensees using the HI-STORM UMAX system are permitted to utilize and apply their existing site ALARA policies, procedures, and practices for ISFSI activities to ensure that personnel exposure requirements of 10CFR20 [11.1.1] are met. Personnel performing ISFSI operations shall be trained on the operation of the HI-STORM UMAX system, and shall be familiarized with the expected dose rates around the MPC, HI-STORM VVM, and HI-TRAC transfer cask during all phases of loading, storage, and unloading operations. Pre-job ALARA briefings will be held with workers and radiological protection personnel prior to work on or around the HI-STORM UMAX system. Worker dose rate monitoring, in conjunction with trained personnel and well-planned activities, will significantly reduce the overall dose received by the workers. When preparing or making changes to site-specific procedures for ISFSI activities, users shall ensure that ALARA practices are implemented and the 10CFR20 [11.1.1] standards for radiation protection are met in accordance with the site's written commitments.

11.1.2 Radiation Exposure Criteria

The radiological protection criteria that limit exposure to radioactive effluents and direct radiation from an ISFSI using the HI-STORM UMAX system are as follows:

1. 10CFR72.104 [11.0.2] requires that for normal operation and anticipated occurrences, the annual dose equivalent to any real individual located beyond the owner-controlled area boundary must not exceed 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other critical organ. This dose would be a result of planned discharges, direct radiation from the ISFSI, and any other radiation from uranium fuel cycle operations in the area. The licensee is responsible for demonstrating site-specific compliance with these requirements. As discussed below, the design features of the HI-STORM UMAX system components are configured to meeting this and other criteria cited below without undue burden to the user.

2. 10CFR72.106 [11.0.2] requires that any individual located on or beyond the nearest owner-controlled area boundary may not receive from any design basis accident the more limiting of a total effective dose equivalent of 5 rem, or the sum of the deep dose equivalent and the committed dose equivalent to any individual organ or tissue (other than the lens of the eye) of 50 rem. The lens dose equivalent shall not exceed 15 rem and the shallow dose equivalent to skin or to any extremity shall not exceed 50 rem. The licensee is responsible for demonstrating site-specific compliance with this requirement.

3. 10CFR20 [11.1.1], Subparts C and D, limit occupational exposure and exposure to individual members of the public. The licensee is responsible for demonstrating site-specific compliance with this requirement.

4. Regulatory Position 2 of Regulatory Guide 8.8 [11.1.2] provides guidance regarding facility and equipment design features. This guidance has been followed in the design of the HI-STORM UMAX storage system as described below:

    - Regulatory Position 2a, regarding access control, is met by locating the ISFSI in a Protected Area in accordance with 10CFR72.212(b)(5)(ii) [11.0.2] Depending on the site-specific ISFSI design, other equivalent measures may be used. Unauthorized access is prevented once a HI-STORM UMAX VVM is loaded in an ISFSI. Due to the passive nature of the system, only limited monitoring is required, thus reducing occupational exposure and supporting ALARA considerations. The licensee is responsible for site-specific compliance with these criteria.

    - Regulatory Position 2b, regarding radiation shielding, is met by the storage cask and transfer cask biological shielding that minimizes personnel exposure, as described in Chapter 5 and in this chapter. Fundamental design considerations that most directly influence occupational exposures with dry storage systems in general and which have been incorporated into the HI-STORM UMAX system design include:

        – system designs that reduce or minimize the number of handling and transfer operations for each spent fuel assembly;

        – system designs that reduce or minimize the number of handling and transfer operations for each MPC loading;

  - system designs that maximize fuel capacity, thereby taking advantage of the self-shielding characteristics of the fuel and the reduction in the number of MPCs that must be loaded and handled;
  - system designs that minimize planned maintenance requirements;
  - system designs that minimize decontamination requirements at ISFSI decommissioning;
  - system designs that optimize the placement of shielding with respect to anticipated worker locations and fuel placement;
  - thick ISFSI pad and Self-hardening Engineered Subgrade (SES) provide gamma and neutron shielding;
  - streaming paths in the HI-STORM UMAX VVM minimized and limited to the air vent passages; and
  - low-maintenance design to reduce occupational dose during long-term storage.

- Regulatory Position 2c, regarding process instrumentation and controls, is met since there are no radioactive systems at an ISFSI.
- Regulatory Position 2d, regarding control of airborne contaminants, is met since the HI-STORM UMAX storage system is designed to withstand all design basis conditions to protect the MPC from losing its confinement integrity. As a result, it is reasonable to postulate that no gaseous releases are anticipated. No surface contamination is expected since the exterior of the MPC is delivered in a clean condition when the transfer cask arrives at the ISFSI.
- Regulatory Position 2e, regarding crud control, is not applicable to a HI-STORM UMAX system ISFSI since there are no radioactive systems at an ISFSI that could contain crud.
- Regulatory Position 2f, regarding decontamination, is met since the exterior of the loaded transfer cask is decontaminated prior to being removed from the plant's fuel building.
- Regulatory Position 2g, regarding monitoring of airborne radioactivity, is met since the MPC provides confinement for all design basis conditions. There is no need for monitoring since no airborne radioactivity is anticipated to be released from the casks at an ISFSI.

- Regulatory Position 2h, regarding resin treatment systems, is not applicable to an ISFSI since there are no treatment systems containing radioactive resins at the ISFSI.
- Regulatory Position 2i, regarding other miscellaneous ALARA items, is met since stainless steel is used in the MPC Enclosure Vessel. This material is resistant to the damaging effects of radiation and is well proven in the used fuel cask service. Use of this material quantitatively reduces or eliminates the need to perform maintenance (or replacement) on the primary confinement system.

11.1.3 Operational Considerations

Operational considerations that most directly influence occupational exposures with dry storage systems in general and that have been incorporated into the design of the HI-STORM UMAX system include:

- totally-passive design requiring minimal maintenance and monitoring (other than security monitoring) during storage;
- remotely operated lift yoke and mating device to reduce time operators spend in the vicinity of the loaded MPC;
- descriptive operating procedures that provide guidance to minimize dose and alert workers to possible changing radiological conditions;
- preparation and inspection of the HI-STORM UMAX VVM and the HI-TRAC transfer cask in low-dose areas;
- HI-STORM UMAX VVM temperature monitoring equipment allows remote monitoring of the vent operability surveillance;
- a sequence of short-term operations based on ALARA considerations; and
- use of mock-ups and dry run training to prepare personnel for actual work situations

11.1.4 Auxiliary/Temporary Shielding

In addition to the design and operational features built into the HI-STORM UMAX system components, a number of ancillary shielding devices can be deployed to mitigate occupational dose. Ancillaries are developed on a site-specific basis that further reduce radiation at key work locations and/or allow for a rapid execution of operations to reduce the time personnel spend in the radiation field. Licensees are encouraged to use such ALARA-friendly ancillaries and practices.

11.2 RADIATION PROTECTION FEATURES IN THE SYSTEM DESIGN

As shown in Chapter 5, the HI-STORM UMAX system has excellent radiation blockage characteristics. The long-term shielding effectiveness in the HI-STORM UMAX system is assured to an extremely high level of confidence by virtue of its physical configuration, choice of materials, and design embodiment, as summarized below:

a. Absence of penetrations in the VVM body: The CEC has no penetrations and thus has no path that can serve as a conduit for radiation streaming. All penetrations are in the lid and are configured to maximize scattering of photons and neutrons.

b. Axisymmetric penetrations in the lid: As shown in the drawings, the only penetration in the lid – the exit vent – is axisymmetric that precludes a direct "line-of-sight" from the fuel to the outside. Because the air passage in the lid is formed by welded steel shapes, they will remain invariant over time, making their shielding performance reliably constant over years of use.

c. Aging of foundation, subgrade: Even though a very stiff support foundation is specified, some settlement of the foundation is expected. However, any settlement of the foundation would have no deleterious effect on the extent of shielding to the environment.

   Furthermore, because the subgrade is unloaded, except when a transporter is passing over it, the settlement of the ISFSI pad is expected to be minimal over the ISFSI's service life. Any subgrade settlement, however, will result in a corresponding compaction of its material, which will improve the subgrade's shielding capability. The settlement of the subgrade will not result in any new loading on the CEC structure (which is autonomously supported on the foundation) or the Closure Lid, which is autonomously supported on the CEC structure. As required by the system's maintenance program, any visible gap or crevice between the Container Flange and the surface pad shall be filled with grout or caulking for both aesthetic purposes and enhancement of degradation and corrosion mitigation.

d. Effect of Corrosion: It can be readily deduced from the VVM's design that the only surfaces that are not accessible for corrosion monitoring are the bottom face and outer cylindrical surface of the CEC. As discussed in Chapter 8, corrosion mitigation measures for these surfaces are prescribed and expected to provide adequate corrosion mitigation beyond the Design Life of the VVM. Additionally, any CEC or bottom plate corrosion would have a negligible effect on the off-site dose as the majority of the off-site dose contribution is from the inlets, the inlet plenum region and the outlet.

Thus, the potential for reduction in the shielding effectiveness of the HI-STORM UMAX system due to corrosion is not a concern.

e. Water Intrusion: The HI-STORM UMAX system has three barriers against water intrusion in the fuel space, each of which is engineered to independently prevent incursion of water:

   i. The Support Foundation pad and the Enclosure shell (see the Drawing package in Section 1.5) provide a robust barrier against seepage of groundwater in the subgrade surrounding the CECs.

   ii. The CEC is a thick-walled welded container that has no penetrations in its body through which water may leak in the MPC storage cavities.

   iii. The MPC is a stainless steel weldment designed with fully volumetrically examined Section III class 1 butt welds.

f. Materials of Construction: The sole material of construction in the underground portion of the CEC is carbon steel, which is a proven material of long-term shielding endurance under neutron and gamma fluence levels that are orders of magnitude greater than those present in the CEC. The Closure Lid is comprised of low carbon steel that encases plain concrete. Concrete, like steel, is a proven durable material in a radiation environment that suffers negligible change in its shielding capability over long periods of use in a radiation environment. Therefore, material-degradation-induced reduction in the shielding effectiveness of the VVM is not a credible concern.

In summary, The design features of the HI-STORM UMAX components ensure that the occupational dose as well as off-site dose from the ISFSI will be ALARA.

11.3 ESTIMATED ON-SITE CUMULATIVE DOSE ASSESSMENT

11.3.1 Estimated Exposures for Loading and Unloading Operations

This section discusses the cumulative exposure to personnel performing loading, unloading, and transfer operations using the HI-STORM UMAX system. Additionally, this section provides measured operational dose values from the actual loading campaigns of an above ground system. As the operational aspects of both underground and aboveground systems are quite similar, as discussed below, the realistic campaign dose of the aboveground system would also be applicable to the HI-STORM UMAX.

The operations associated with the use of the HI-STORM UMAX, described in Chapter 9, are quite similar to the operations for all other variations of the HI-STORM 100 and HI-STORM FW systems. 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 UMAX, an installation that requires bolting. Installation of the outlet vent cover places workers over the lid and adds some time to the operation. As the dose rates on the side of the outlet vent (dose location 2 in Chapter 5) and top of the VVM lid (dose location 3 in Chapter 5) are small (see Tables 5.1.1 and 5.1.2), the operational dose for this operation would be very small compared to the entire MPC transfer into the VVM. Nevertheless, it is recommended that the operators do not spend any unnecessary time on top of the lid to ensure/meet the ALARA principle.

As for the above-ground systems, exposure estimates for loading operations are expected to bound those for unloading operations for the HI-STORM UMAX. This assessment is based on the similarity of many loadings versus operations with the elimination of several of the more dose-intensive operations (such as weld inspections and leakage testing).

In summary, the estimates of occupational exposure for the entire MPC transfer operations from Reference [11.3.2] are directly applicable to the HI-STORM UMAX, and no further evaluations are performed here.

Additionally, experience has shown that the occupational doses are in general significantly lower than those estimated in [11.3.1] and [11.3.2]. To highlight this, typical total occupational doses for 5 cask loadings are listed in Table 11.3.1, while Table 11.3.2 presents the dose of each operational step for Casks 4 and 5 from Table 11.3.1. These are for aboveground systems using a 100 t HI-TRAC. As discussed above, since the operational sequence for loading the HI-STORM UMAX is essentially the same as for the above ground systems, similar values would be expected for the HI-STORM UMAX.

11.3.2 Excavation Activities

In the event it is desired to expand an ISFSI utilizing the HI-STORM UMAX design, excavation of material (i.e., soil) is required. Radiation protection of the excavation activities is achieved by prescribing a minimum proximity of any excavation to an existing HI-STORM UMAX array. Site specific radiation protection measures for excavation activities need to include confirmation of the minimum SES 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. Table 5.4.4 presents a representative dose rate at the surface of the radiation protection space. Additionally, a general accident scenario evaluation has been performed for the HI-STORM UMAX design. The impact of a tornado missile penetrating the SES creating a horizontal hole extending 5.5 feet from the external surface of the radiation protection boundary was considered. This evaluation, presented in Table 5.1.4, demonstrates that the dose at the site boundary is below the limit specified in 10 CFR 72.

11.3.3 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 radiations 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 UMAX 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 SES providing shielding is limited between adjacent VVMs. Therefore, radiation passing through the SES to the unloaded VVM will have a path of less shielding and could contribute to occupational dose. This evaluation is presented in Chapter 5, 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 SES access tube, or test station, that is part of the ICCPS design and could represent a potential streaming path. Therefore, radiation passing through the SES access tube could contribute to occupational dose. This evaluation is presented in Chapter 5, 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 SES 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.

11.3.4 Estimated Exposures for Surveillance and Maintenance

Because of its low profile, the surveillance at a HI-STORM UMAX ISFSI can be performed without physically walking between the VVMs and therefore, occupational exposure required for security surveillance and maintenance will be bounded by above ground systems [11.3.2]. Typical estimates of the occupational exposure required for security surveillance and maintenance of an ISFSI can be found in References [11.3.1][11.3.2]. Security surveillance time is based on a daily security patrol around the perimeter of the ISFSI security fence. Users may opt to utilize electronic temperature monitoring of the HI-STORM UMAX modules or remote viewing methods instead of performing direct visual observation of the modules. Although the HI-STORM UMAX system requires only minimal maintenance during storage (e.g., touch-up paint), maintenance will be required around the ISFSI for items such as security equipment maintenance, grass cutting, snow removal, vent system surveillance, drainage system maintenance, and lighting, telephone, and intercom repair. Such infrequent activities are not included in the site boundary dose assessment.

Table 11.3.1

MEASURED TOTAL OPERATIONAL DOSE FOR A LOADING CAMPAIGN USING HI-STORM SYSTEMS

Cask Number	Total Heat Load (kW)	Total Campaign Dose (mrem)
1	23.79	370
2	24.96	208
3	25.70	183
4	25.75	164
5	26.36	187

Table 11.3.2

MEASURED OPERATIONAL DOSE FOR DIFFERENT TASKS FOR CASKS 4 AND 5 IN TABLE 11.3.1

Task Description	Cask 4 (mrem)	Cask 5 (mrem)
	25.75 kW	26.36 kW
Preparations and placement of HI-TRAC in spent fuel pool	2	3
Fuel loading and verification	13	8
Placement of HI-TRAC in the decontamination pit and decontamination	35	34
Welding of MPC lid	14	18
Drying operation	20	19
Welding of the closure plates	33	34
Stackup operation	43	60
Move HI-STORM to ISFSI	4	11
Total dose	**164**	**187**

11.4 REFERENCES

[11.0.1] NUREG-1536, “Standard Review Plan for Dry Cask Storage Systems”, U.S. Nuclear Regulatory Commission, January 1997.

[11.0.2] *U.S. Code of Federal Regulations,* Title 10, "Energy" Part 72 "Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste".

[11.1.1] *U.S. Code of Federal Regulations,* Title 10, "Energy" Part 20 "Standards for Protection Against Radiation".

[11.1.2] U.S. Nuclear Regulatory Commission "Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power at Nuclear Power Stations will be As Low As Reasonably Achievable", Regulatory Guide 8.8, June 1978.

[11.1.3] U.S. Nuclear Regulatory Commission, "Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As is Reasonably Achievable", Regulatory Guide 8.10, Revision 1-R, May 1997.

[11.3.1] “Final Safety Analysis Report for the HI-STORM 100 Cask System”, HI-2002444,USNRC Docket 72-1014.

[11.3.2] “Final Safety Analysis Report for the HI-STORM FW MPC Storage System”, Holtec Report # 2114830,USNRC Docket #72-1032.

CHAPTER 12: ACCIDENT EVALUATION

12.0 INTRODUCTION

This chapter is focused on the safety evaluation of all off-normal and accident events germane to the HI-STORM UMAX vertical ventilated module (VVM) containing a loaded Multi-purpose Canister (MPC). For each postulated event, the event cause, means of detection, consequences, and corrective actions, as applicable, are discussed and evaluated. For other miscellaneous events (i.e., those not categorized as either design basis off-normal or accident condition events), a similar outline for safety analysis is followed. As applicable, the evaluation of consequences includes the impact on the structural, thermal, shielding, criticality, confinement, and radiation protection performance of the system due to each postulated event.

The analyses summarized in this chapter focus on the governing canisters out of the population of MPCs listed in Table 1.2.1. This chapter, however, supports the certification of only MPC-37 and MPC-89 at this time. The analyses reported for smaller canisters are for reference purposes only.

The structural, thermal, shielding, criticality, and confinement features and performance of the HI-STORM UMAX system under the short-term operations and various conditions of storage are discussed in Chapters 3, 4, 5, 6, and 7. The evaluations provided in this chapter are based on the design features and analyses reported therein. The accidents considered in this chapter follow the guidance in NUREG-1536.

Technical descriptions and safety analyses pertaining to the components common to the "FW" and the "UMAX" systems are referenced in this FSAR, as appropriate, to the HI-STORM FW FSAR. To facilitate convenient access to the referenced material, the latest edition of the HI-STORM FW FSAR has been placed in this docket and a list of "FW" FSAR sections germane to this chapter is provided in Table 12.0.1 herein.

TABLE 12.0.1

APPLICABLE SECTIONS OF HI-STORM FW FSAR[*]

Location of UMAX FSAR	Subject of the Reference	Location in HI-STORM FW FSAR, Revision 1
Sub-Section 12.1.1	Structural evaluation of the MPC enclosure vessel for off-normal internal pressure conditions	Sub-Section 3.4.4
Sub-Section 12.1.2	Limitations on the use of the HI-TRAC VW cask for loading MPCs under off-normal thermal conditions	Sub-Section 12.1.2
Sub-Section 12.1.3	Leakage of one MPC seal weld	Sub-Section 12.1.3
Sub-Section 12.1.6	FHD malfunction evaluations	Sub-Section 12.1.5
Sub-Section 12.2.1	Fire accident evaluation	Sub-Section 12.2.4
Sub-Section 12.2.2	Partial blockage of MPC basket vent holes	Sub-Section 12.2.5
Sub-section 12.2.3	Tornado analysis for HI-TRAC VW	Sub-Section 12.2.6
Sub-Section 12.2.7	Confinement Boundary Leakage	Section 7.1
Sub-Section 12.2.13	HI-TRAC VW handling accidents	Sub-Section 12.2.1
Sub-Section 12.3.2	MPC reflood evaluation	Sub-Section 12.3.1

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[*] For convenience of reference, the specific revision of the HI-STORM FW FSAR that is referenced in the safety analysis herein is placed in this docket. Updated versions of the HI-STORM FW FSAR shall be placed in this docket as necessary so as to ensure that the safety analyses on the "UMAX" docket (72-1040) remain aligned with the material referenced in the HI-STORM FW FSAR.

12.1 OFF-NORMAL CONDITIONS

Off-normal conditions, as defined in accordance with ANSI/ANS-57.9, are those conditions which, although not occurring regularly, are expected to occur no more than once a year. In this section, design events pertaining to off-normal operation for expected operational occurrences are considered. The off-normal conditions are described in Section 2.3.

The following off-normal events are applicable to the HI-STORM UMAX system:

- Off-Normal Pressure
- Off-Normal Environmental Temperature
- Leakage of One Seal
- Partial Blockage of the Air Inlet Plenum
- Hypothetical Non-Quiescent Wind
- FHD Malfunction

The results of the evaluations presented herein demonstrate that the HI-STORM UMAX System can withstand the effects of off-normal events and remain in compliance with the applicable acceptance criteria.

12.1.1 Off-Normal Pressure

The sole pressure boundary in the HI-STORM UMAX storage System is the MPC enclosure vessel. The off-normal pressure condition is specified in Section 2.3. The off-normal pressure for the MPC internal cavity is a function of the initial helium fill pressure and the steady state temperature reached within the MPC cavity under normal ambient temperature. The MPC internal pressure under the off-normal condition is evaluated with 10% of the fuel rods ruptured and with 100% of ruptured rods fill gas and 30% of ruptured rods fission gases released to the cavity.

12.1.1.1 Postulated Cause of Off-Normal Pressure

After fuel assembly loading, the MPC is drained, dried, and backfilled with an inert gas (helium) to assure long-term fuel cladding integrity during dry storage. Therefore, the probability of failure of intact fuel rods in dry storage is extremely low. Nonetheless, the event is postulated and evaluated.

12.1.1.2 Detection of Off-Normal Pressure

The HI-STORM UMAX system is designed to withstand the MPC off-normal internal pressure without any effects on its ability to meet its safety requirements. There is no requirement or safety imperative for detection of off-normal pressure and, therefore, no monitoring is required.

12.1.1.3 Analysis of Effects and Consequences of Off-Normal Pressure

The MPC off-normal internal pressure is reported in Section 4.6.1.4 for the limiting fuel storage scenario wherein the canister pressurized to the technical specification maximum helium backfill pressure sustains a 10% rod rupture that causes a 100% of the ruptured rod fill gas and 30% of the ruptured rod gaseous fission products released into the MPC cavity.

The analysis of the above scenario shows that the MPC pressure remains below the design MPC internal pressure (given in Table 2.3.5).

i. Structural

The structural evaluation of the MPC enclosure vessel for off-normal internal pressure conditions is discussed in the HI-STORM FW FSAR [4.1.2]. The stresses resulting from the off-normal pressure are confirmed to be bounded by the applicable pressure boundary stress limits.

ii. Thermal

The MPC internal pressure for off-normal conditions is reported in Table 4.4.7. The design basis internal pressure used in the structural evaluation (Table 2.3.5) bounds the computed off-normal condition pressure.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

v. 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 above, all pressure boundary stresses remain within allowable ASME Code values, assuring Confinement Boundary integrity.

vi. 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.

12.1.1.4 Corrective Action for Off-Normal Pressure

The HI-STORM UMAX system is designed to withstand the off-normal pressure without any effects on its ability to maintain safe storage conditions. Therefore, there is no corrective action requirement for off-normal pressure.

12.1.1.5 Radiological Impact of Off-Normal Pressure

The event of off-normal pressure has no radiological impact because the confinement barrier and shielding integrity are not affected.

12.1.1.6 Conclusion

Based on this evaluation, it is concluded that the off-normal pressure does not affect the safe operation of the HI-STORM UMAX system.

12.1.2 Off-Normal Environmental Temperatures

The HI-STORM UMAX System is designed for use at any site in the United States. Off-normal environmental temperatures have been conservatively selected to bound the environmental temperatures at all candidate sites in the United States (See Subsection 2.3.3 for definition of the term off-normal environmental temperature). The off-normal temperature limits are reported in Table 2.3.6.

12.1.2.1 Postulated Cause of Off-Normal Environmental Temperatures

The off-normal environmental temperature is postulated as a constant ambient temperature caused by extreme weather conditions. To determine the effects of the off-normal temperatures, it is conservatively assumed that these temperatures persist for a sufficient duration to allow the HI-STORM UMAX System to achieve thermal equilibrium. Because of the large mass of the HI-STORM UMAX System with its corresponding large thermal inertia and the limited duration for the off-normal temperatures, this assumption is conservative.

12.1.2.2 Detection of Off-Normal Environmental Temperatures

The HI-STORM UMAX System is designed to withstand the off-normal environmental temperatures without any effects on its ability to maintain safe storage conditions. There is no requirement for detection of off-normal environmental temperatures for the HI-STORM UMAX overpack and MPC. The limitations on the use of the transfer cask for loading canisters in the HI-STORM UMAX system under off-normal thermal conditions are contained in Section 12.1.2 of the HI-STORM FW FSAR which must be observed.

12.1.2.3 Analysis of Effects and Consequences of Off-Normal Environmental Temperatures

The off-normal event is considered to be characterized by an off-normal environmental temperature with insolation for sufficient duration to reach thermal equilibrium. The evaluation is performed for a limiting fuel storage configuration. The off-Normal ambient temperature condition is evaluated in Subsection 4.6.1.1. The results are in compliance with off-normal pressure and temperature limits in Tables 2.3.5 and 2.3.7 in Chapter 2.

The off-normal event considering an environmental temperature of -40°F and no solar insolation for a sufficient duration to reach thermal equilibrium is evaluated with respect to material design temperatures of the HI-STORM UMAX VVM. The HI-STORM UMAX VVM structure is conservatively assumed to reach the extreme cold condition (-40°F) throughout its body. The qualification of the VVM structure under the extreme cold condition is provided in Chapter 8.

i. Structural

The effect on the MPC for the upper off-normal thermal conditions is an increase in the internal pressure. As shown in Section 4.6.1.1, the resultant pressure is below the off-normal design pressure (Table 2.3.5). The stresses resulting from the off-normal pressure are confirmed to be bounded by the applicable pressure boundary stress limits. 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 Chapter 8.

ii. Thermal

The resulting off-normal system and fuel assembly cladding temperatures for the hot conditions are provided in Table 4.6.1. This evaluation indicates that all temperatures for the off-normal environmental temperatures event are within the allowable values for off-normal conditions listed in Table 2.3.7. Additionally, the increased temperatures generate an elevated MPC internal pressure, reported in Table 4.6.5, which is less than the off-normal design pressure limit specified in Table 2.3.5. The temperatures and pressures resulting from the off-normal ambient temperature event are confirmed to be bounded by the applicable system temperature and pressure limits; therefore, there is no adverse effect on the system's thermal function.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this off-normal event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

v. 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 above, all pressure boundary stresses in the canister remain within allowable ASME Code values, assuring Confinement Boundary integrity.

vi. 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.

12.1.2.4 Corrective Action for Off-Normal Environmental Temperatures

The HI-STORM UMAX System is designed to withstand the off-normal environmental temperatures without any effects on its ability to maintain safe storage conditions. As required by the HI-STORM FW FSAR [4.1.2], for ambient temperatures from 0° to 32°F, ethylene glycol fortified water must be used in the water jacket of the HI-TRAC VW transfer cask to prevent freezing. There are no corrective actions required for off-normal environmental temperatures.

12.1.2.5 Radiological Impact of Off-Normal Environmental Temperatures

Off-normal environmental temperatures have no radiological impact, as the confinement barrier and shielding integrity are not affected.

12.1.2.6 Conclusion

Based on the above evaluation, it is concluded that the specified off-normal environmental temperatures do not affect the safe operation of the HI-STORM UMAX System.

12.1.3 Leakage of One MPC Seal Weld

Leakage of one MPC seal weld evaluated in the HI-STORM FW FSAR Section 12.1.3 [4.1.2] is incorporated by reference.

12.1.4 Partial Blockage of Air Inlet Plenum

Partial blockage (50%) of the air intake system has been postulated as an off-normal event in Section 2.5.

The HI-STORM UMAX intake ducts are designed with debris screens, as is the outlet vent flue located in the Closure Lid. These screens protect the openings from the incursion of foreign objects. However, as required by the design criteria presented in Chapter 2, it is conservatively assumed that 50% of the air inlet opening is completely blocked. The scenario of the partial blockage of air inlets is evaluated with a normal ambient temperature (Table 2.3.6), full solar insolation, and Design Basis SNF decay heat value case. This condition is analyzed in Chapter 4 to demonstrate the acceptability of the system thermal performance during this event.

12.1.4.1 Postulated Cause of Partial Blockage of Air Inlets

The presence of screens prevents foreign objects from entering the openings and the screens are either inspected periodically or the system temperature field is monitored per the technical specifications. It is, however, possible that blowing debris may partially block the inlet openings for a short time until the openings are cleared of debris.

12.1.4.2 Detection of Partial Blockage of Air Inlet

The detection of the partial blockage of air inlet openings will occur during the routine visual inspection of the screens or temperature monitoring of the outlet air required by the technical specifications. The frequency of inspection is based on an assumed complete blockage of all air inlet openings. There is no inspection requirement as a result of the postulated partial inlet blockage because the complete blockage of all air inlet openings is bounding.

12.1.4.3 Analysis of Effects and Consequences of Partial Blockage of Air Inlets

i. Structural

The effect of partial blockage of the air inlet plenum on the MPC is an increase in component and fuel cladding temperatures and internal pressure and thus an increase in pressure boundary stresses. However, the resultant temperatures and pressures are below the off-normal design limits as discussed in the thermal effects evaluation below. The MPC stresses resulting from the partial blockage of air inlets are confirmed to be bounded by the applicable pressure boundary stress limits; therefore, there is no effect on structural function.

In summary, there are no structural consequences as a result of this off-normal event since the HI-STORM UMAX components do not exceed the off-normal temperature limits (Table 2.3.7).

ii. Thermal

The thermal evaluation of partial blockage of air inlet is discussed in Subsection 4.6.1.2. The calculated bounding temperatures conservatively evaluated as a 50% blockage of sufficient duration to reach the asymptotic maximum (steady-state) temperature field are reported in Table 4.6.1 and below the MPC and VVM off-normal design temperature limits specified in Table 2.3.7, as applicable. Additionally, the increased temperatures generate an elevated MPC internal pressure, reported in Table 4.6.5, which is less than the off-normal design pressure limit specified in Table 2.3.5. The temperatures and pressures resulting from the partial blockage of air inlet event are confirmed to be bounded by the applicable system temperature and pressure limits; therefore, there is no adverse effect on the system's thermal function.

iii. Shielding

There is no adverse effect on the function of shielding features of storage the system as a result of this off-normal event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this off-normal event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this off-normal event.

vi. Radiation Protection

Since there is no degradation in shielding or confinement capabilities as discussed above, there is no predicted adverse effect on occupational or public exposures as a result of this off-normal event.

12.1.4.4 Corrective Action for Partial Blockage of Air Inlets

The corrective action for the partial blockage of air inlet openings is the removal, cleaning, and replacement of the affected mesh screens. After clearing of the blockage, the storage module temperatures will return to the normal temperatures reported in Chapter 4. Partial blockage of air inlet openings does not affect the safe operation of the HI-STORM UMAX System.

Periodic inspection of the HI-STORM UMAX air opening screens is required per the technical specifications. Alternatively, per the technical specifications, the outlet air temperature is monitored. The frequency of inspection is based on an assumed blockage of all air inlet openings analyzed in Section 12.2.

12.1.4.5 Radiological Impact of Partial Blockage of Air Inlets

The off-normal event of partial blockage of the air inlet opening has no radiological impact because the confinement barrier is not breached and the system's shielding effectiveness is not diminished.

12.1.4.6 Conclusion

Based on the above evaluation, it is concluded that the off-normal partial blockage of air inlet ducts event does not affect the safe operation of the HI-STORM UMAX VVM.

12.1.5 Hypothetical Non-Quiescent Wind

12.1.5.1 Cause of Event

Wind is a meteorological event that occurs in every area in the world. The normal condition of storage of the canisters assumes quiescent ambient conditions with an annular average temperature that bounds the historical data for all sites in the United States. The hypothetical non-quiescent wind condition is intended to simulate the thermal response of a site subject to a persistent wind event that tends to disrupt the heat rejection performance of the system.

12.1.5.2 Simulation of the Event

The HI-STORM UMAX storage system is designed to store the canisters listed in Table 1.2.1 at any ISFSI site in the United States in compliance with this FSAR. Chapter 4 evaluates the effects of low speed wind postulated as a constant horizontal wind caused by hypothetical weather conditions (see Section 4.6.1.3). To determine the effects of this hypothetical wind event, it is conservatively assumed that the wind persists in a fixed direction for a sufficient duration to allow the HI-STORM UMAX system to reach thermal equilibrium. Temperature results are compared with off-normal temperature limits. Because of the large mass of the HI-STORM UMAX System with its corresponding large thermal inertia and the unlikely condition of a unidirectional wind existing for a long period of time, this assumption is extremely conservative.

12.1.5.3 Safety Analysis

The following is an evaluation of effects on structural, thermal, criticality, confinement, and radiation protection performance on the HI-STORM UMAX storage system:

i. Structural

The effect on the MPC for the hypothetical non-quiescent wind condition is an increase in component and fuel cladding temperatures and internal pressure and thus an increase in pressure boundary stresses. However, the resultant temperatures and pressures are below the off-normal design limits as discussed in the thermal effects evaluation below. The MPC stresses resulting from the off-normal temperature event are confirmed to be bounded by the applicable pressure boundary stress limits; therefore, there is no effect on structural function.

ii. Thermal

Chapter 4 calculates peak fuel cladding temperatures as a function of the horizontal wind speed. The calculated maximum peak cladding temperatures reported in Table 4.6.4 are below the off-normal limits specified in Table 2.3.7 for both moderate burnup and high burnup fuel. Additionally, the elevated MPC internal pressure is reported in Table 4.6.5, which is less than the off-normal design pressure limit specified in Table 2.3.5. By this evaluation, temperatures and pressures resulting from the hypothetical non-quiescent wind event are confirmed to be bounded by the applicable system off-normal temperature and pressure limits; therefore, there is no effect on thermal function.

iii. Shielding

There is no effect on the function of shielding features of the system as a result of this event.

iv. Criticality

There is no effect on the function criticality control features of the MPC as a result of this event.

v. Confinement

There is no effect on the function of confinement features of the MPC as a result of this event.

vi. Radiation Protection and Consequences

Since there is no effect on shielding or confinement functions as discussed above, there is no radiological consequence (from effluents and direct radiation) and no expected increase to occupational exposures as a result of this event.

12.1.5.4 Corrective Action and Counter-measures

Because the HI-STORM UMAX System is designed to withstand the hypothetical non-quiescent wind event without any effect on its ability to maintain safe storage conditions, there is no requirement for detection and counter-measures.

12.1.5.5 Conclusion

Based on this evaluation, it is concluded that the hypothetical non-quiescent wind event does not affect the safe operation of the HI-STORM UMAX VVMs.

12.1.6 FHD Malfunction

FHD malfunction evaluated in the HI-STORM FW FSAR Section 12.1.5 [4.1.2] is incorporated by reference.

12.2 ACCIDENT EVENTS

Accidents, in accordance with ANSI/ANS-57.9, are either infrequent events that could reasonably be expected to occur during the lifetime of the HI-STORM UMAX system or events postulated because their consequences may affect the public health and safety. Sections 2.4 and 2.5, respectively, define the structurally and thermally significant loadings that are classified design basis accidents. These design basis accident events have been evaluated in this FSAR to quantify the safety margins in the storage system.

The load combinations evaluated for postulated accident conditions are defined in Chapter 2. The structural qualification of accidents is provided in Chapter 3.

The following accident events germane to the safety evaluation of HI-STORM UMAX system are identified by reference to Sections 2.4 and 2.5:

- Fire Accident
- Partial Blockage of MPC Basket Vent Holes in long- term storage
- Tornado
- Flood
- Earthquake
- 100% Fuel Rod Rupture
- Confinement Boundary Leakage
- Explosion
- Lightning
- 100% Blockage of Air Inlets
- Burial Under Debris
- Extreme Environmental Temperature
- HI-TRAC VW Transfer Cask Handling Accident

The results of the evaluations performed in this FSAR demonstrate that the HI-STORM UMAX storage system can withstand the effects of all credible and hypothetical accident conditions and natural phenomena without affecting its safety function, In the following, the evaluation of the design basis postulated accident conditions and natural phenomena is presented which demonstrates that the requirements of 10CFR72.122 and of 10 CFR72.106(b) and 10CFR20 are met.

12.2.1 Design Basis Fire Event (Load Case 5 in Section 2.4)

12.2.1.1 Cause of Fire

The potential of a fire accident near an ISFSI pad is considered to be rendered extremely remote by ensuring that there are no significant combustible materials in the area. The only credible concern is related to a transport vehicle fuel tank fire engulfing a loaded HI-STORM UMAX

VVM or a HI-TRAC VW transfer cask. HI-TRAC VW transfer cask fire evaluated in the HI-STORM FW FSAR Section 12.2.4 [4.1.2] is incorporated by reference. HI-STORM UMAX fire is evaluated in the following.

12.2.1.2 Fire Analysis

The HI-STORM UMAX System must withstand elevated temperatures under the Design Basis Fire event defined in Table 2.3.1. The acceptance criteria for the fire accident are provided in Section 2.3 and the thermal analysis is contained in Section 4.6.2.1.

i. Structural

The effect of the fire accident on the HI-STORM UMAX system is an increase in fuel cladding and system component temperatures and MPC internal pressure and thus an increase in MPC pressure boundary stresses. However, the resultant temperatures and pressures are below the accident design limits as discussed below. The MPC stresses resulting from the fire accident event are confirmed to be bounded by the applicable pressure boundary stress limits; therefore, there is no effect on structural function.

ii. Thermal

As discussed in Chapter 4, the effect of the fire does not cause any system component or the contained fuel to exceed any limit set in this FSAR. The Design Basis Fire has a negligible impact on MPC pressure. The temperatures and pressures resulting from the fire accident event are confirmed to be bounded by the applicable system temperature and pressure limits; therefore, there is no deleterious effect on the system's thermal function.

iii. Shielding

The loss of shielding, if any, has been determined by scoping calculations to be of insignificant consequence in Chapter 4. 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 FSAR.

Less than 5% of the Closure Lid concrete thickness is computed to exceed the short-term temperature limit therefore the effect of this small amount of degraded (not lost) shielding material is not estimated or evaluated in this FSAR.

iv Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event since the structural integrity of the confinement boundary is unaffected.

vi. Radiation Protection

Since there is minimal reduction, if any, 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.

12.2.1.3 Fire Accident Corrective Actions

Upon detection of a fire adjacent to a loaded HI-STORM UMAX VVM, the ISFSI owner shall take the appropriate immediate actions necessary to extinguish the fire. Following the termination of the fire, a visual and radiological inspection of the equipment shall be performed.

If damage to the HI-STORM UMAX VVM as the result of a fire event is widespread, and/or as radiological conditions require (based on dose rate measurements), the MPC shall be removed from the HI-STORM UMAX VVM in accordance with the procedure set down in Chapter 9. However, the thermal analysis described herein demonstrates that only a limited amount of lid concrete which is behind the carbon steel enclosure exceeds its design temperature. The HI-STORM UMAX VVM may be returned to service after appropriate restoration (reapplication of coatings, etc.) if there is no significant increase in the measured dose rates (i.e., the shielding effectiveness of the overpack is confirmed) and if the visual inspection is satisfactory.

There is no effect on the function of criticality control features of the MPC as a result of this accident event.

Based on the foregoing evaluation, it is concluded that the overpack fire accident does not affect the safe operation of the HI-STORM UMAX VVMs.

12.2.1.4 Conclusion

Based on the above evaluation, it is concluded that the Design Basis Fire accident does not affect the safe operation of the HI-STORM UMAX System.

12.2.2 Partial Blockage of MPC Basket Vent Holes

Partial blockage of MPC basket vent holes evaluated in the HI-STORM FW FSAR Section 12.2.5 [4.1.2] is incorporated by reference.

12.2.3 Tornado (Load Case 02 in Section 2.4)

12.2.3.1 Causal Factors

Tornado and high winds are principally caused by the uneven heating of the earth's atmosphere, coupled with gravitational forces and the rotation of the earth. The HI-STORM UMAX System will be deployed in an open area environment and thus will be subject to ambient environmental conditions throughout the storage period. Additionally, the transfer of the MPC between the HI-TRAC VW transfer cask and the storage overpack may be performed at the unsheltered ISFSI concrete pad. It is therefore possible that the HI-STORM UMAX storage system may experience the extreme environmental conditions resulting in the impact from a tornado-borne projectile.

12.2.3.2 Tornado Analysis

A tornado event is characterized by high wind velocities and tornado-generated missiles. The reference missiles considered in this FSAR (see Table 2.3.3) are of three sizes: small, medium, and large. A small projectile, upon collision with a cask, would tend to penetrate it. A large projectile, such as an automobile, on the other hand, would tend to cause deformation.

Because of its underground construction, the HI-STORM UMAX is not subject to overturning action 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 UMAX must, however, be considered.

The tornado analysis for a HI-TRAC VW transfer cask evaluated in the HI-STORM FW FSAR Section 12.2.6 [4.1.2] is incorporated by reference.

The evaluation of effects on structural, thermal, criticality, confinement, and radiation protection performance on the HI-STORM UMAX system is summarized below.

i. Structural

Analyses presented in Chapter 3 show that the impact of large and intermediate tornado missiles (see Table 2.3.3) on the HI-STORM UMAX closure lid does not result in the perforation of the lid or result in a structural collapse of the lid. The sole effect of the tornado missile impact on the HI-STORM UMAX VVM is some minor global deformation of the VVM Closure Lid under the large missile and some localized deformation of the VVM Closure Lid under the intermediate missile. All Design Basis missiles are found to be stopped by the VVM assembly before reaching the MPC stored inside. Therefore, MPC damage by impact from a Design Basis Missile is ruled out.

ii. Thermal

There is no effect on the function of HI-STORM UMAX VVM heat transfer features as a result of this accident event. The deformations in the VVM Closure Lid due to missile impact are minor relative to the available area of the flow opening.

iii. Shielding

Certain tornado missile scenarios may result in shielding degradation of the HI-STORM UMAX Closure Lid; however, the overall shielding effect will be negligible due to the sheer size and mass of the Closure Lid. (The HI-STORM UMAX VVM is heavily shielded (a thick MPC lid protected by the monolithic steel-concrete-steel VVM Closure Lid weighing in excess of 30,000 lbs; see Section 3.2.)

iv. Criticality

There is no effect on the criticality control features of the MPC as a result of this accident event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this accident event.

12.2.3.3 Radiation Protection and Consequences

There is no effect on shielding or confinement functions of the MPC. The effect on shielding function of the VVM Closure Lid is negligible and therefore the radiological impact on the site boundary dose will be negligible. Thus, a negligible increase in radiological consequence (from effluents and direct radiation) is expected as a result of this accident. A minor increase to occupational exposures for the performance of corrective actions is also expected.

12.2.3.4 Tornado Accident Corrective Action

Following exposure of the HI-STORM UMAX System to a tornado, the ISFSI owner shall perform a visual and radiological inspection of the facility.

Damage sustained by the VVMs or vent screens shall be inspected and may be repaired, if required, while in-service. The system may continue in service after appropriate restoration (reapplication of coatings, etc.) if there is no significant increase in the measured dose rates (i.e., the system's shielding effectiveness is confirmed) and if the final visual inspection is satisfactory.

12.2.3.5 Conclusion

Based on the above evaluation, it is concluded that the Design Basis tornado accident will not affect the safe operation of the HI-STORM UMAX System.

12.2.4 Flood (Load Case 7 in Table 2.4.1)

12.2.4.1 Cause of Flood

Many ISFSIs are located in flood plains susceptible to floods. Therefore, it is necessary for such ISFSIs to define a Design Basis Flood (DBF). The potential sources for the floodwater may be swelling rivers or streams from heavy rains or rapid melting of upstream snow, tsunami, dam break, earthquake, hurricane, etc.

12.2.4.2 Analysis

Because of its underground construction, the HI-STORM UMAX is not subject to overturning action by moving floodwater. The permissible height of floodwater for storing an MPC is governed by the design basis flood defined in Table 2.4.1. An MPC not qualified to withstand the external pressure from a site's Design Basis Flood event shall not deployed in the HI-STORM UMAX system.

The following is an evaluation of effects on structural, thermal, criticality, confinement, and radiation protection performance on the HI-STORM UMAX system.

i. Structural

Unlike free standing casks, moving flood water is not an event of safety consequence to the HI-STORM UMAX: The buried configuration of the HI-STORM UMAX system renders it immune from sliding (that is germane to above ground freestanding casks) under the action of a design basis flood. Since the CEC shell is directly in contact with the Self-hardening Engineered Subgrade, there is no risk of a global deformation of the CEC under the DBF event.

ii. Thermal

The flooded HI-STORM UMAX ISFSI will reject heat to the floodwater. Because the heat transfer coefficient in water is considerably greater than that under the ventilation air, the temperature of the contents will be lowered. Furthermore, the heat dissipated from MPC and MPC pedestal flood tends to boil the flood water entering "UMAX" cavity and lower water level to restore sufficient air ventilation flow. Thus, the thermal effect of flood is actually salutary for the system's performance.

Partial blockage of the bottom cutout is evaluated in Section 4.6.2.5. The resulting maximum temperatures are provided in Table 4.6.9, and confirmed to maintain below the accident temperature limits specified in Table 2.3.7. In the case when flood water/soil is just high enough to completely block the divider shell cutout, it is bounded by the 100% inlet duct blockage accident discussed in Section 12.2.10.

iii. Shielding

There is no adverse effect on the function of shielding features of the system as a result of this accident event. The floodwater provides additional shielding that would further reduce radiation dose.

iv. Criticality

There is no adverse effect on the criticality control features of the stored MPC as a result of this accident event. The criticality analysis is unaffected because under the flooding condition water cannot enter the MPC contents space and therefore the reactivity would be less than that under the loading condition in the spent fuel pool (when the MPC is flooded).

v. Confinement

Because, as shown in Chapter 3, the external pressure on the MPC from the DBF is well below its design basis pressure bearing capacity, there is no risk of degradation of 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.

vi. Radiation Protection and Consequences

Since there is no effect on shielding or confinement functions as discussed above, there is no radiological consequence (from effluents and direct radiation) as a result of this accident event. A minor increase to occupational exposures for the performance of corrective actions is expected.

12.2.4.3 Flood Accident Corrective Action

The configuration of the HI-STORM UMAX VVMs makes them uniquely suited to withstand a flooding event. Indeed, introducing water in the CEC is an effective method to lower the MPC contents' temperature. However, accumulation of debris in the intake plenum or the storage cavities is undesirable as is the risk of corrosion from long-term exposure to floodwaters. Thus, while the short-term effect of flood on the loaded HI-STORM UMAX VVM is essentially benign, corrective actions after such an event are necessary. Visual examination using a boroscope or a camera or temperature monitoring of the exiting air to identify blockage of the cooling passages following flooding or other site specific natural events is necessary to ensure adequate cooling.

If a state of vent blockage is discovered, then corrective actions to alleviate such condition will be required. To restore the system to a normal configuration, all floodwater and any debris deposited by the receding water must be removed. The specific methods to be used shall be addressed in the site emergency action plan. Examples of acceptable cleaning approaches include:

1. The MPC is removed from the VVM using the HI-TRAC VW 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 are used to directly clean the VVM passages and surfaces.

2. Appropriate vacuuming equipment is inserted through the inlet plenum and down to the transverse shells. Water is sprayed in through the outlet vents. Remote cameras are used to inspect the VVM cooling passages to identify and remove debris.

The adequacy of the cooling passages clearance operation is verified by visual inspection or, if the optional temperature monitoring is used, the return of the control temperatures to within allowable limits.

12.2.4.4 Conclusion

Based on the above evaluation, it is concluded that the flood accident does not affect the safe operation of the loaded HI-STORM UMAX VVMs.

12.2.5 Earthquake (Load Case 03 in Section 2.4)

12.2.5.1 Cause of Event

Earthquake is a terrestrial instability event cause by relative movements in the mantle of the earth. The extent of seismic motion at an ISFSI location is established by geotechnical analyses. The intensity of the earthquake is substantially affected by the time span within which its probability is prognosticated.

12.2.5.2 Analysis of the Effect of Design Basis Earthquake (DBE)

The HI-STORM UMAX storage system has been qualified to a fully articulated DBE event set down in Section 2.4. The specified seismic event for the candidate ISFSI must satisfy the acceptance criteria defined in Chapters 2 and 3 to permit the HI-STORM UMAX ISFSI to be established at the site.

i. Structural

The most significant structural effect of the earthquake on the HI-STORM UMAX system are those corresponding to interface forces arising from the MPC rattling action, which acts to apply stresses on the MPC shell and MPC fuel basket panels. The MPC primary stresses resulting from the earthquake event are confirmed to be bounded by the applicable stress limits, and MPC shell secondary stresses local to the area of MPC lid are limited to small plastic deformation without risk of breaching the MPC shell; therefore, there is no effect on structural function.

All other effects correspond to ability of the VVM CEC, ISFSI Pad, and Support Foundation Pad to resist the earthquake loadings. 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. Because of its underground construction, the HI-STORM UMAX VVM is inherently safe under seismic events. Analyses presented in Chapter 3 show that the VVM will continue to render its intended function under a seismic event whose severity is bounded by the Design Basis Earthquake set forth in Chapter 2. Therefore, there is no adverse effect on the structural function of the system.

ii. Thermal

There is no effect on the function of HI-STORM UMAX VVM heat transfer features as a result of this accident event because no constriction of the air flow passages within the system is predicted to occur. Concentricity between the MPC within the CEC shell is maintained by design features and therefore the effect of MPC movement within the storage cavity has a negligible impact on air flow distribution. Thus, the cooling effectiveness of the HI-STORM UMAX VVMs is expected to remain essentially undiminished in the wake of a DBE event.

iii. Shielding

There is no adverse effect on the function of shielding features of the system as a result of this accident event.

iv. Criticality

There is no effect on the criticality control features of the MPC as a result of this accident event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. Structural evaluation shows all stresses and strains do not exceed design criteria, assuring confinement boundary integrity.

vi. Radiation Protection and Consequences

Since there is no effect on shielding or confinement functions as discussed above, there is no radiological consequence (from effluents and direct radiation) as a result of this accident event. A minor increase to occupational exposures for the performance of corrective actions is expected.

12.2.5.3 Earthquake Accident Corrective Action

Under a seismic event at an ISFSI, any damage to the HI-STORM UMAX system is expected to be localized and limited to the MPC guides and the MPC shell. A visual inspection in the wake of a seismic event shall be performed as follows:

- Visual inspection to confirm the extent of damage (if any) to the MPC shell is negligible.
- Visual inspection to verity the extent of damage (if any) to other VVM components important-to-safety is negligible.
- Visual inspection to confirm that the insulation attached to the Divider shell remains securely attached and undamaged
- Visual inspection to confirm all air flow passages are clear of obstructions.

Inspections requirements may be modified depending on the severity of the earthquake and other site-specific conditions. Corrective actions shall be implemented based on the results of the inspection.

12.2.5.4 Conclusion

Based on the above evaluation, it is concluded that the Design Basis Earthquake will not affect the safe operation of the HI-STORM UMAX system. Corrective actions, however, may be necessary to restore the system to the pre-seismic condition.

12.2.6 100% Fuel Rod Rupture

This accident event postulates the non-mechanistic condition that all the fuel rods rupture and that the quantities of fission product gases and fill gas are released from the fuel rods into the MPC cavity consistent with ISG-5, Revision 1.

12.2.6.1 Cause of 100% Fuel Rod Rupture

Through all credible accident conditions, the HI-STORM UMAX system maintains the spent nuclear fuel in an inert environment while maintaining the peak fuel cladding temperature below the required short-term temperature limits, thereby providing assurance of fuel cladding integrity. Therefore, there is no credible cause for 100% fuel rod rupture. This accident is postulated in NUREG-1536 to evaluate the MPC confinement barrier for the maximum possible internal pressure based on the *non-mechanistic* failure of 100% of the fuel rods.

12.2.6.2 Analysis

The following is an evaluation of effects on structural, thermal, criticality, confinement, and radiation protection performance on the HI-STORM UMAX storage system.

i. Structural

The effect of 100% rod rupture on the MPC is an increase in pressure boundary stresses. Calculations in Chapter 4 show that the accident internal pressure limit bounds the pressure from the 100% fuel rod rupture event; therefore, there is no effect on the MPC's structural function.

ii. Thermal

A bounding MPC internal pressure for the 100% fuel rod rupture condition is presented in Table 4.4.7. The design basis accident condition MPC internal pressure set in Table 2.3.5 and used in the structural evaluation bounds the calculated value. The increased pressure due to the 100% rod rupture has the concomitant (beneficial) effect of enhanced heat transfer through the gases in the MPC cavity. It is concluded that temperatures and pressures resulting from the accident event are bounded by the applicable system temperature and pressure limits; therefore, there is no adverse effect on thermal function.

v. Shielding

There is no adverse effect on function of the shielding features of the system as a result of this accident event.

vi. Criticality

There is no effect on the function of criticality control features of the MPC as a result of this accident event.

vii. Confinement

There is no effect on the function of confinement features of the MPC as a result of this accident event. Structural evaluation shows all stresses remain within allowable values, assuring confinement boundary integrity.

viii. Radiation Protection and Consequences

Since there is no effect on shielding or confinement functions as discussed above, there is no radiological consequence (from effluents and direct radiation) and no expected increase to occupational exposures as a result of this accident event.

Based on the above, it is concluded that the non-mechanistic 100% fuel rod rupture accident event does not affect the safe operation of the HI-STORM UMAX system.

12.2.6.3 100% Fuel Rod Rupture Dose Calculations

The breach of fuel cladding postulated in this accident event does not result in any physical change to the storage system other than some release of gases and a limited quantity of solids (particulates) into the gaseous helium space. The amount of the radiation source remains unaffected. Hence, the radiation dose at the site boundary will not change perceptibly, i.e., there are no consequences to the site boundary dose.

12.2.6.4 100% Fuel Rod Rupture Accident Corrective Action

As shown in the analysis of the 100% fuel rod rupture accident, the MPC Confinement Boundary is not damaged. The HI-STORM UMAX storage System is designed to withstand this accident and continue performing the safe storage of spent nuclear fuel under normal storage conditions. No corrective actions are required.

12.2.6.5 Conclusion

The above evaluation shows that this accident event will not adversely affect the continued safety of the storage system

12.2.7 Confinement Boundary Leakage

None of the postulated environmental phenomenon or accident conditions identified in Chapter 2 has been determined to precipitate failure of the confinement boundary. The MPC uses redundant confinement closures to assure that there is no release of radioactive materials. The analyses presented in the HI-STORM FW FSAR and in Chapter 3 herein demonstrate that the MPC remains intact during all postulated accident conditions. The information contained in Chapter 7 of the HI-STORM FW FSAR demonstrates that the MPC is designed, fabricated, tested, and inspected to meet the guidance of ISG-18 such that unacceptable leakage from the Confinement Boundary is non-credible.

12.2.8 Explosion (Load Case 01 in Section 2.4)

12.2.8.1 Cause of Explosion

An explosion within the protected area of an ISFSI is improbable since there are no explosive materials permitted within the site boundary. However, an explosion as a result of combustion of the fuel contained in a cask transport vehicle is possible. As the fuel available for the explosion is limited in quantity, the effects of an explosion on a reinforced structure are minimal. Explosions that are credible for a specific ISFSI would require a site hazards evaluation under the provisions of 10CFR72.212 regulations by the ISFSI owner using the methodology set forth in Chapter 3.

12.2.8.2 Explosion Analysis

Any credible explosion accident for the MPC is bounded by the accident external design pressure (Table 2.3.5). Because explosive materials are not stored within close proximity to the casks, the design basis pressure wave from explosion is limited to a small value (Table 2.3.1). The bounding analysis in Chapter 3 shows that the MPC and the CEC can withstand the effects of substantial accident external pressures without collapse or rupture.

i. Structural

The effect of explosion at the HI-STORM UMAX ISFSI is a near instantaneous increase of external pressure over the top exterior surface of the VVM closure lid and in the air passages and cavity space of the VVM due to the explosion-induced pressure wave. Chapter 3 includes an evaluation of the effect of the design-basis pressure wave set in Table 2.3.1 and applied as a static pressure on the exterior surfaces of the closure lid producing a downward force. Since the pressure wave entering the VVM through the closure lid vents will have slightly less energy, there is no need to consider uplift of the closure lid. Thus, the evaluation shows that the overpressure wave does not result in lid separation and that all lid stresses are a fraction of the allowable limits. Therefore, the continued structural integrity of the Closure Lid is assured.

Site-specific explosion scenarios that are not evidently bounded by the design basis explosion load considered in this FSAR shall be evaluated under the provisions of 10CFR72.212.

ii. Thermal

There is no effect on the function of HI-STORM UMAX VVM heat transfer features as a result of this accident event occurring at the ISFSI. No deformation of the HI-STORM UMAX VVM components that would result in the constriction of the air flow passages within the VVM is indicated.

iii. Shielding

There is no effect on the function of shielding features of the system as a result of this accident event.

v. Criticality

There is no effect on the function of criticality control features of the MPC as a result of this accident event.

vi. Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. As the above mentioned structural evaluation shows, all stresses remain within allowable values, assuring confinement boundary integrity.

vii. Radiation Protection and Consequences

Since there is no effect on shielding or confinement functions as discussed above, there is no radiological consequence (from effluents and direct radiation) as a result of this accident event. A negligible-to-minor increase to occupational exposures for the performance of corrective actions is expected.

12.2.8.3 Corrective Action

As there is no permanent damage indicated by this accident event, there is no need for a corrective action.

12.2.8.4 Conclusion

Based on the above evaluation, it is concluded that the design basis explosion accident event does not affect the safe operation of the loaded HI-STORM UMAX storage system.

12.2.9 Lightning

12.2.9.1 Cause of Lightning

Lightning is a meteorological event that occurs in all parts of the world.

12.2.9.2 Lightning Analysis

Because of its underground construction, the subterranean portion of the HI-STORM UMAX System is unlikely to be subjected to a direct lightning strike. The HI-STORM UMAX closure lid is, however, aboveground (albeit a low profile structure) and could be subjected to a direct strike.

When the HI-STORM UMAX VVM is struck with lightning, the lightning will discharge through the steel shell of the lid and the CEC structure to the ground. Lightning strikes have high currents, but their duration is short (i.e., less than a second). The VVM shell and lid are composed of conductive carbon steel and, as such, provides a direct path to the ground into the substrate with which it has a large interface.

Because the VVMs are buried in substrate, they are self-grounding. The lightning current will discharge into the VVM steel structure and directly into the ground. Therefore, the MPC (made of relatively non-conductive austenitic stainless steel) will be unaffected.

i. Structural

There is no structural consequence as a result of this event.

ii. Thermal

There is no effect on the thermal performance of the system as a result of this event.

iii. Shielding

There is no effect on the shielding performance of the system as a result of this event.

iv. Criticality

There is no effect on the criticality control features of the system as a result of this event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this event.

vi. 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 event.

12.2.9.3 Lightning Dose Calculations

As lightning strike has no effect on the Confinement Boundary or shielding materials, no dose analysis is necessary.

12.2.9.4 Lightning Accident Corrective Action

The HI-STORM UMAX System will not sustain any damage from the lightning accident that might adversely affect its performance. Therefore, no surveillance or corrective action is required subsequent to a lightning action at the HI-STORM UMAX ISFSI.

12.2.9.5 Conclusion

Based on this evaluation, it is concluded that a lightning event will not affect the safe operation of the HI-STORM UMAX System.

12.2.10 100% Blockage of Air Inlet

12.2.10.1 Cause of 100% Blockage of Air Inlet

This event is defined as a complete blockage of all VVM inlets. A complete blockage of all VVM inlets cannot be realistically postulated to occur at most sites. However, a flood, blizzard snow accumulation, tornado debris, or volcanic activity, where applicable, can cause a significant blockage.

12.2.10.2 100% Blockage of Air Inlet Analysis

The immediate consequence of a complete blockage of the air inlet openings 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 outlet opening, and the MPC will continue to radiate heat to the relatively cooler soil. 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 HI-STORM UMAX overpack, the MPC and the stored fuel assemblies will rise as a function of time.

As a result of the large mass and correspondingly large thermal capacity of the HI-STORM UMAX overpack, it is expected that a significant temperature rise is only possible if the blocked condition is allowed to persist for an extended duration. This accident condition is, however, a short duration event that will be identified by the ISFSI staff, at worst, during scheduled periodic surveillance at the ISFSI site and corrected using the site's emergency response process.

i. Structural

There are no structural consequences as a result of this event

ii. Thermal

A thermal analysis is performed in Subsection 4.6.2.3 to determine the effect of a complete blockage of all inlets for an extended duration. For this event, both the fuel cladding and component temperatures (see Table 4.6.7) remain below their accident temperature limits (see Table 2.3.7). The MPC internal pressure for this event is evaluated and reported in Table 4.6.10 and is bounded by the design basis internal pressure for accident conditions (see Table 2.3.5).

iii. Shielding

The above thermal results indicate insignificant loss of material and, therefore, the effect of this event on the shielding capacity is expected to be negligible.

iv. Criticality

There is no effect on the function of criticality control features of the MPC as a result of this accident event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this accident event.

vi. Radiation Protection and Consequences

Since there is no effect on shielding or confinement functions as discussed above, there is no radiological consequence (from effluents and direct radiation) as a result of this event. A negligible-to-minor increase to occupational exposures for the performance of corrective actions is expected.

12.2.10.3 Corrective Action

Analysis of the 100% blockage of air inlet accident shows that the temperatures for system components and fuel cladding are within the accident temperature limits if the blockage is cleared within the maximum elapsed period between scheduled surveillance inspections. Upon detection of the complete blockage of the air inlet openings, the ISFSI owner shall activate its emergency response procedure to remove the blockage with mechanical and manual means as necessary. After clearing the overpack openings, the system shall be visually and radiologically inspected for any damage. If exit air temperature monitoring is performed in lieu of direct visual inspections, the difference between the ambient air temperature and the exit air temperature will be the basis for the assurance that the temperature limits are not exceeded.

For an accident event that completely blocks the inlet or outlet air openings for greater than the analyzed duration, a site-specific evaluation or analysis may be performed to whether adequate heat removal for the duration of the event would occur. Adequate heat removal is defined as the minimum rate of heat dissipation that ensures cladding temperatures limits are met and structural integrity of the MPC and overpack is not compromised. For those events where an evaluation or analysis is not performed or is not successful in showing that cladding temperatures remain below their short term temperature limits, the site's emergency plan shall include provisions to address removal of the material blocking the air inlet openings and to provide alternate means of cooling prior to exceeding the time when the fuel cladding temperature reaches its short-term temperature limit. Alternate means of cooling could include, for example, spraying water into the air outlet opening using pumps or fire-hoses or blowing air into the air outlet opening, to directly cool the MPC.

12.2.10.4 Conclusion

Based on the above evaluation, it is concluded that the 100% blockage of air inlet accident event does not affect the safe operation of the HI-STORM UMAX System, if the blockage is removed in the specified time period.

12.2.11 Burial Under Debris

12.2.11.1 Cause of Burial Under Debris

Complete burial of the entire HI-STORM UMAX VVM assembly is not a credible accident because it is a large structure (see the drawing package in Section 1.5) and during storage at the ISFSI, there are no large structures above the casks that may collapse and bury the VVM. The minimum regulatory distance(s) from the ISFSI to the nearest site boundary and the controlled area around the ISFSI concrete pad precludes the close proximity of substantial amounts of vegetation. However, for purposes of safety evaluation, complete burial of the VVM including blockage of all inlet and outlet flow passages is assumed.

12.2.11.2 Burial Under Debris Analysis

Burial of the inlet plenum under debris will adversely affect thermal performance because the debris will block the inflow of air. This will cause the fuel cladding temperatures to increase. A thermal analysis has been performed to determine the time for the fuel cladding temperatures to reach the *accident condition temperature limit* due to a burial of the inlet plenum under debris accident, assuming that the debris causes complete cut-off of cool air through the inlet passages. This computed time, T-max, is specified in the Technical Specification as an LCO.

i. Structural

The effect of 100% blockage of air inlet on the MPC is an increase in component and fuel cladding temperatures and internal pressure and thus an increase in pressure boundary stresses. However, the resultant temperatures and pressures, for a burial duration equal to T-max, are below the accident condition design limits as discussed in the thermal effects evaluation below. The MPC stresses resulting from the blockage of air inlet are confirmed to be bounded by the applicable ASME code limits; therefore, there is no effect on structural function.

ii. Thermal

The fuel cladding and MPC integrity is evaluated in Subsection 4.6.2.4. The evaluation demonstrates that the fuel cladding and confinement function of the MPC are not compromised even if the burial event lasts for a substantial duration.

iii. Shielding

The above thermal results indicate that there will be no material loss in the shielding capacity of the system.

iv. Criticality

There is no effect on the function of criticality control features of the MPC as a result of this accident event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this accident event.

vi. Radiation Protection and Consequences

Since there is no effect on shielding or confinement functions as discussed above, there is no radiological consequence (from effluents and direct radiation) as a result of this event. A negligible-to-minor increase to occupational exposures for the performance of corrective actions is expected.

12.2.11.3 Corrective Action

Analysis of the burial-under-debris accident shows that the fuel cladding peak temperatures are not exceeded for the duration of the accident equal to T-max. Upon detection of the burial-under-debris accident, the ISFSI operator shall assign personnel to remove the debris from around and inside the VVM cavity with mechanical and manual means as necessary. After removing the debris, the storage cavities shall be visually inspected for any damage. The loaded MPC may have to be removed from the VVM cavities to allow complete inspection of the VVM cavities. Removal of obstructions to the air flow path shall be performed prior to the re-insertion of the MPC. The site's emergency action plan shall include provisions for the implementation of this corrective action.

12.2.11.4 Conclusion

Based on the above evaluation, it is concluded that the burial-under-debris accident event does not affect the safe operation of the HI-STORM UMAX System, if the blockage is removed in the specified time period.

12.2.12 Extreme Environmental Temperature

12.2.12.1 Cause of Extreme Environmental Temperature

The extreme environmental temperature is postulated (see Table 2.3.6) as a 3-day average temperature caused by extreme weather conditions.

12.2.12.2 Extreme Environmental Temperature Analysis

To determine the effects of the extreme temperature, it is conservatively assumed that the temperature persists for a sufficient duration (3 days) to allow the HI-STORM storage system to achieve thermal equilibrium.

The accident condition considering an extreme environmental temperature (Table 2.3.6) for a duration sufficient to reach thermal equilibrium is evaluated with respect to accident condition design temperatures listed in Table 2.3.7.

i. Structural

The effect on the MPC for the extreme environmental temperature conditions is an increase in component and fuel cladding temperatures and internal pressure and thus an increase in pressure boundary stresses. However, the resultant temperatures and pressures are below the accident design limits as discussed in the thermal effects evaluation below. The MPC stresses resulting from the extreme environmental temperatures event are confirmed to be bounded by the applicable pressure boundary stress limits; therefore, there is no effect on structural function.

ii. Thermal

The thermal evaluation of extreme environmental temperature is discussed in Section 4.6.2.2. The calculated bounding temperatures and pressures are conservatively evaluated assuming the asymptotic maximum (steady-state) condition to have been reached. Temperature results reported in Table 4.6.6 indicate that all thermal criteria are met. Additionally, the increased temperatures generate an elevated MPC internal pressure, reported in Table 4.6.10, which is less than the accident design pressure limit specified in Table 2.3.5. The temperatures and pressures resulting from the increased pressure event are confirmed to be bounded by the applicable system temperature and pressure limits; therefore, there is no effect on thermal function.

iii. Shielding

There is no effect on the function of shielding features of the system as a result of this accident event. Concrete temperatures in the lid are confirmed to remain below its accident temperature limit.

iv. Criticality

There is no effect on the function of criticality control features of the MPC as a result of this accident event.

v. Confinement

There is no effect on the confinement function of the MPC as a result of this accident event. Structural evaluation shows all stresses remain within allowable values, assuring confinement boundary integrity.

vi. Radiation Protection and Consequences

Since there is no effect on shielding or confinement functions as discussed above, there is no radiological consequence (from effluents and direct radiation) and no increase to occupational or public exposures as a result of this accident event.

12.2.12.3 Corrective Action

The extreme environmental temperature is a self-correcting event. No corrective action is required.

12.2.12.4 Conclusion

Based on this evaluation, it is concluded that the extreme environment temperature accident event does not affect the safe operation of the HI-STORM UMAX System.

12.2.13 HI-TRAC VW Transfer Cask Handling Accident

HI-TRAC VW transfer cask handling accident evaluated in the HI-STORM FW FSAR Section 12.2.1 [4.1.2] is incorporated by reference.

12.3 OTHER EVENTS

This section addresses miscellaneous events, which are placed in the category of "other events" since they cannot be categorized as off-normal or accident events. The following "other events" are discussed in this chapter:

- Hazards during Construction Proximate to the ISFSI
- MPC Reflood

The results of the evaluations performed herein demonstrate that the loaded HI-STORM UMAX VVMs can withstand the effects of "other events" without affecting safety function.

12.3.1 Construction Proximate to an Operating ISFSI

12.3.1.1 Cause of the Event

This situation will arise if the facility owner decides to expand the existing storage capacity by adding VVM assemblies adjacent to an operating ISFSI. As demonstrated in Chapter 3, the Self-hardening Engineered Subgrade (SES), in the absence of the optional Enclosure Wall, can remain intact under the Design Basis Earthquake condition and can effectively protect loaded VVMs against tornado missile impacts. This FSAR permits excavation adjacent to one side of the HI-STORM UMAX ISFSI at any given time. However, the excavation depth shall be limited to the bottom surface of the Support Foundation Pad (SFP).

12.3.1.2 Safety Analysis

i. Structural

The soil-structure interaction analysis of the ISFSI assuming that the subgrade has been excavated down to the SFP elevation for (a theoretically) infinite distance next to one side of the ISFSI has been performed. The analyses show that the storage system is kinematically stable and the stresses in the reinforced concrete structures meet the applicable ACI limits and that the canister retrievability in the wake of an earthquake is assured. In the absence the optional Enclosure Wall, the tensile stress developed in the SES under the Design Basis Earthquake condition is well below the tensile capacity of the SES material. Moreover, the local strains in the stored canisters from internal impact are well within the limit specified in this FSAR.

Furthermore, the scenario of a tornado missile striking the exposed SES has also been considered in Chapter 3. Analyses summarized in Section 3.4 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 any stored MPC.

ii. Thermal

There is no effect on the thermal performance of the system as a result of this event.

vii. Shielding

There is no effect on the function of shielding features of the system as a result of this event.

viii. Criticality

There is no effect on the function criticality control features of the MPC as a result of this event.

ix. Confinement

There is no effect on the function of confinement features of the MPC as a result of this event.

x. Radiation Protection

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 is prescribed in the licensing drawings. This radiation protection space (RPS) defines the no-construction zone around the installed and loaded VVMs (see Chapter 1).

A generic evaluation of the shielding consequences of digging a cavity adjacent to the RPS has been considered in Chapter 5 of this FSAR. The analyses show that the dose at the edge of the cavity is well below 0.2 mrem/hr, which is well below the customary limit that requires radiation posting at nuclear power plants. Therefore, the excavation activities shall be ALARA.

Nevertheless, the owner will implement appropriate measures and provide appropriate safety training to the construction crew in keeping with the plant's radiation protection plan. Analysis 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. 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.

Because the actual projectiles for a specific ISFSI site are often different from the tornado-borne missiles analyzed in Chapters 3 and 5 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.

To summarize, the RPS provides sufficient margin (buffer) against design basis projectiles analyzed in Chapter 3. In addition to the generic analyses documented in this FSAR, a 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.

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 "UMAX" ISFSI, like its aboveground counterpart, are within the purview of the plant's §72.212 process.

12.3.1.3 Corrective Action

As the excavation work is a planned activity, no corrective action is required.

12.3.1.4 Conclusion

An excavation activity adjacent to an operating ISFSI is permitted provided all safety and radiation protection requirements of the host plant are followed.

12.3.2 MPC Reflood

MPC reflood evaluated in the HI-STORM FW FSAR Section 12.3.1 [4.1.2] is incorporated by reference.

CHAPTER 13: OPERATING CONTROLS AND LIMITS

13.0 INTRODUCTION

This chapter defines the operating controls and limits (i.e., Technical Specifications) including their supporting bases for deployment and storage of an approved MPC type (see Table 1.2.1) in a HI-STORM UMAX VVM at an ISFSI. Table 1.2.1 provides the CoC amendment numbers for the MPCs that have been considered in the safety analysis documented in this report. Thus while the safety analyses have been carried out in this FSAR for all MPCs presently certified in Docket # 72-1014 (HI-STORM 100) and Docket # 1032 (HI-STORM UMAX), the Certificate-of- Compliance sought pursuant to this licensing submittal is limited to qualifying only MPC-37 and MPC-89 which have been previously certified in the HI-STORM FW docket.

13.1 PROPOSED OPERATING CONTROLS AND LIMITS

13.1.1 NUREG-1536 (Standard Review Plan) Acceptance Criteria

This portion of the FSAR establishes the commitments regarding the HI-STORM UMAX system and its use. Other 10CFR72 [13.1.1] and 10CFR20 [13.1.2] requirements in addition to the Technical Specifications may apply. The conditions for a general license holder found in 10CFR72.212 [13.1.1] shall be met by the licensee prior to loading spent fuel into the HI-STORM UMAX system. The general license conditions governed by 10CFR72 [13.1.1] are not repeated within these Technical Specifications. Licensees are required to comply with all commitments and requirements.

The Technical Specifications provided in Appendix A to the CoC and the authorized contents and design features provided in Appendix B to the CoC are primarily established to maintain subcriticality, the confinement boundary, shielding and radiological protection, heat removal capability, and structural integrity under normal, off-normal and accident conditions.

Table 13.1.1 addresses each of these conditions applicable to HI-STORM UMAX and identifies the appropriate Technical Specification(s) designed to control the condition Table 13.1.2 provides the list of Technical Specifications for the loading operations and long term fuel storage in the HI-STORM UMAX system.

Table 13.1.1

HI-STORM UMAX SYSTEM CONTROLS

Condition to be Controlled	**Applicable Technical Specifications**[†]
Criticality Control	3.3.1 Boron Concentration
Confinement boundary integrity and integrity of cladding on undamaged fuel	3.1.1 Multi-Purpose Canister (MPC)
Shielding and radiological protection	3.1.1 Multi-Purpose Canister (MPC) 3.1.3 MPC Reflooding 3.2.1 TRANSFER CASK Surface Contamination 5.1 Radioactive Effluent Control Program 5.3 Radiation Protection Program
Heat removal capability	3.1.1 Multi-Purpose Canister (MPC) 3.1.2 SFSC Heat Removal System
Structural integrity	5.2 Transport Evaluation Program

[†] Technical Specifications are located in Appendix A to the CoC. Authorized contents are specified in this FSAR in Subsection 2.1.8

Table 13.1.2

HI-STORM UMAX SYSTEM TECHNICAL SPECIFICATIONS

NUMBER	**TECHNICAL SPECIFICATION**
1.0	USE AND APPLICATION
1.1	DEFINITIONS
1.2	LOGICAL CONNECTORS
1.3	COMPLETION TIMES
1.4	FREQUENCY
2.0	Not Used
3.0	LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY SURVEILLANCE REQUIREMENT (SR) APPLICABILITY
3.1	SFSC Integrity
3.1.1	Multi-Purpose Canister (MPC)
3.1.2	SFSC Heat Removal System
3.1.3	MPC Cavity Reflooding
3.2	SFSC Radiation Protection
3.2.1	TRANSFER CASK Surface Contamination
3.3	SFSC Criticality Control
3.3.1	Boron Concentration
Table 3-1	MPC Cavity Drying Limits
Table 3-2	MPC Helium Backfill Limits
4.0	Not Used
5.0	ADMINSTRATIVE CONTROLS
5.1	Radioactive Effluent Control Program
5.2	Transport Evaluation Program
5.3	Radiation Protection Program

13.2 DEVELOPMENT OF OPERATING CONTROLS AND LIMITS

This section provides a discussion of the operating controls and limits, and training requirements for the HI-STORM UMAX system to assure long-term performance consistent with the conditions analyzed in this FSAR.

13.2.1 Training Modules

Training modules are to be developed under the licensee's training program to require a comprehensive, site-specific training, assessment, and qualification (including periodic re-qualification) program for the operation and maintenance of the HI-STORM UMAX Spent Fuel Storage Cask (SFSC) System and the Independent Spent Fuel Storage Installation (ISFSI). The training modules shall include the following elements, at a minimum:

1. HI-STORM UMAX System Design (overview);

2. ISFSI Facility Design (overview);

3. Systems, Structures, and Components Important-to-Safety (overview);

4. HI-STORM UMAX System Safety Analysis Report (overview);

5. NRC Safety Evaluation Report (overview);

6. Certificate of Compliance conditions;

7. HI-STORM UMAX Technical Specifications, Approved Contents, Design Features and other Conditions for Use;

8. HI-STORM UMAX Regulatory Requirements (e.g., 10CFR72.48, 10CFR72, Subpart K, 10CFR20, 10CFR73);

9. Required instrumentation and use;

10. Operating Experience Reviews

11. HI-STORM UMAX System and ISFSI Procedures, including
    - Procedural overview
    - Fuel qualification and loading
    - MPC /HI-TRAC/VVM Closure Lid rigging and handling, including safe load pathways
    - MPC welding operations

- HI-TRAC/VVM staging operation
- Auxiliary equipment operation and maintenance (e.g., draining, moisture removal, helium backfilling and cooldown)
- MPC/HI-TRAC/VVM pre-operational and in-service inspections and tests
- Transfer and securing of the loaded HI-TRAC onto the transport vehicle
- Movement of HI-TRAC to ISFSI.
- Transfer of MPC to VVM
- Preparation of MPC/HI-TRAC VVM for fuel unloading
- Retrieval of MPC from VVM
- Surveillance
- Radiation protection
- Maintenance
- Security
- Off-normal and accident conditions, responses, and corrective actions

13.2.2 Dry Run Training

A dry run training exercise of the loading, closure, handling, and transfer of the HI-STORM UMAX system shall be conducted by the licensee prior to the first use of the system to load spent fuel assemblies. Dry run training already performed successfully for the HI-STORM 100 System can be substituted for dry run steps applicable to HI-STORM UMAX. The dry run shall include, but is not limited to the following:

1. Inspection of the HI-STORM UMAX System components.

2. Moving the MPC/HI-TRAC into the spent fuel pool.

3. Preparation of the MPC/HI-TRAC for fuel loading.

4. Selection and verification of specific fuel assemblies to ensure conformance.

5. Locating specific assemblies and placing assemblies into the MPC/HI-TRAC (using a dummy fuel assembly), including appropriate independent verification.

6. Remote installation of the MPC lid and removal of the MPC/HI-TRAC from the spent fuel pool.

7. MPC welding, NDE inspections, pressure testing, draining, moisture removal, and helium backfilling (for which a mockup MPC may be used).

8 Movement of the loaded HI-TRAC to the ISFSI.

9. Transfer of the MPC from the HI-TRAC into the HI-STORM UMAX VVM at the ISFSI.

13.2.3 Functional and Operating Limits, Monitoring Instruments, and Limiting Control Settings

The controls and limits apply to operating parameters and conditions which are observable, detectable, and/or measurable. The HI-STORM UMAX system is completely passive during storage and requires no monitoring instruments. The user may choose to implement a temperature monitoring system or visually inspect the vent screens to verify operability of the VVM heat removal system in accordance with Technical Specification Limiting Condition for Operation (LCO) 3.1.2.

13.2.4 Limiting Conditions for Operation (LCO)

Limiting Conditions for Operation (LCO) specify the minimum capability or level of performance that is required to assure that the HI-STORM UMAX system can fulfill its safety functions.

13.2.5 Equipment

The HI-STORM UMAX system and its components have been analyzed for specified normal, off-normal, and accident conditions, including extreme environmental conditions. Analysis has shown that no credible condition or event prevents the HI-STORM UMAX system from meeting its safety function. As a result, there is no threat to public health and safety from any postulated accident condition or analyzed event. When all equipment is loaded, tested, and placed into storage in accordance with procedures developed for the ISFSI, no failure of the system to perform its safety function is expected to occur.

13.2.6 Surveillance Requirements

The analyses show that the HI-STORM UMAX system fulfills its safety functions, provided that the Technical Specifications and the Authorized Contents described in Subsection 2.1.8 are met. Surveillance requirements during loading, unloading, and storage operations are provided in the Technical Specifications.

13.2.7 Design Features

This subsection describes HI-STORM UMAX system design features that are Important to Safety. These features require design controls and fabrication controls. The design features, detailed in this FSAR and in Appendix B to the CoC, are established in specifications and drawings which are controlled through the quality assurance program. Fabrication controls and inspections are in place to ensure that the HI-STORM UMAX system is fabricated in accordance with the licensing drawings in Section 1.5.

13.2.8 MPC

a. Basket material composition, properties, dimensions, and tolerances for criticality control.
b. Canister material mechanical properties for structural integrity of the confinement boundary.
c. Canister and basket material thermal properties and dimensions for heat transfer control.
d. Canister and basket material composition and dimensions for dose rate control.

13.2.9 HI-STORM UMAX VVM

a. HI-STORM UMAX VVM material mechanical properties and dimensions for structural integrity to provide protection of the MPC and shielding of the spent nuclear fuel assemblies during handling and storage operations.
b. HI-STORM UMAX VVM material thermal properties and dimensions for heat transfer control.
c. HI-STORM UMAX VVM material composition and dimensions for dose rate control.

13.2.10 HI-TRAC Transfer Cask

a. HI-TRAC transfer cask material mechanical properties and dimensions for structural integrity to provide protection of the MPC and shielding of the spent nuclear fuel assemblies during loading, unloading and handling operations.
b. HI-TRAC transfer cask material thermal properties and dimensions for heat transfer control.
c. HI-TRAC transfer cask material composition and dimensions for dose rate control.

13.2.11 Verifying Compliance with Fuel Assembly Decay Heat, Burnup, and Cooling Time Limits

The examples below execute the methodology for determining allowable decay heat, burnup, and cooling time for the approved contents.

Example 1

In this example, it will be assumed that the MPC-37 is being loaded with array/class 17x17A fuel in its regionalized loading pattern as shown in Figure 2.1.7 with heat loads from Table 2.1.8.

Table 13.2.1 provides four hypothetical fuel assemblies in the 17x17A array/class that will be evaluated for acceptability for loading in the MPC-37. The decay heat values and the fuel classification in Table 13.2.1 are determined by the user. The other information is taken from the fuel assembly and reactor operating records.

Fuel Assembly Number 1 is acceptable for storage in Region 2 of MPC-37. Fuel Assembly Number 1 is not acceptable for storage in Region 1 or Region 3 because the total heat load of the fuel assembly and the non-fuel hardware exceeds the decay heat limit for those regions.

Fuel Assembly Number 2 is not acceptable for loading. Fuel Assembly 2 is limited to the cell locations for DFCs in the MPC-37 (Figure 2.1.1). These cells, which are a subset of Region 3, have a decay heat limit lower than the decay heat of the assembly. This assembly will need additional cooling time (reduction in decay heat) to be acceptable for loading in the MPC-37.

Fuel Assembly Number 3 is acceptable for loading in Region 1 or Region 2. The fuel assembly is limited to these locations due to the non-fuel hardware (Figure 2.1.5) and the total heat load of the fuel assembly and non-fuel hardware is less than the decay heat limits for these regions.

Fuel Assembly Number 4 is not acceptable for loading in the MPC-37 because its cooling time is less than the minimum of 3 years. When the fuel assembly attains three years cooling time it can be reevaluated based on the decay heat.

Example 2

In this example, it will be assumed that the MPC-89 is being loaded with array/class 10x10A fuel in its regionalized storage pattern as shown in Figure 2.1.8 with heat loads from Table 2.1.9.

Table 13.2.2 provides four hypothetical fuel assemblies in the 10x10A array/class that will be evaluated for acceptability for loading in the MPC-89. The decay heat values and the fuel classification in Table 13.2.2 are determined by the user. The other information is taken from the fuel assembly and reactor operating records.

Fuel Assembly Number 1 is acceptable for loading in the MPC-89. Fuel Assembly 1 is limited to the cell locations for DFCs in the MPC-89 (Figure 2.1.2). These cells, which are a subset of Region 3, have a decay heat limit higher than the decay heat of the assembly, therefore the assembly is acceptable for loading in the MPC-89, but it is limited to the cells depicted in Figure 2.1.2

Fuel Assembly Number 2 is not acceptable for loading in the MPC-89. Fuel Assembly 2 is limited to the cell locations for DFCs in the MPC-89 (Figure 2.1.2). These cells, which are a subset of Region 3, have a decay heat limit lower than the decay heat of the assembly. This assembly will need additional cooling time (reduction in decay heat) to be acceptable for loading in the MPC-89.

Fuel Assembly Number 3 is acceptable for loading in Regions 1, 2 or 3 of the MPC-89.

Fuel Assembly Number 4 is acceptable for loading in Region 2 of the MPC-89 only. The fuel assembly is limited to these locations due to the total heat load of the fuel assembly.

Table 13.2.1

SAMPLE CONTENTS TO DETERMINE ACCEPTABILITY FOR STORAGE
(Array/Class 17x17A)

FUEL ASSEMBLY NUMBER	**1**	**2**	**3**	**4**
INITIAL ENRICHMENT (WT. % ^{235}U)	3.0	3.2	4.3	4.5
FUEL ASSEMBLY BURNUP (MWD/MTU)	37100	35250	41276	55000
FUEL ASSEMBLY COOLING TIME (YEARS)	4.7	3.3	18.2	2.9
FUEL ASSEMBLY DECAY HEAT (KW)	1.01	1.45	0.4	2.08
NON-FUEL HARDWARE STORED WITH ASSEMBLY	BPRA	None	NSA	None
NFH DECAY HEAT (KW)	0.5	0	0.3	0
FUEL CLASSIFICATION	Undamaged	Damaged	Undamaged	Undamaged

Table 13.2.2

SAMPLE CONTENTS TO DETERMINE ACCEPTABILITY FOR STORAGE
(Array/Class 10x10A)

FUEL ASSEMBLY NUMBER	**1**	**2**	**3**	**4**
INITIAL ENRICHMENT (WT. % ^{235}U)	3.0	3.2	4.3	4.5
FUEL ASSEMBLY BURNUP (MWD/MTU)	37100	35250	41276	55000
FUEL ASSEMBLY COOLING TIME (YEARS)	4.7	3.3	18.2	7
FUEL ASSEMBLY DECAY HEAT (KW)	0.43	0.55	0.2	0.61
FUEL CLASSIFICATION	Damaged	Damaged	Undamaged	Undamaged

13.3 TECHNICAL SPECIFICATIONS

Technical Specifications for the HI-STORM UMAX system are provided in Appendix A to the Certificate of Compliance. Authorized Contents (i.e., fuel specifications) and Design Features are provided in Appendix B to the CoC. Bases applicable to the Technical Specifications are provided in the FSAR Appendix 13.A. The format and content of the HI-STORM UMAX system Technical Specifications and Bases are that of the Improved Standard Technical Specifications for power reactors, to the extent they apply to a dry spent fuel storage cask system. NUMARC Document 93-03, "Writer's Guide for the Restructured Technical Specifications" [13.3.1] was used as a guide in the development of the Technical Specifications and Bases.

13.4 REGULATORY EVALUATION

Table 13.1.2 lists the Technical Specifications for the HI-STORM UMAX system. The Technical Specifications are detailed in Appendix A to the Certificate of Compliance. Authorized Contents (i.e., fuel specifications) and Design Features are provided in Appendix B to the CoC.

The conditions for use of the HI-STORM UMAX system identify necessary Technical Specifications, limits on authorized contents (i.e., fuel), and design features to satisfy 10 CFR Part 72, and the applicable acceptance criteria have been satisfied. Compliance with these Technical Specifications and other conditions of the Certificate of Compliance provides reasonable assurance that the HI-STORM UMAX system will provide safe storage of spent fuel and is in compliance with 10 CFR Part 72, the regulatory guides, applicable codes and standards, and accepted practices.

13.5 REFERENCES

[13.1.1] U.S. Code of Federal Regulations, Title 10, *Energy*, Part 72, *Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste.*"

[13.1.2] U.S. Code of Federal Regulations, Title 10, *Energy*, Part 20, *Standards for Protection Against Radiation.*"

[13.3.1] Nuclear Management and Resources Council, Inc. – *Writer's Guide for the Restructured Technical Specifications,* NUMARC 93-03, February 1993.

HI-STORM UMAX SYSTEM FSAR

APPENDIX 13.A

TECHNICAL SPECIFICATION BASES

FOR THE HOLTEC HI-STORM UMAX CANISTER STORAGE SYSTEM

BASES TABLE OF CONTENTS

Note: The text matter in the "arial" font is excerpted from the HI-STORM FW FSAR.

B 3.0 LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY

BASES	
LCOs	LCO 3.0.1, 3.0.2, 3.0.4, and 3.0.5 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.
LCO 3.0.1	LCO 3.0.1 establishes the Applicability statement within each individual Specification as the requirement for when the LCO is required to be met (i.e., when the facility is in the specified conditions of the Applicability statement of each Specification).
LCO 3.0.2	LCO 3.0.2 establishes that upon discovery of a failure to meet an LCO, the associated ACTIONS shall be met. The Completion Time of each Required Action for an ACTIONS Condition is applicable from the point in time that an ACTIONS Condition is entered. The Required Actions establish those remedial measures that must be taken within specified Completion Times when the requirements of an LCO are not met. This Specification establishes that: a. Completion of the Required Actions within the specified Completion Times constitutes compliance with a Specification; and b. Completion of the Required Actions is not required when an LCO is met within the specified Completion Time, unless otherwise specified. There are two basic types of Required Actions. The first type of Required Action specifies a time limit in which the LCO must be met. This time limit is the Completion Time to restore a system or component or to restore variables to within specified limits. Whether stated as a Required Action or not, correction of the entered Condition is an action that may always be considered upon entering ACTIONS. The second type of Required Action specifies the remedial measures that permit continued operation that is not further restricted by the Completion Time. In this case, compliance with the Required Actions provides an acceptable level of safety for continued operation.

(continued)

BASES

LCO 3.0.2 (continued)

Completing the Required Actions is not required when an LCO is met or is no longer applicable, unless otherwise stated in the individual Specifications.

The Completion Times of the Required Actions are also applicable when a system or component is removed from service intentionally. The reasons for intentionally relying on the ACTIONS include, but are not limited to, performance of Surveillances, preventive maintenance, corrective maintenance, or investigation of operational problems. Entering ACTIONS for these reasons must be done in a manner that does not compromise safety. Intentional entry into ACTIONS should not be made for operational convenience.

LCO 3.0.3

This specification is not applicable to a dry storage cask system because it describes conditions under which a power reactor must be shut down when an LCO is not met and an associated ACTION is not met or provided. The placeholder is retained for consistency with the power reactor technical specifications.

LCO 3.0.4

LCO 3.0.4 establishes limitations on changes in specified conditions in the Applicability when an LCO is not met. It precludes placing the HI-STORM UMAX System in a specified condition stated in that Applicability (e.g., Applicability desired to be entered) when the following exist:

a. Facility conditions are such that the requirements of the LCO would not be met in the Applicability desired to be entered; and

b. Continued noncompliance with the LCO requirements, if the Applicability were entered, would result in being required to exit the Applicability desired to be entered to comply with the Required Actions.

Compliance with Required Actions that permit continuing with dry fuel storage activities for an unlimited period of time in a specified condition provides an acceptable level of safety for continued operation. This is without regard to the status of the dry storage system. Therefore, in such cases, entry into a specified condition in the Applicability may be made in accordance with the provisions of the Required Actions. The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified condition in the Applicability.

(continued)

BASES

LCO 3.0.4 (continued)

The provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS. In addition, the provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that are related to the unloading of an SFSC.

Exceptions to LCO 3.0.4 are stated in the individual Specifications. Exceptions may apply to all the ACTIONS or to a specific Required Action of a Specification.

LCO 3.0.5

LCO 3.0.5 establishes the allowance for restoring equipment to service under administrative controls when it has been removed from service or determined to not meet the LCO to comply with the ACTIONS. The sole purpose of this Specification is to provide an exception to LCO 3.0.2 (e.g., to not comply with the applicable Required Action(s)) to allow the performance of testing to demonstrate:

a. The equipment being returned to service meets the LCO; or

b. Other equipment meets the applicable LCOs.

The administrative controls ensure the time the equipment is returned to service in conflict with the requirements of the ACTIONS is limited to the time absolutely necessary to perform the allowed testing. This Specification does not provide time to perform any other preventive or corrective maintenance.

B 3.0 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

BASES

SRs SR 3.0.1 through SR 3.0.4 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.

SR 3.0.1 SR 3.0.1 establishes the requirement that SRs must be met during the specified conditions in the Applicability for which the requirements of the LCO apply, unless otherwise specified in the individual SRs. This Specification is to ensure that Surveillances are performed to verify that systems and components meet the LCO and variables are within specified limits. Failure to meet a Surveillance within the specified Frequency, in accordance with SR 3.0.2, constitutes a failure to meet an LCO.

Systems and components are assumed to meet the LCO when the associated SRs have been met. Nothing in this Specification, however, is to be construed as implying that systems or components meet the associated LCO when:

a. The systems or components are known to not meet the LCO, although still meeting the SRs; or

b. The requirements of the Surveillance(s) are known to be not met between required Surveillance performances.

Surveillances do not have to be performed when the HI-STORM UMAX System is in a specified condition for which the requirements of the associated LCO are not applicable, unless otherwise specified.

Surveillances, including Surveillances invoked by Required Actions, do not have to be performed on equipment that has been determined to not meet the LCO because the ACTIONS define the remedial measures that apply. Surveillances have to be met and performed in accordance with SR 3.0.2, prior to returning equipment to service. Upon completion of maintenance, appropriate post-maintenance testing is required. This includes ensuring applicable Surveillances are not failed and their most recent performance is in accordance with SR 3.0.2. Post maintenance testing may not be possible in the current specified conditions in the Applicability due to the necessary dry storage cask system parameters not having been established. In these situations, the equipment may be considered to meet the LCO provided testing has been satisfactorily completed to the extent possible and the equipment is not otherwise believed to be incapable of performing its function. This will allow dry fuel storage activities to proceed to a specified condition where other necessary post maintenance tests can be completed.

(continued)

BASES

SR 3.0.2

SR 3.0.2 establishes the requirements for meeting the specified Frequency for Surveillances and any Required Action with a Completion Time that requires the periodic performance of the Required Action on a "once per..." interval.

SR 3.0.2 permits a 25% extension of the interval specified in the Frequency. This extension facilitates Surveillance scheduling and considers facility conditions that may not be suitable for conducting the Surveillance (e.g., transient conditions or other ongoing Surveillance or maintenance activities).

The 25% extension does not significantly degrade the reliability that results from performing the Surveillance at its specified Frequency. This is based on the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the SRs. The exceptions to SR 3.0.2 are those Surveillances for which the 25% extension of the interval specified in the Frequency does not apply. These exceptions are stated in the individual Specifications as a Note in the Frequency stating, "SR 3.0.2 is not applicable."

As stated in SR 3.0.2, the 25% extension also does not apply to the initial portion of a periodic Completion Time that requires performance on a "once per..." basis. The 25% extension applies to each performance after the initial performance. The initial performance of the Required Action, whether it is a particular Surveillance or some other remedial action, is considered a single action with a single Completion Time. One reason for not allowing the 25% extension to this Completion Time is that such an action usually verifies that no loss of function has occurred by checking the status of redundant or diverse components or accomplishes the function of the affected equipment in an alternative manner.
The provisions of SR 3.0.2 are not intended to be used repeatedly merely as an operational convenience to extend Surveillance intervals or periodic Completion Time intervals beyond those specified.

(continued)

BASES

SR 3.0.3

SR 3.0.3 establishes the flexibility to defer declaring affected equipment as not meeting the LCO or an affected variable outside the specified limits when a Surveillance has not been completed within the specified Frequency. A delay period of up to 24 hours or up to the limit of the specified Frequency, whichever is less, applies from the point in time that it is discovered that the Surveillance has not been performed in accordance with SR 3.0.2, and not at the time that the specified Frequency was not met.

This delay period provides adequate time to complete Surveillances that have been missed. This delay period permits the completion of a Surveillance before complying with Required Actions or other remedial measures that might preclude completion of the Surveillance.

The basis for this delay period includes consideration of HI-STORM UMAX System conditions, adequate planning, availability of personnel, the time required to perform the Surveillance, the safety significance of the delay in completing the required Surveillance, and the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the requirements. When a Surveillance with a Frequency based not on time intervals, but upon specified facility conditions, is discovered not to have been performed when specified, SR 3.0.3 allows the full delay period of 24 hours to perform the Surveillance.

SR 3.0.3 also provides a time limit for completion of Surveillances that become applicable as a consequence of changes in the specified conditions in the Applicability imposed by the Required Actions.

Failure to comply with specified Frequencies for SRs is expected to be an infrequent occurrence. Use of the delay period established by SR 3.0.3 is a flexibility which is not intended to be used as an operational convenience to extend Surveillance intervals.

(continued)

BASES

SR 3.0.3 (continued)

If a Surveillance is not completed within the allowed delay period, then the equipment is considered to not meet the LCO or the variable is considered outside the specified limits and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon expiration of the delay period. If a Surveillance is failed within the delay period, then the equipment does not meet the LCO, or the variable is outside the specified limits and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon the failure of the Surveillance.

Completion of the Surveillance within the delay period allowed by this Specification, or within the Completion Time of the ACTIONS, restores compliance with SR 3.0.1.

SR 3.0.4

SR 3.0.4 establishes the requirement that all applicable SRs must be met before entry into a specified condition in the Applicability.

This Specification ensures that system and component requirements and variable limits are met before entry into specified conditions in the Applicability for which these systems and components ensure safe conduct of dry fuel storage activities.

The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified condition in the Applicability.

However, in certain circumstances, failing to meet an SR will not result in SR 3.0.4 restricting a change in specified condition. When a system, subsystem, division, component, device, or variable is outside its specified limits, the associated SR(s) are not required to be performed per SR 3.0.1, which states that Surveillances do not have to be performed on equipment that has been determined to not meet the LCO. When equipment does not meet the LCO, SR 3.0.4 does not apply to the associated SR(s) since the requirement for the SR(s) to be performed is removed. Therefore, failing to perform the Surveillance(s) within the specified Frequency does not result in an SR 3.0.4 restriction to changing specified conditions of the Applicability. However, since the LCO is not met in this instance, LCO 3.0.4 will govern any restrictions that may (or may not) apply to specified condition changes.

(continued)

BASES

SR 3.0.4 (continued)

The provisions of SR 3.0.4 shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS. In addition, the provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that are related to the unloading of an SFSC.

The precise requirements for performance of SRs are specified such that exceptions to SR 3.0.4 are not necessary. The specific time frames and conditions necessary for meeting the SRs are specified in the Frequency, in the Surveillance, or both. This allows performance of Surveillances when the prerequisite condition(s) specified in a Surveillance procedure require entry into the specified condition in the Applicability of the associated LCO prior to the performance or completion of a Surveillance. A Surveillance that could not be performed until after entering the LCO Applicability would have its Frequency specified such that it is not "due" until the specific conditions needed are met. Alternately, the Surveillance may be stated in the form of a Note as not required (to be met or performed) until a particular event, condition, or time has been reached. Further discussion of the specific formats of SRs' annotation is found in Section 1.4, Frequency.

B 3.1 SFSC Integrity

B 3.1.1 Multi-Purpose Canister (MPC)

BASES

BACKGROUND

A TRANSFER CASK with an empty MPC is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the CoC. A lid is then placed on the MPC. The TRANSFER CASK and MPC are raised to the top of the spent fuel pool surface. The TRANSFER CASK and MPC are then moved into the preparation area where the MPC lid is welded to the MPC shell and the welds are inspected and tested. The water is drained from the MPC cavity and drying is performed. The MPC cavity is backfilled with helium. Then, the MPC vent and drain port cover plates and closure ring are installed and welded. Inspections are performed on the welds.

MPC cavity moisture removal using vacuum drying or forced helium dehydration is performed to remove residual moisture from the MPC cavity space after the MPC has been drained of water. If vacuum drying is used, any water that has not drained from the fuel cavity evaporates from the fuel cavity due to the vacuum. This is aided by the temperature increase due to the decay heat of the fuel.

If forced helium dehydration is used, the dry gas introduced to the MPC cavity through the vent or drain port absorbs the residual moisture in the MPC. This humidified gas exits the MPC via the other port and the absorbed water is removed through condensation and/or mechanical drying. The dried helium is then forced back to the MPC until the temperature acceptance limit is met.

After the completion of drying, the MPC cavity is backfilled with helium meeting the requirements of the CoC.

Backfilling of the MPC fuel cavity with helium promotes gaseous heat dissipation and the inert atmosphere protects the fuel cladding. Backfilling the MPC with helium in the required quantity eliminates air in-leakage over the life of the MPC because the cavity pressure rises due to heat up of the confined gas by the fuel decay heat during storage.

(continued)

BASES	
APPLICABLE SAFETY ANALYSIS	The confinement of radioactivity during the storage of spent fuel in the MPC is ensured by the confinement boundary of the MPC in which the fuel assemblies are stored. Long-term integrity of the fuel and cladding depend on storage in an inert atmosphere. This is accomplished by removing water from the MPC and backfilling the cavity with an inert gas. The thermal analyses of the MPC assume that the MPC cavity is filled with dry helium of a minimum quantity to ensure the assumptions used for convection heat transfer are preserved. Keeping the backfill pressure below the maximum value preserves the initial condition assumptions made in the MPC over-pressurization evaluation.
LCO	A dry, helium filled, and sealed MPC establishes an inert heat removal environment necessary to ensure the integrity of the fuel cladding. Moreover, it also ensures that there will be no air in-leakage into the MPC cavity that could damage the fuel cladding over the storage period.
APPLICABILITY	The dry, sealed, and inert atmosphere is required to be in place prior to TRANSPORT OPERATIONS to ensure both the confinement and heat removal mechanisms are in place during these operating periods. These conditions are not required during LOADING OPERATIONS or UNLOADING OPERATIONS as these conditions are being established or removed, respectively, during these periods in support of other activities being performed with the stored fuel.

(continued)

BASES

ACTIONS

A note has been added to the ACTIONS which states that, for this LCO, separate Condition entry is allowed for each MPC. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each MPC not meeting the LCO. Subsequent MPCs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the cavity vacuum drying pressure or demoisturizer exit gas temperature limit has been determined not to be met prior to TRANSPORT OPERATIONS, an engineering evaluation is necessary to determine the potential quantity of moisture left within the MPC cavity. Since moisture remaining in the cavity during these modes of operation represent a long-term degradation concern, immediate action is not necessary. The Completion Time is sufficient to complete the engineering evaluation commensurate with the safety significance of the CONDITION.

A.2

Once the quantity of moisture potentially left in the MPC cavity is determined, a corrective action plan shall be developed and actions initiated to the extent necessary to return the MPC to an analyzed condition. Since the quantity of moisture estimated under Required Action A.1 can range over a broad scale, different recovery strategies may be necessary. Since moisture remaining in the cavity during these modes of operation represent a long-term degradation concern, immediate action is not necessary. The Completion Time is sufficient to develop and initiate the corrective actions commensurate with the safety significance of the CONDITION.

(continued)

BASES

ACTIONS (continued)

B.1

If the helium backfill quantity limit has been determined not to be met prior to TRANSPORT OPERATIONS, an engineering evaluation is necessary to determine the quantity of helium within the MPC cavity. Since too much or too little helium in the MPC during these modes represents a potential overpressure or heat removal degradation concern, an engineering evaluation shall be performed in a timely manner. The Completion Time is sufficient to complete the engineering evaluation commensurate with the safety significance of the CONDITION.

B.2

Once the quantity of helium in the MPC cavity is determined, a corrective action plan shall be developed and initiated to the extent necessary to return the MPC to an analyzed condition either by adding or removing helium or by demonstrating through analysis that all system limits will continue to be met. Since the quantity of helium estimated under Required Action B.1 can range over a broad scale, different recovery strategies may be necessary. Since elevated or reduced helium quantities existing in the MPC cavity represent a potential overpressure or heat removal degradation concern, corrective actions should be developed and implemented in a timely manner. The Completion Time is sufficient to develop and initiate the corrective actions commensurate with the safety significance of the CONDITION.

C.1

If the helium leak rate limit has been determined not to be met prior to TRANSPORT OPERATIONS, an engineering evaluation is necessary to determine the impact of increased helium leak rate on heat removal and off-site dose. Since the HI-STORM UMAX VVM is a ventilated system, any leakage from the MPC is transported directly to the environment. Since an increased helium leak rate represents a potential challenge to MPC heat removal and the off-site doses, reasonably rapid action is warranted. The Completion Time is sufficient to complete the engineering evaluation commensurate with the safety significance of the CONDITION.

(continued)

BASES

ACTIONS (continued)

C.2

Once the consequences of the elevated leak rate from the MPC are determined, a corrective action plan shall be developed and initiated to the extent necessary to return the MPC to an analyzed condition. Since the recovery mechanisms can range over a broad scale based on the evaluation performed under Required Action C.1, different recovery strategies may be necessary. Since an elevated helium leak rate represents a challenge to heat removal rates and offsite doses, reasonably rapid action is required. The Completion Time is sufficient to develop and initiate the corrective actions commensurate with the safety significance of the CONDITION.

D.1

If the MPC fuel cavity cannot be successfully returned to a safe, analyzed condition, the fuel must be placed in a safe condition in the spent fuel pool. The Completion Time is reasonable based on the time required to re-flood the MPC, cut the MPC lid welds, move the TRANSFER CASK into the spent fuel pool, remove the MPC lid, and remove the spent fuel assemblies in an orderly manner and without challenging personnel.

SURVEILLANCE REQUIREMENTS

SR 3.1.1.1 , SR 3.1.1.2, and SR 3.1.1.3

The long-term integrity of the stored fuel is dependent on storage in a dry, inert environment. Under certain conditions, cavity dryness may be demonstrated either by evacuating the cavity to a very low absolute pressure and verifying that the pressure is held over a specified period of time or by recirculating dry helium through the MPC cavity to absorb moisture until the gas temperature or dew point at the specified location reaches and remains below the acceptance limit for the specified time period. A low vacuum pressure or a demoisturizer exit temperature meeting the acceptance limit is an indication that the cavity is dry. Other conditions require the forced helium dehydration method of moisture removal to be used to provide necessary cooling of the fuel during drying operations.

(continued)

BASES

SURVEILLANCE REQUIREMENTS (continued)

Cooling provided by normal operation of the forced helium dehydration system ensures that the fuel cladding temperature remains below the applicable limits since forced recirculation of helium provides more effective heat transfer than that which occurs during normal storage operations.

The conditions and requirements for drying the MPC cavity based on the burnup class of the fuel (moderate or high), heat load, and the applicable short-term temperature limit are given in the CoC/TS Appendix A, Table 3-1. The temperature limits and associated cladding hoop stress calculation requirements are consistent with the guidance in NRC Interim Staff Guidance (ISG) Document 11.

Having the proper quantity of helium in the MPC ensures adequate heat transfer from the fuel to the fuel basket and surrounding structure of the MPC and precludes any overpressure event from challenging the normal, off-normal, or accident design pressure of the MPC.

Meeting the helium leak rate limit prior to TRANSPORT OPERATIONS ensures there is adequate helium in the MPC for long term storage and that there is no credible effluent dose from the MPC.

All of these surveillances must be successfully performed once, prior to TRANSPORT OPERATIONS to ensure that the conditions are established for SFSC storage which preserve the analysis basis supporting the MPC design.

REFERENCES

1. FSAR Chapters 1, 4, 7 and 9 of the HI-STORM UMAX and HI-STORM FW FSARs
2. Interim Staff Guidance Document 11, Rev. 3
3. Interim Staff Guidance Document 18, Rev. 1

B 3.1 SFSC Integrity

B 3.1.2 SFSC Heat Removal System

BASES	
BACKGROUND	The SFSC Heat Removal System is a passive, air-cooled, convective heat transfer system that ensures heat from the MPC canister is transferred to the environs by the chimney effect. Air is drawn into the inlet ducts and travels down the space between the Cavity Enclosure Container (CEC) and the Divider Shell, through the cut-outs at the bottom of the Divider Shell, up the space between the Divider Shell and the MPC, and out through the outlet duct. The MPC transfers its heat from its surface to the air via natural convection. The buoyancy created by the heating of the air creates a chimney effect.
APPLICABLE SAFETY ANALYSIS	The thermal analyses of the SFSC take credit for the decay heat from the spent fuel assemblies being ultimately transferred to the ambient environment surrounding the VVM. Transfer of heat away from the fuel assemblies ensures that the fuel cladding and other SFSC component temperatures do not exceed applicable limits. Under normal storage conditions, the inlet and outlet duct screens are unobstructed and full air flow occurs. Analyses have been performed for half and complete obstruction of the inlet duct screens. Blockage of half of the inlet ducts reduces air flow through the VVM and decreases heat transfer from the MPC. Under this off-normal condition, no SFSC components exceed the short term temperature limits. The complete blockage of all inlet air ducts stops normal air cooling of the MPC. The MPC will continue to radiate heat to the relatively cooler subgrade. With the loss of normal air cooling, the SFSC component temperatures will increase toward their respective short-term temperature limits. None of the components reach their temperature limits over the duration of the analyzed event.

(continued)

BASES

LCO

The SFSC Heat Removal System must be verified to be operable to preserve the assumptions of the thermal analyses. Operability is defined as 50% or less of the inlet air ducts are obstructed. Operability of the heat removal system ensures that the decay heat generated by the stored fuel assemblies is transferred to the environs at a sufficient rate to maintain fuel cladding and other SFSC component temperatures within design limits.

The intent of this LCO is to address those occurrences of air duct screen blockage that can be reasonably anticipated to occur from time to time at the ISFSI (i.e., Design Event I and II class events per ANSI/ANS-57.9). These events are of the type where corrective actions can usually be accomplished within one 8-hour operating shift to restore the heat removal system to operable status (e.g., removal of loose debris).

This LCO is not intended to address low frequency, unexpected Design Event III and IV class events (ANSI/ANS-57.9) such as design basis accidents and extreme environmental phenomena that could potentially block one or more of the air ducts for an extended period of time (i.e., longer than the total Completion Time of the LCO). This class of events is addressed site-specifically as required by Section 3.4.11 of Appendix B to the CoC.

APPLICABILITY

The LCO is applicable during STORAGE OPERATIONS. Once an OVERPACK containing an MPC loaded with spent fuel has been placed in storage, the heat removal system must be operable to ensure adequate dissipation of the decay heat from the fuel assemblies.

ACTIONS

A note has been added to the ACTIONS which states that, for this LCO, separate Condition entry is allowed for each SFSC. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each SFSC not meeting the LCO. Subsequent SFSCs that don't meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

(continued)

BASES

ACTIONS (continued)

A.1

Although the heat removal system remains operable, the blockage should be cleared expeditiously.

B.1

If the heat removal system has been determined to be inoperable, it must be restored to operable status within eight hours. Eight hours is a reasonable period of time to take action to remove the obstructions in the air flow path.

C.1

If the heat removal system cannot be restored to operable status within eight hours, the VVM and the fuel may experience elevated temperatures. Therefore, dose rates are required to be measured to verify the effectiveness of the radiation shielding provided by the concrete. This Action must be performed immediately and repeated every twelve hours thereafter to provide timely and continued evaluation of the effectiveness of the concrete shielding. As necessary, the system user shall provide additional radiation protection measures such as temporary shielding. The Completion Time is reasonable considering the expected slow rate of deterioration, if any, of the concrete under elevated temperatures.

C.2.1

In addition to Required Action C.1, efforts must continue to restore cooling to the SFSC. Efforts must continue to restore the heat removal system to operable status by removing the air flow obstruction(s) unless optional Required Action C.2.2 is being implemented.

This Required Action must be complete in 24 hours. The Completion Time is consistent with the thermal analyses of this event, which show that all component temperatures remain below their short-term temperature limits up to 32 hours after event initiation.

(continued)

BASES

ACTIONS (continued)

C.2.1 (continued)

The Completion Time reflects the 8 hours to complete Required Action B.1 and the appropriate balance of time consistent with the applicable analysis results. The event is assumed to begin at the time the SFSC heat removal system is declared inoperable. This is reasonable considering the low probability of all inlet ducts becoming simultaneously blocked.

C.2.2

In lieu of implementing Required Action C.2.1, transfer of the MPC into a TRANSFER CASK will place the MPC in an analyzed condition and ensure adequate fuel cooling until actions to correct the heat removal system inoperability can be completed. Transfer of the MPC into a TRANSFER CASK removes the SFSC from the LCO Applicability since STORAGE OPERATIONS does not include times when the MPC resides in the TRANSFER CASK.

An engineering evaluation must be performed to determine if any deterioration which prevents the VVM from performing its design function. If the evaluation is successful and the air inlet duct screens have been cleared, the VVM heat removal system may be considered operable and the MPC transferred back into the VVM. Compliance with LCO 3.1.2 is then restored. If the evaluation is unsuccessful, the user must transfer the MPC into a different, fully qualified VVM to resume STORAGE OPERATIONS and restore compliance with LCO 3.1.2

In lieu of performing the engineering evaluation, the user may opt to proceed directly to transferring the MPC into a different, fully qualified VVM or place the TRANSFER CASK in the spent fuel pool and unload the MPC.

The Completion Time of 24 hours reflects the Completion Time from Required Action C.2.1 to ensure component temperatures remain below their short-term temperature limits for the respective decay heat loads.

(continued)

BASES

SURVEILLANCE REQUIREMENTS

SR 3.1.2

The long-term integrity of the stored fuel is dependent on the ability of the SFSC to reject heat from the MPC to the environment. There are two options for implementing SR 3.1.2, either of which is acceptable for demonstrating that the heat removal system is OPERABLE.

Visual observation that all air inlet duct screens are unobstructed ensures that the SFSC is operable. If greater than 50% of the air inlet duct screens are blocked the heat removal system is inoperable and this LCO is not met. While 50% or less blockage of the total air inlet duct screen area does not constitute inoperability of the heat removal system, corrective actions should be taken promptly to remove the obstruction and restore full flow.

As an alternative, for VVMs with air temperature monitoring instrumentation installed in the air outlets, the temperature difference between the outlet air and the ambient air may be monitored to verify operability of the heat removal system. Blocked air inlet duct screens will reduce air flow and increase the outlet duct air temperature. Based on the analyses, if the temperature difference between the ambient air and the outlet duct air meets the criteria in the LCO, adequate air flow is occurring to provide assurance of long term fuel cladding integrity. The reference ambient temperature used to perform this Surveillance shall be measured at the ISFSI facility.

The Frequency of 24 hours is reasonable based on the time necessary for SFSC components to heat up to unacceptable temperatures assuming design basis heat loads, and allowing for corrective actions to take place upon discovery of blockage of air ducts.

REFERENCES

1. FSAR Chapter 4
2. ANSI/ANS 57.9-1992

B 3.1 SFSC INTEGRITY

B 3.1.3 MPC Cavity Reflooding

BASES

BACKGROUND

In the event that an MPC must be unloaded, the TRANSFER CASK with its enclosed MPC is returned to the preparation area to begin the process of fuel unloading. The MPC closure ring, and vent and drain port cover plates are removed. The MPC gas is sampled to determine the integrity of the spent fuel cladding. The pressure in the MPC cavity is ensured to be less than the 100 psig design pressure. This is accomplished via direct measurement of the MPC gas pressure or via analysis.

After ensuring the MPC cavity pressure meets the LCO limit, the MPC is then reflooded with water at a controlled rate and/or the pressure monitored to ensure that the pressure remains below 100 psig. Once the cavity is filled with water, the MPC lid weld is removed leaving the MPC lid in place. The TRANSFER CASK and MPC are placed in the spent fuel pool and the MPC lid is removed. The fuel assemblies are removed from the MPC and the MPC and TRANSFER CASK are removed from the spent fuel pool and decontaminated.

Ensuring that the MPC cavity pressure is less than the LCO limit ensures that any steam produced within the cavity is safely vented to an appropriate location and eliminates the risk of high MPC pressure due to sudden generation of large steam quantities during re-flooding.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in the MPC is ensured by the MPC in which the fuel assemblies are stored. Standard practice in the dry storage industry has historically been to directly reflood the storage canister with water. This standard practice is known not to induce fuel cladding failures.

The integrity of the MPC depends on maintaining the internal cavity pressures within design limits. This is accomplished by introducing water to the cavity in a controlled manner such that there is no sudden formation of large quantities of steam during MPC reflooding. (Ref. 1).

(continued)

BASES

LCO

Determining the MPC cavity pressure prior to and during re-flooding ensures that there will be sufficient venting of any steam produced to avoid excessive MPC pressurization.

APPLICABILITY

The MPC cavity pressure is controlled during UNLOADING OPERATIONS after the TRANSFER CASK and integral MPC are back in the FUEL BUILDING and are no longer suspended from, or secured in, the transporter. Therefore, the MPC Reflood LCO does not apply during TRANSPORT OPERATIONS and STORAGE OPERATIONS.

A note has been added to the APPLICABILITY for LCO 3.1.3 which states that the LCO is only applicable during wet UNLOADING OPERATIONS. This is acceptable since the intent of the LCO is to avoid uncontrolled MPC pressurization due to water flashing during re-flooding operations. This is not a concerning for dry UNLOADING OPERATIONS.

ACTIONS

A note has been added to the ACTIONS which states that, for this LCO, separate Condition entry is allowed for each MPC. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each MPC not meeting the LCO. Subsequent MPCs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A

If the MPC cavity pressure limit is not met, actions must be taken to restore the parameters to within the limits before initiating or continuing re-flooding the MPC.

Immediately is an appropriate Completion Time because it requires action to be initiated promptly and completed without delay, but does not establish any particular fixed time limit for completing the action. This offers the flexibility necessary for users to plan and implement any necessary work activities commensurate with the safety significance of the condition, which is governed by the MPC heat load.

(continued)

BASES

SURVEILLANCE REQUIREMENTS

SR 3.1.3.1

The integrity of the MPC is dependent on controlling the internal MPC pressure. By controlling the MPC internal pressure prior to and during re-flooding the MPC, sufficient steam venting capacity exists during MPC re-flooding.

The LCO must be met on each SFSC before the initiation of MPC re-flooding operations to ensure the design and analysis basis are preserved.

REFERENCES

1. FSAR Chapters 3, 4, 9 and 12 of HI-STORM FW FSAR

B 3.2 SFSC Radiation Protection

B 3.2.1 TRANSFER CASK Surface Contamination

BASES	
BACKGROUND	A TRANSFER CASK is immersed in the spent fuel pool in order to load the spent fuel assemblies. As a result, the surface of the TRANSFER CASK may become contaminated with the radioactive material from the spent fuel pool water. This contamination is removed prior to moving the TRANSFER CASK to the ISFSI, in order to minimize the radioactive contamination to personnel or the environment. This allows dry fuel storage activities to proceed without additional radiological controls to prevent the spread of contamination and reduces personnel dose due to the spread of loose contamination or airborne contamination. This is consistent with ALARA practices.
APPLICABLE SAFETY ANALYSIS	The radiation protection measures, implemented during MPC transfer and transportation using the TRANSFER CASK, are based on the assumption that the exterior surfaces of the TRANSFER CASK have been decontaminated. Failure to decontaminate the surfaces of the TRANSFER CASK could lead to higher-than-projected occupational doses.
LCO	Removable surface contamination on the TRANSFER CASK exterior surfaces and accessible surfaces of the MPC is limited to 1000 dpm/100 cm^2 from beta and gamma sources and 20 dpm/100 cm^2 from alpha sources. These limits are taken from the guidance in IE Circular 81-07 (Ref. 2) and are based on the minimum level of activity that can be routinely detected under a surface contamination control program using direct survey methods. Only loose contamination is controlled, as fixed contamination will not result from the TRANSFER CASK loading process.

(continued)

BASES

LCO (continued)

Experience has shown that these limits are low enough to prevent the spread of contamination to clean areas and are significantly less than the levels which would cause significant personnel skin dose. LCO 3.2.1 requires removable contamination to be within the specified limits for the exterior surfaces of the TRANSFER CASK and accessible portions of the MPC. The location and number of surface swipes used to determine compliance with this LCO are determined based on standard industry practice and the user's plant-specific contamination measurement program for objects of this size. Accessible portions of the MPC means the upper portion of the MPC external shell wall accessible after the inflatable annulus seal is removed and before the annulus shield ring is installed. The user shall determine a reasonable number and location of swipes for the accessible portion of the MPC. The objective is to determine a removable contamination value representative of the entire upper circumference of the MPC, while implementing sound ALARA practices.

APPLICABILITY

Verification that the surface contamination is less than the limit in the LCO is performed during LOADING OPERATIONS. This occurs before TRANSPORT OPERATIONS, when the LCO is applicable. Measurement of surface contamination is unnecessary during UNLOADING OPERATIONS as surface contamination would have been measured prior to moving the subject TRANSFER CASK to the ISFSI.

(continued)

BASES

ACTIONS

A note has been added to the ACTIONS which states that, for this LCO, separate Condition entry is allowed for each TRANSFER CASK. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each TRANSFER CASK not meeting the LCO. A subsequent use of the TRANSFER CASK that does not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the removable surface contamination of a TRANSFER CASK or MPC, as applicable, which has been loaded with spent fuel is not within the LCO limits, action must be initiated to decontaminate the TRANSFER CASK or MPC and bring the removable surface contamination to within limits. The Completion Time of 7 days is appropriate given that sufficient time is needed to prepare for, and complete the decontamination once the LCO is determined not to be met.

SURVEILLANCE REQUIREMENTS

SR 3.2.1.1

This SR verifies that the removable surface contamination on the TRANSFER CASK and/or accessible portions of the MPC is less than the limits in the LCO. The Surveillance is performed using smear surveys to detect removable surface contamination. The Frequency requires performing the verification during LOADING OPERATIONS in order to confirm that the TRANSFER CASK or VVM can be moved to the ISFSI without spreading loose contamination.

REFERENCES

1. HI-STORM FW FSAR Chapter 9
2. NRC IE Circular 81-07.

B 3.3 SFSC Criticality Control

B 3.3.1 Boron Concentration

BASES	
BACKGROUND	A TRANSFER CASK with an empty MPC is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Certificate of Compliance. A lid is then placed on the MPC. The TRANSFER CASK and MPC are raised to the top of the spent fuel pool surface. The TRANSFER CASK and MPC are then moved into the preparation area where the MPC lid is welded to the MPC shell and the welds are inspected and tested. The water is drained from the MPC cavity and drying is performed. The MPC cavity is backfilled with helium. Then, the MPC vent and drain cover plates and MPC closure ring are installed and welded. Inspections are performed on the welds. For those MPCs containing PWR fuel assemblies credit is taken in the criticality analyses for boron in the water within the MPC. *To preserve the analysis basis, users must verify that the boron* concentration of the water in the MPC meets specified limits when there is fuel and water in the MPC. This may occur during LOADING OPERATIONS and UNLOADING OPERATIONS.
APPLICABLE SAFETY ANALYSIS	The spent nuclear fuel stored in the SFSC is required to remain subcritical ($k_{eff} \leq 0.95$) under all conditions of storage. The HI-STORM UMAX SFSC is analyzed to store a wide variety of spent nuclear fuel assembly types with differing initial enrichments. For all PWR fuel loaded in the MPC-37, credit was taken in the criticality analyses for neutron poison in the form of soluble boron in the water within the MPC. Compliance with this LCO preserves the assumptions made in the criticality analyses regarding credit for soluble boron.

(continued)

LCO

Compliance with this LCO ensures that the stored fuel will remain subcritical with a $k_{eff} \leq 0.95$ while water is in the MPC. LCOs 3.3.1.a provides the minimum concentration of soluble boron required in the MPC water for the MPC-37. The amount of soluble boron is dependent on the initial enrichment of the fuel assemblies to be loaded in the MPC. Fuel assemblies with an initial enrichment less than or equal to 4.0 wt. % U-235 require less soluble boron than those with initial enrichments greater than 4.0 wt. % U-235. For initial enrichments greater than 4.0 wt. % U-235 and up to 5.0 wt. % U-225, interpolation is permitted to determine the required minimum amount of soluble boron.

All fuel assemblies loaded into the MPC-37 are limited by analysis to maximum enrichments of 5.0 wt. % U-235.

The LCO also requires that the minimum soluble boron concentration for the most limiting fuel assembly array/class and classification to be stored in the same MPC be used. This means that the highest minimum soluble boron concentration limit for all fuel assemblies in the MPC applies in cases where fuel assembly array/classes are mixed in the same MPC. This ensures the assumptions pertaining to soluble boron used in the criticality analyses are preserved.

APPLICABILITY

The boron concentration LCO is applicable whenever an MPC-37 has at least one PWR fuel assembly in a storage location and water in the MPC.

During LOADING OPERATIONS, the LCO is applicable immediately upon the loading of the first fuel assembly in the MPC. It remains applicable until the MPC is drained of water.

During UNLOADING OPERATIONS, the LCO is applicable when the MPC is reflooded with water. Note that compliance with SR 3.0.4 assures that the water to be used to flood the MPC is of the correct boron concentration to ensure the LCO is satisfied upon entering the Applicability.

(continued)

BASES

ACTIONS

A note has been added to the ACTIONS which states that, for this LCO, *separate Condition entry is allowed for each MPC*. This is acceptable since the Required Actions for each Condition provide appropriate compensatory measures for each MPC not meeting the LCO. Subsequent MPCs that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1 and A.2

Continuation of LOADING OPERATIONS, UNLOADING OPERATIONS or positive reactivity additions (including actions to reduce boron concentration) is contingent upon maintaining the SFSC in compliance with the LCO. If the boron concentration of water in the MPC is less than its limit, all LOADING OPERATIONS, UNLOADING OPERATIONS or positive reactivity additions must be suspended immediately.

A.3

In addition to immediately suspending LOADING OPERATIONS, UNLOADING OPERATIONS and positive reactivity additions, action to restore the concentration to within the limit specified in the LCO must be initiated immediately. One means of complying with this action is to initiate boration of the affected MPC. In determining the required combination of boration flow rate and concentration, there is no unique design basis event that must be satisfied; only that boration is initiated without delay. In order to raise the boron concentration as quickly as possible, the operator should begin boration with the best source available for existing plant conditions.

Once boration is initiated, it must be continued until the boron concentration is restored. The restoration time depends on the amount of boron that must be injected to reach the required concentration.

(continued)

BASES

SURVEILLANCE REQUIREMENTS

SR 3.3.1.1

The boron concentration in the MPC water must be verified to be within the applicable limit within four hours prior to entering the Applicability of the LCO. For LOADING OPERATIONS, this means within four hours of loading the first fuel assembly into the MPC using two independent measurements to ensure the requirements of 10 CFR 72.124(a) are met. These two independent measurements will be repeated every 48 hours while the MPC is submerged in water or if water is to be added to or recirculated through the MPC.

For UNLOADING OPERATIONS, this means verifying the boron concentration in the source of borated water to be used to reflood the MPC within four hours of commencing reflooding operations and every 48 hours after until all the fuel is removed from the MPC. Two independent measurements will be taken to ensure the requirements of 10 CFR 72.124(a) are met. This ensures that when the LCO is applicable (upon introducing water into the MPC), the LCO will be met.

Surveillance Requirement 3.3.1.1 is modified by a note which states that SR 3.3.1.1 is only required to be performed if the MPC is submerged in water or if water is to be added to, or recirculated through the MPC. This reflects the underlying premise of this SR which is to ensure, once the correct boron concentration is established, it need only be verified thereafter if the MPC is in a state where the concentration could be changed. After the completion of the surveillance methods, events which might change the soluble boron concentration will be administratively controlled per the LCO. If actions are taken that could result in a reduction in the boron concentration the surveillance will be performed again.

There is no need to re-verify the boron concentration of the water in the MPC after it is removed from the spent fuel pool unless water is to be added to, or recirculated through the MPC, because these are the only credible activities that could potentially change the boron concentration during this time. This note also prevents the interference of unnecessary sampling activities while lid closure welding and other MPC storage preparation activities are taking place in an elevated radiation area atop the MPC. Plant procedures should ensure

BASES	
SURVEILLANCE REQUIREMENTS	that any water to be added to, or recirculated through the MPC is at a boron concentration greater than or equal to the minimum boron concentration specified in the LCO.
REFERENCES	1. HI-STORM FW FSAR Chapter 6.

CHAPTER 14[†]: QUALITY ASSURANCE PROGRAM

14.0 INTRODUCTION

14.0.1 Overview

This chapter provides a summary of the quality assurance program implemented by Holtec International for activities related to the design, qualification analyses, material procurement, fabrication, assembly, testing and use of structures, systems, and components of the Company's dry storage/transport systems including the HI-STORM UMAX System which includes the HI-TRAC transfer cask. This chapter is included in this FSAR to fulfill the requirements in 10 CFR 72.140 (c) (2) and 72.2(a)(1),(b).

Important-to-safety activities related to construction and deployment of the HI-STORM UMAX System are controlled under the NRC-approved Holtec Quality Assurance Program. The Holtec QA program manual [14.0.1] is approved by the NRC [14.0.2] under Docket 71-0784. The Holtec QA program satisfies the requirements of 10 CFR 72, Subpart G and 10 CFR 71, Subpart H. In accordance with 10 CFR 72.140(d), this approved 10 CFR 71 QA program will be applied to spent fuel storage cask activities under 10 CFR 72. The additional recordkeeping requirements of 10 CFR 72.174 are addressed in the Holtec QA program manual and must also be complied with.

The Holtec QA program is implemented through a hierarchy of procedures and documentation, listed below.

1. Holtec Quality Assurance Program Manual
2. Holtec Quality Assurance Procedures
3. a. Holtec Standard Procedures
   b. Holtec Project Procedures

Quality activities performed by others on behalf of Holtec are governed by the supplier's quality assurance program or Holtec's QA program extended to the supplier. The type and extent of Holtec QA control and oversight is specified in the procurement documents for the specific item or service being procured. The fundamental goal of the supplier oversight portion of Holtec's QA program is to provide the assurance that activities performed in support of the supply of safety-significant items and services are performed correctly and in compliance with the procurement documents.

[†] This chapter has been prepared in the format and section organization set forth in Regulatory Guide 3.61.

14.0.2 Graded Approach to Quality Assurance

Holtec International uses a graded approach to quality assurance on all safety-related or important-to-safety projects. This graded approach is controlled by Holtec Quality Assurance (QA) program documents as described in Subsection 14.0.1.

NUREG/CR-6407 [14.0.3] provides descriptions of quality categories A, B and C. Using the guidance in NUREG/CR-6407, Holtec International assigns a quality category to each individual, important-to-safety component of the HI-STORM UMAX System and HI-TRAC transfer cask. The ITS categories assigned to the HI-STORM UMAX cask components are identified in licensing drawing in Section 1.5. Quality categories for ancillary equipment are provided in Chapter 9 of this FSAR. Quality categories for other equipment needed to deploy the HI-STORM UMAX System at a licensee's ISFSI are defined on a case-specific basis considering the component's design function using the guidelines of NUREG/CR-6407 [14.0.3].

Activities affecting quality are defined by the purchaser's procurement contract for use of the HI-STORM UMAX System at an independent spent fuel storage installation (ISFSI) under the general license provisions of 10CFR72, Subpart K. These activities include any or all of the following: design, procurement, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair and monitoring of HI-STORM UMAX structures, systems, and components (SSCs) that are important-to-safety.

The quality assurance program described in the QA Program Manual fully complies with the requirements of 10CFR72 Subpart G and the intent of NUREG-1536 [14.0.4]. However, NUREG-1536 does not explicitly address incorporation of a QA program manual by reference. Therefore, invoking the NRC-approved QA program in this FSAR constitutes a literal deviation from NUREG-1536. This deviation is acceptable since important-to-safety activities are implemented in accordance with the latest revision of the Holtec QA program manual and implementing procedures. Further, incorporating the QA Program Manual by reference in this FSAR avoids duplication of information between the implementing documents and the FSAR and any discrepancies that may arise from simultaneous maintenance to the two program descriptions governing the same activities.

14.1 REFERENCES

[14.0.1] Holtec International Quality Assurance Program, Latest Approved Revision on Docket 71-0784.

[14.0.2] NRC QA Program Approval for Radioactive Material Packages No. 0784, Docket 71-0784.

[14.0.3] NUREG/CR-6407, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety," February 1996.

[14.0.4] NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems," Rev 1, USNRC, 2010.